Ninth Annual Administrative Report

Pond Dynamics/Aquaculture

Collaborative Research Support Program 1991

Pond Dynamics/Aquaculture CRSP
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Collaborative Research Support Program

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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 1990 to 31 August 1991. Program activities are funded in part by the United States Agency for International Development under Grant: DAN-4023-G-00-0031-00.

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I. INTRODUCTION

The Pond Dynamics/Aquaculture Collaborative Research Support Program (PD/A CRSP) is an international effort to develop aquacultural technology as a means of confronting food and nutritional problems in developing countries, and to help people learn management skills and earn income. The program is funded by the U.S. Agency for International Development (USAID), under authority of the International Development and Food Assistance Act of 1975 (P.L. 94-161), and by the universities and institutions that participate in the CRSP. Oregon State University (OSU) is the Management Entity (ME) 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 United States 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 1 September 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 AID Agricultural Sector Council Subcommittee. The plan, which went into effect on 1 September 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 and through continuing financial commitments of the USAID Mission, 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, as described in subsequent work plans, conforms to that of the original three cycles to allow comparison between sites over time. Field experiments blend program-oriented and project-oriented (site-specific) considerations in response to the results of the earlier experiments.

In the past few years the CRSP has actively pursued new funding opportunities to support project activities. The CRSP has been successful in attracting funding in four target areas: economics research, gender studies, on-farm studies, and outreach. As projects in these new focus areas are showing their first results, we find that they have added a broader dimension to the CRSP experience. Natural resources management has always been a cornerstone of our CRSP; therefore, we do not consider our continued efforts in this area new. What is new is the integration of our natural resources work with socio-cultural and economic dimensions of aquaculture.

An economics study initiated in Thailand by researchers from the University of Arkansas at Pine Bluff and Michigan State University yielded important information on profit-making fish culture enterprises in the impoverished Northeast region. This study complements the economics study currently underway in Rwanda—funded primarily through a buy-in from USAID's Historic Black Colleges and Universities Program—and the ongoing private sector research for commercial shrimp and tilapia farms in Honduras. The HBCU grant also enables the University of Arkansas at Pine Bluff to augment core CRSP biological research in Rwanda. CRSP researchers in Rwanda regularly assist the USAID Mission in their natural resources projects and have helped transfer CRSP technologies to Rwandan farmers, who are now experiencing widespread success with fish culture. The proposal for a gender study of women in fish farming, which was submitted to several donors by researchers from Oregon State University and Rwanda, received funding from PPC/WID (USAID), the USAID Mission in Kigali, and from a number of other sources. The CRSP is pleased with this opportunity for enrichment and regrets only that it does not have a larger financial commitment from USAID to support long-term research in Women in Development. In addition to the myriad grants and cooperators affiliated with the CRSP project in Rwanda, the European Economic Community recently contributed funds to improve and expand the pond facilities at our research station at the National University of Rwanda.

Other potential "buy-in" activities include: a proposal for a comprehensive pond dynamics project in Egypt, and a proposal to the International Center for Living Aquatic Resources Management (ICLARM) for collaboration on an aquaculture methods manual. This CRSP was one of the principal players in the CRSP Council's efforts to attract funding for a large-scale agroecological study in Honduras involving their two most important export products, shrimp and melons.

The twenty percent increase in funding that the CRSP received in May of 1991 funded projects addressing the critical needs defined by JCARD, BIFADEC, the External Evaluation Panel, and the CRSP Technical Committee. Part of the funding was used as seed money to leverage support from other sources. The funds allocated to a Women in Development study helped to leverage funds from a number of sources (see above); the funds for testing CRSP models on farms in the Philippines were matched by University of Hawaii and Central Luzon State University; and a small grant to Auburn University to conduct field trials and workshops in Panama was made possible through the Panamanian Department of Aquaculture's donation of ponds, staff, feed, and fertilizers. (Note that this study has been postponed due to travel restrictions imposed by the Brooke Amendment.) Other new studies included investigations in tropical pond soils, which will allow us to facilitate linkages with other soils projects such as the TropSoils CRSP; a workshop in Rwanda for East Central African fishfarmers and extensionists; polyculture research using native (non-introduced) species; and research on ecologically sound alternatives to therapeutic drugs used in fish culture.

Our CRSP has benefitted from its involvement in the CRSP Council, a group composed of all eight USAID-funded Collaborative Research Support Programs, although full participation in this group extracts a high cost in terms of time and capital from the smaller CRSPs such as ourselves. We are nevertheless grateful for the partial support made available to us from USAID grants to the CRSP Council (disbursed by the University of Nebraska and Michigan State University). Through the Council, the PD/A CRSP participated in presentations to Congress, the World Bank, USDA, USAID, JCARD, and environmental groups in the winter of 1991. One impact of this effort was to increase public awareness of our programs. The Council plans another series of presentations in 1992.

Many other technical and programmatic accomplishments are described in detail in this Ninth Annual Administrative Report, which covers the period from 1 September 1990 to 31 August 1991.

II. SUMMARY OF ACTIVITIES AND ACCOMPLISHMENTS: 1 SEPTEMBER 1990 TO 31 AUGUST 1991

The major technical accomplishments of this reporting period included an examination of the cost-effectiveness of various fertilization strategies; the development of models on pond dynamics; the calibration and validation of models and expert systems; and continued efforts toward the dissemination of results and information. Other major accomplishments occurred in the areas of project development, training, and the social sciences.

Data Analysis and Synthesis

Work on the validation and calibration of three mechanistic models described in previous reports continued at the University of California at Davis (UCD). 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. Researchers continued to develop descriptive models, based on CRSP data, for the analysis of fish growth histories. At UCD, studies relating to primary production and respiration processes and to the physical environment in ponds were undertaken this year, and a simplified model of temperature stratification has been developed and is being tested. A quarterly newsletter for CRSP participants was initiated this year by the DAST.

At Oregon State University (OSU) work on the CRSP expert system, called PONDCLASS, has progressed well. The Macintosh version is ready for beta testing, and the version for DOS-driven systems (IBM format) has been completed and is being debugged. 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. PONDCLASS will be a user-friendly, computerized version of the pond management guidelines, and will also serve as the source for the printed version, the Manual of Pond Management Guidelines, which should go to print this year.

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 the individual sites, data on physical variables (e.g., solar radiation, temperature, and rainfall) and chemical variables (e.g., water and soil chemical characteristics) are collected concurrently 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, which have been transmitted from the research sites.

The utility of the Central Data Base extends beyond the 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. It can also serve 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. A committee was convened this year to evaluate the usefulness of the CRSP data base to CRSP researchers and to those outside the CRSP. Although the final report of the committee will not be made until 31 December, renewed interest in using the central data base is evident from the preliminary survey responses.

Field Sites

Researchers at all three CRSP sites investigated alternatives to using therapeutic chemicals in fish culture. Hormones are widely used throughout the world to reverse the sex of fish to facilitate pond management and improve growth and survival of fish, but the effects of these chemicals on humans and the environment are not well documented. In Honduras, Rwanda, and Thailand, researchers tested the efficacy of using indigenous piscivorous fishes to naturally control unwanted reproduction in ponds. All three studies also evaluated the added benefits of higher yields through polyculture. These studies are especially timely because of the recent (November 1991) Food and Drug Administration restrictions on the use of hormones for fish culture in the United States.

As fish yield increases with increasing fertilization, balancing manure and inorganic supplements becomes essential. In keeping with empirical models developed by CRSP scientists in Thailand, researchers in Honduras, Rwanda, and Thailand participated in a global experiment to fertilize organically enriched ponds with nitrogen supplements. With no artificial aeration or feed, researchers in Thailand achieved yields of 32 kg/ha/day in a growth period of 150 days; they found that the key was optimizing phosphorus:nitrogen:carbon ratios. In Honduras, researchers found that the correct application of supplemental nitrogen with high inputs of chicken litter resulted in higher profit than when chicken litter was used as the sole input. Excessive use of nitrogen, however, may produce blue-green algae blooms which have been known to produce toxins that cause off-flavor in fish. In Rwanda and Honduras, additional work is required to determine the optimum levels of supplemental nitrogen so that ponds are not over- or under-fertilized. The model developed by the Data Analysis and Synthesis Team will be used in subsequent trials to assist in establishing optimal management guidelines.

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 Fish and Aquaculture and Auburn University are developing new technologies to increase tilapia production by maintaining critical dissolved oxygen concentrations through the minimal use of aerators. The researchers found this method to be cost-effective for moderate to large-scale commercial tilapia farms. They also studied the effects of supplemental nitrogen fertilization, polyculture, and wind speed on pond production.

Red tilapia is one of the most popular varieties for tilapia culture in many countries. In a comparison of two red strains and the wild-type Nile tilapia strain found in Honduras, researchers found that yields of red tilapia were lower because of poorer survival—most likely because they were an easier target for ospreys.

Rwanda. CRSP researchers in Rwanda (National University of Rwanda, Oregon State University, Auburn University, and the University of Arkansas at Pine Bluff) continued to study the effects of temperature and elevation on pond productivity. In colder climates, tilapia reproduction is usually low and survival is poor. Researchers funded under a CRSP/UAPB buy-in grant from the Historical Black Colleges and Universities program found that fish grown at the high temperatures (28°C) had much higher growth rates than fish grown in colder waters. The effects of elevation are closely tied to temperature. Responding to reports that Rwandan farmers get lower yields at high elevations (2000m) than at lower elevations (1700m), researchers came up with new recommendations for optimizing growth in lower elevation ponds and reproduction in high elevation ponds. Another CRSP study, in collaboration with a researcher from Catholic University in Belgium, found that commercial tilapia production is economically feasible at the high elevations in Rwanda. High stocking densities (300 fish/100 m^2) resulted in greater profitability than lower densities in monosex culture. Supplemental feeding with rice bran resulted in 2 to 3 times greater yields than that obtained using compost as the sole input.

The principal food source for tilapia in enriched ponds in developing countries is naturally occurring organisms. However, the energy content of these natural foods may be inadequate. In order to determine whether supplemental feeding is truly necessary, researchers studied the digestibility of natural food organisms ingested by tilapia grown in organically and inorganically enriched ponds.

Thailand. Researchers from three U.S. 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) continued to study the effects of fertilization on fish growth. Other studies focused on fisheries monitoring techniques (i.e., instantaneous mortalities, reporting growth rates, and sampling biases), physical pond processes (i.e., aeration, circulation, and stratification), maintenance of minimum dissolved oxygen concentrations, and ecosystem dynamics.

Whether a farmer should use organic or inorganic fertilizer depends on the relative environmental and economic efficiencies of transferring nutrients into fish biomass. The choice of organic inputs must be made carefully because of inherent problems with with deoxygenation, labor intensiveness, transportation costs, and rapid filling of ponds. Researchers found that chicken litter was not as cost-effective as using inorganic nitrogen fertilizers in Thailand. Urea is slowly decomposed in ponds by bacteria and is also utilized by phytoplankton. Furthermore, researchers found that urea has low toxicity and should not result in fish kills.

Information Dissemination, Technology Transfer, and Other Activities

As the CRSP has matured, the work of the Global Experiment has been supported by increased country-specific research, transfer of technology, and educational efforts. Substantial investments have been made in enlarging the community of farmer-researchers in Rwanda, Thailand, Honduras, and the Philippines. On-farm trials of CRSP-developed technology become living laboratories in which farmers learn how to determine optimal conditions for fish production, along with the basics of scientific method and enterprise planning and management. The results of the trials help identify the gaps in scientific knowledge or socioeconomic infrastructure that prevent successful implementation of fish culture. As the pool of on-farm researchers is increased, CRSP technology will ripple out through the communities.

All U.S. staff overseas maintain close contact with on-farm researchers and contribute time to extension work such as training students and technicians, teaching short courses on aquaculture and water quality, and working with local extension agents. CRSP researchers serve as advisors for graduate students at host country institutions. The number of individuals involved in all forms of training, from non-degree activities to work on advanced degrees, has grown to almost 500 since the CRSP's inception. These activities are described in the sections "Public Service and Project Development," and "Program Management and Technical Guidance."

The CRSP contributes to the world aquaculture community through dissemination and publication of research results. The CRSP *List of Publications*, with over 370 entries, attests to the productivity of the CRSP research. Reports are also published through the Management Office, and distributed to an international audience of over 300. Details on publications can be found in the "Program Management and Technical Guidance" section.

This CRSP affords host country scientists and administrators the opportunity to join the international network of scientific and agricultural researchers. CRSP support allows attendance at international meetings. The effectiveness of CRSP research has helped attract funding from other governmental and private sector donors to enhance the core CRSP project.

III. CRSP RESEARCH PROGRAM BACKGROUND

The Pond Dynamics/Aquaculture CRSP has three components:

- the Global Experiment;
- Special Topics Projects in Host Countries;
- 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.

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 Plans (1987 to 1990 and 1990 to 1995), 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 present status are described in this section.

The Global CRSP 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. Overseas sites were surveyed 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 became apparent that there were two important aspects of improving the efficiency of pond culture systems: the need to improve the technological reliability of pond production systems, and the need for economic optimization consistent with local conditions.

The wide variation observed in the productivity of different pond systems illustrates the need for improved production technologies. 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, the results are often not reproducible when these same practices are applied to other ponds. 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.

Rigorous economic analyses of pond aquaculture systems must be part of the aquaculture development strategy in both the U.S. and developing countries. 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. Therefore, the common denominator in both improving production technologies and facilitating economic analyses is 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 than some CRSPs. 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, these reports cannot be statistically compared to one another because of the lack of standardization in experimental design, data collection, and analysis, and are consequently of limited utility for predicting the performance of pond culture systems. The approach taken by the CRSP in developing 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 evaluate pond performance quantitatively 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 project sites were 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 1 September 1987, the program has conducted experiments in only three of the countries originally selected, which 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 to the Data Analysis and Synthesis Team for analysis. 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.

Six work plans have been developed to date. The First Work Plan specified standardized methods for pond preparation and monitoring, so that all ponds were managed in exactly the same way to establish a detailed baseline of data on pond variables.

CRSP participants developed the Work Plan for the second experimental cycle in April 1984. Participants reviewed accomplishments and discussed problems encountered during the first cycle of experiments. They then developed a detailed plan for the second experimental cycle, comparing the responses of ponds receiving organic fertilizers to those of ponds receiving inorganic fertilizers.

The third cycle of pond dynamics experiments was developed in March 1985. Based upon experiences to that 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 in February 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 January 1988. As recommended by the External Evaluation Panel during the first Triennial Review, a biennial work plan was adopted because it avails greater opportunity for results to be analyzed before planning subsequent research. The Fourth Work Plan therefore encompassed two years of experimental protocols rather than one.

The Fifth Work Plan was developed during the CRSP Annual Meeting in May 1989. It follows the same approach as the Fourth Work Plan in that different, but related, experiments were 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 were planned. Like the Fourth Work Plan, the Fifth encompassed two years of experimental protocols; activities specified in it continued through 31 August 1991.

The Sixth Work Plan, which describes activities to be undertaken during the period from 1 September 1991 through 31 August 1993, was developed by the Technical Committee during the winter and spring of 1991, using a process of peer review to refine the experimental design. The Work Plan was approved at the Ninth Annual Meeting in Auburn, Alabama in May and implemented during this reporting period. Also at the Annual Meeting, the Technical Committee formed an Executive Panel to evaluate proposals for a 20% funding increase. The committee used as criteria the the relevancy of the proposals to the goals of the PD/A CRSP and to sustainable agriculture and natural resource management, the proposal's technical merit, and the realistic expectation that the proposal's objectives could be met within time and budget limitations. The ten proposals that were approved are part of the Sixth Work Plan.

Data Management

Consistent with its long-term goal, the CRSP continues to develop practical pond management models to improve the efficiency of pond culture systems. The development of quantitative models depends upon the efficient management of standardized 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 (DAST). The DAST 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 half a million observations that were compiled and translated into standardized formats. During this reporting period additional 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.

The Global Experiment and Beyond

During this reporting period, the CRSP grant was renewed through August 1995. Under the terms of the continuation plan, 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. The CRSP reduced its research sites in 1987 from seven to three without altering the overall emphasis of the program.

The continuation plan builds on the experience and knowledge gained through previous cycles of the CRSP Global Experiment. During the first three years of the continuation plan, global models will be refined and on-farm trials will be initiated. The final two years will focus on the verification of the models through continued on-farm trials and field testing. Research will emphasize oxygen dynamics, aeration, sediment-water quality interactions, the influence of temperature on productivity at high altitudes, use of supplemental feeds, effects of pond size and nutrient addition schedules on fish production, and effects of density on intraspecific competition and maturation schedules of tilapia. Intensive sampling of pond variables, using standardized sampling protocol, will continue during the course of field experiments, and the standardized data will be added to the CRSP Central Data Base. In addition to these variables, CRSP researchers will study the interaction of fish culture with existing socioeconomic systems at all research sites.

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 original Global Experiment (1982-1987) followed one another logically. Although the main objective changed from cycle to cycle, consistency in experimental design allowed the comparison of results between cycles. The global nature of the program has been preserved in the experimental cycles as described in the Fourth, Fifth and Sixth Work Plans. The Sixth Work Plan, for 1991-1993, was completed during this reporting period. The experimental protocol for all studies remains consistent with that used in the Global Experiment, thereby enhancing the statistical accuracy of the data base and allowing standardized comparisons to continue to be made. The world aquaculture community can now access in the wealth of data amassed by the CRSP.

Results of the Global Experiment

The seventh 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. Preparations for field trials in the Philippines (with Central Luzon State University and the University of Hawaii) and in Panama (with the Panamanian Department of Aquaculture and Auburn University) began in late spring, after the CRSP received an additional 20% increase in funding. Experiments at the freshwater sites in Honduras, Rwanda, and Thailand dealt with a wide range of important topics, including the use of other species in polyculture with tilapia, the optimization of feeding in conjunction with the fertilization of ponds, the testing of CRSP technologies on farms, and 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* ("tambaquí") and *Cichlasoma managuense* ("guapote tigre") in Honduras. Each site particpated in a global experiment on the effects of supplementing organic fertilization with inorganic fertilization, as described by researchers from the Thailand CRSP site.

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.

HONDURAS TECHNICAL REPORTS

Yield Improvement by Maintaining Critical Oxygen Concentations in Tilapia Ponds

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Introduction

Moderate use of supplemental aeration has been demonstrated to profitably increase catfish production and decrease feed conversion ratios (Hollerman and Boyd 1980; Lai-Fa and Boyd 1988; Boyd 1990). Supplemental aeration is regular use of aeration at night to maintain a minimum dissolved oxygen (DO) concentration.

Tilapia are well known to endure periods of very low oxygen concentration by rising to the pond surface to pass oxygen-rich water across their gills by operculation. At El Carao, tilapia have been documented to endure up to six hours of zero mg/L oxygen. It was suspected that stress from low DO may reduce tilapia growth, even if there was no mortality. Supplemental aeration could maintain DO levels that would not be detrimental to tilapia growth. However, the critical oxygen concentration at which to begin aeration was not known. Indiscriminate use of aerators would waste energy and increase operating costs. The objectives of this study were: 1) to determine the critical DO level at which to initiate aeration in order to minimize operational time; 2) to determine if aeration affected primary productivity and other water quality variables.

Materials and Methods

Nine 0.1-ha ponds at the El Carao National Fish Culture Research Center were randomly assigned to three treatments. Vertical pump aerators (0.5 HP AIR-O-LATOR) were placed in six ponds, and were activated when DO reached 30% or 10% of saturation. There was no aeration in the remaining three ponds. Aerators were activated automatically by a computerized data-logging system described in detail by Green and Teichert-Coddington (in press). Water samples were drawn hourly by pump from six points between 0.05 and 0.70 m depth, and delivered as a pooled sample to oxygen and temperature sensors. The oxygen saturation concentration per measured temperature was calculated, and compared with the measured dissolved oxygen concentration. If the measured value was equal to or less than the critical level (10 or 30% of saturation), the aerator in that pond was activated for an hour until the next sampling time when the process was repeated.

Ponds were stocked on 8 August 1990 with 24g male *Oreochromis niloticus* fingerlings at 20,000/ha, 1.4g guapote tigre (*Cichlasoma managuense*) fingerlings at 500/ha, and 12g *Cichlasoma maculicauda* at 290/ha. The *C. maculicauda* was a native cichlid being tested for potential as pond culture fish. Fish were monitored monthly for growth. Ponds were fertilized only with chicken litter at 1000 kg total solids/ha per week for the first two months of growth. Thereafter, fish were fed a commercial shrimp ration (20% crude protein) 6 days per week at 3% of tilapia biomass in the fastest growing treatment. All ponds received equal quantities of inputs. After 148 days, ponds were completely drained, and fish were counted and weighed. Ponds were maintained at a depth of approximately 0.75 m.

Water was obtained for analyses by pooling subsamples taken with a 0.75-m column sampler along a transect of the pond, collected between 0700 and 0800 h. Chlorophyll *a* was determined twice a week, and Secchi disk visibility, total ammonia-nitrogen, organic-nitrogen, pH, filterable orthophosphate, total phosphorus, total solids, and volatile solids were measured once a week. Dark-bottle respiration, total alkalinity, and total hardness were measured several times during the study. Zooplankton, filtered twice a week from 14 liters of pond water using an 80-μ mesh net, were enumerated according to the major groups: copepoda, cladocera, rotifera, and nauplii. Daily wind speed, solar radiation, evaporation, and rainfall were recorded. Data were analyzed by regression analyses and unpaired t-tests to determine if aeration treatments (data pooled) were different from the control (no aeration), and if aeration at 30% of saturation produced differences compared with 10% of saturation ($P \leq 0.05$).

Results

Aeration resulted in significantly greater fish yield and larger fish than no aeration, but there were no differences in fish yield between levels of aeration (Table 1).

Table 1. Mean yield (± SE) of *Oreochromis niloticus, Cichlasoma managuense* (guapote), and *Cichlasoma maculicauda* after 148 days in ponds without oxygen regulation (Control), or with minimum dissolved oxygen concentrations maintained at 10% or 30% of saturation by aeration.

Treatment	Tilapia yield (kg/ha)	Maculicauda yield (kg/ha)	Guapote yield (kg/ha)	Reproduction (kg/ha)	Total fish yield (kg/ha)	Mean tilapia weight (g/fish)	Tilapia survival (%)
Control	3404 ± 383	8 ± 4	20 ± 6	41 ± 16	3473 ± 404	194 ± 15.5	87.1 ± 3.1
10%	4133 ± 130	15 ± 0	18 ± 1	34 ± 11	4201 ± 139	229 ± 2.7	90.2 ± 2.1
30%	4269 ± 176	20 ± 2	19 ± 4	32 ± 1	4340 ± 182	235 ± 3.9	91.0 ± 2.3

Beneficial effect of aeration was not evident until the last six weeks, when growth in the non-aerated ponds decreased relative to aerated ponds (Figure 1). A higher stocking density would probably have elicited a quicker response to aeration. On the other hand, these data indicate that aeration was not necessary until the end of the experiment when high inputs resulted in longer periods of low DO. Aerators in both aerated treatments began functioning during the first month of growth. Yields among non-aerated ponds were much more variable than yields among aerated ponds, indicating that low-oxygen stress may contribute to the large natural variation seen within treatments in tilapia production. Yield of *C. maculicauda* was low, despite aeration and a combination of a high quality ration and abundant natural food. These data indicated that this fish was not suitable for aquaculture.

The mixing action of the aerators could possibly benefit fish production through its indirect effect on natural productivity, though this was not supported by data. Aeration resulted in significant increases in total ammonia-N and total suspended solids, but there were no significant differences for organic-N,

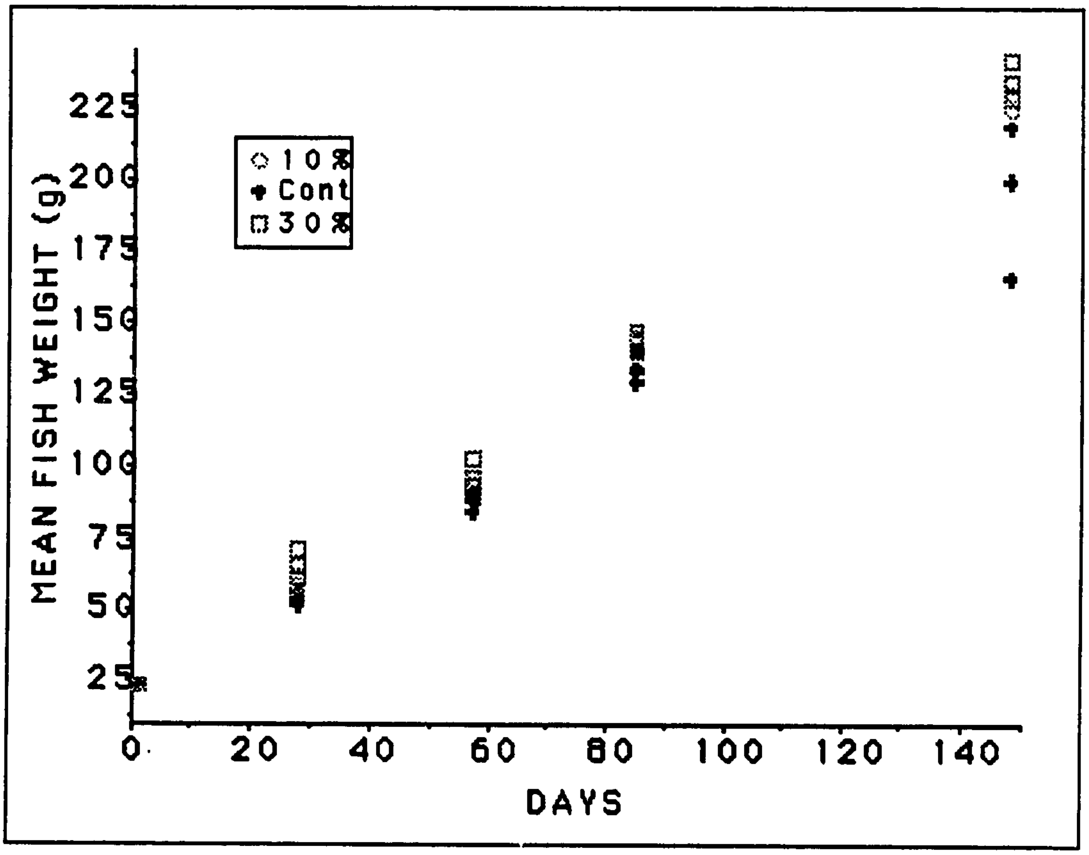

Figure 1. Growth of *Oreochromis niloticus* in ponds without oxygen regulation (Control), or with minimum dissolved oxygen concentrations maintained at 10% or 30% of saturation by aeration.

chlorophyll *a*, or total volatile solids (Table 2). Total ammonia may have been increased by the suspension of benthic material with subsequent decomposition and release of ammonia. Aeration did result in obvious clay turbidity that was measured as suspended solids.

Table 2. Means (± SE) of selected water quality variables in ponds without oxygen regulation (Control), or with minimum dissolved oxygen concentrations maintained at 10% or 30% of saturation by aeration.

Treatment	Chlorophyll *a* (µg/L)	Secchi disk visibility (cm)	Organic-N (mg NH_3-N/L)	Total ammonia (mg NH_3-N/L)	Suspended solids (mg/L)	Volatile solids (mg/L)
Control	274 ± 7.3	16.4 ± 0.11	3.43 ± 0.03	0.074 ± 0.013	433 ± 15	167 ± 10
10%	322 ± 17.9	13.3 ± 0.20	3.49 ± 0.02	0.117 ± 0.015	492 ± 9	180 ± 12
30%	342 ± 53.8	12.5 ± 0.94	3.41 ± 0.15	0.122 ± 0.012	538 ± 33	174 ± 8

Anticipated Benefits

Minimal use of aerators can be used to increase tilapia production under conditions of regular periods of low DO. However, more work will have to be done to justify the profitability of aerator use. It seems apparent that aeration in Central America will only be applicable in moderate to large-scale commercial ventures.

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Supplemental Nitrogen Fertilization of Organically Fertilized Ponds: Variation of the C:N Ratio

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Introduction

Water quality analyses from organically fertilized ponds in Honduras have consistently resulted in low concentrations (< 0.1 mg/L) of total ammonia and nitrate-nitrogen during several years of research. Low inorganic nitrogen concentrations may indicate that nitrogen is limiting primary productivity. Preliminary work in Honduras indicated that weekly applications of urea at 10 kg N/ha in addition to chicken litter did result in significantly higher chlorophyll *a* ($P < 0.05$), but not greater tilapia production (Teichert-Coddington et al. 1991).

Batterson et al. (1990) reported higher primary productivity and fish yields by increasing weekly organic fertilization rates from 44 to 200 kg/ha, and supplementing with urea to maintain N:P ratios of 5:1. In a subsequent experiment, Knud-Hansen et al. (1991a) maintained weekly total N and P inputs of 35 and 8.4 kg/ha, respectively, by supplementing organic fertilization (25 to 225 kg chicken litter/ha per week) with urea and triple superphosphate (TSP). They reported increased fish yields up to 75 kg chicken litter/ha per week, and a decrease thereafter. Conclusions of these studies were that greater fish yield could be achieved with higher concentrations of nitrogen than that supplied solely by chicken litter, and that inorganic nitrogen and phosphorus could be substituted for organic sources.

In Honduras, fish yield and net income increased as weekly application rates of chicken litter increased from 125 to 1000 kg/ha (Green et al. 1990). However, recommended fertilizer rates have been reduced to 750 kg/ha per week, because low early morning DO that inhibits fish growth may result from higher rates. Using 750 kg/ha as a basis, the objective of this study was to quantify the effects of additional nitrogen fertilization on tilapia yield and production economics in Honduras.

Materials and Methods

Twelve 0.1-ha ponds at the El Carao National Fish Culture Research Center were randomly assigned to four treatments. Ponds were fertilized weekly with chicken litter at 750 kg total solids/ha. In addition, urea was applied to achieve C:N ratios of 12:1 (corresponds to no supplemental N), 8:1, 6:1, or 4:1. Manure was frequently analyzed for nitrogen and organic carbon, and results were used to calculate urea fertilization rates. Ponds were maintained at a depth of approximately 0.9 m. Ponds were stocked on 26 February 1991 with male *Oreochromis niloticus* fingerlings at 20,000/ha. Guapote tigre (*Cichlasoma managuense*) fingerlings were stocked at 500/ha to prey on any tilapia reproduction. Fish were monitored monthly for growth. After 154 days, ponds were completely drained, and fish were counted and weighed.

Water was obtained for analyses by pooling sub-samples taken with a 0.75-m column sampler along a transect of the pond, collected between 0700 and 0800 h. Chlorophyll a, Secchi disk visibility and primary productivity were measured once a week. Total ammonia-nitrogen, oxidized nitrogen (NO_3-N plus NO_2-N), organic nitrogen, pH, filterable orthophosphate, and total phosphorus were measured every two weeks. Total solids, volatile solids, dark-bottle respiration, total alkalinity and total hardness were measured three times during the study. Zooplankton, filtered weekly from 14 liters of pond water using an 80-µ mesh net, were enumerated according to four major groups: copepoda, cladocera, rotifera, and nauplii. Daily wind speed, solar radiation, evaporation and rainfall were recorded. Data were analyzed by regression analyses and unpaired t-tests to determine if each of the supplemental nitrogen treatments was different from the control ($P \leq 0.05$).

Results

Mean total nitrogen and organic carbon composition of chicken litter was 2.28 and 25.0%, respectively. Total weekly nitrogen inputs, including supplemental urea, ranged from 17.1 kg/ha for control ponds to 46.9 kg/ha for C4:N1 ponds (Table 1). The C6:N1 treatment resulted in total weekly N input (31.1 kg/ha) that was slightly lower than the 35 kg/ha per week recommended for Thailand (Knud-Hansen et al. 1991a). However, available nitrogen may have been substantially lower if only about 40% of the nitrogen in chicken litter was available for algal use (Knud-Hansen et al. 1991b). Therefore, the C4:N1 ratio probably resulted in available N inputs which more closely approximated Thailand recommendations.

Table 1. Weekly inputs of carbon and nitrogen as chicken litter and urea to maintain C:N ratios of 8:1, 6:1 or 4:1 compared with 11:1 for only chicken litter (control).

Treatment	Chicken litter		Supplemental N	Total	C:N
	C (kg/ha)	N (kg/ha)	(kg/ha)	N (kg/ha)	
C11:N1 (control)	187.8	17.1	0.0	17.1	11.0
C8:N1	187.8	17.1	6.3	23.3	8.0
C6:N1	187.8	17.1	14.1	31.1	6.0
C4:N1	187.8	17.1	29.9	46.9	4.0

Response of fish yield to increased levels of supplemental nitrogen was discontinuous (Figure 1; Table 2) with large variation in some treatments. Only the C6:N1 ratio resulted in significantly increased fish yield compared with the control. Analyses were complicated by complete fish mortalities in one replicate pond of each treatment, except the control. The first mortality occurred during the second month in treatment C6:N1, 12 hours after ponds were fertilized with urea. A spike in ammonia was suspected, although early morning total ammonia (< 0.1 mg/L) and pH (8.2) were low two days before the kill. Afterwards, the weekly urea dose for all treatments was divided into two applications per week. A 95% mortality in pond B9 (treatment C8:N1) occurred inexplicably during the last month of the study; fish growth had been good up to that point. A complete mortality in pond B10 (treatment C4:N1) occurred during the last month, following several months of low growth (Figure 1) apparently induced by a heavy blue-green algae bloom.

Blue-green algae (*Anacystis* sp.) became dominant in pond B10 within six weeks of stock-out. A thick surface scum formed, and eventually covered half the pond. Fish growth ceased after 2 to 3 months, although primary productivity was high and early morning dissolved oxygen concentrations were not low relative to other ponds. Stress from a combination of blue-green algae toxicity and relatively high early morning total ammonia (1.02 mg/L) and pH (8.9) were the presumed causative factors of the mortality. Pond B7 (treatment C4:1N) also developed a heavy blue-green surface scum, and yield of fish was relatively low in this pond (2,191 kg/ha) compared with pond B6 (3,186 kg/ha) (treatment C4:N1), where

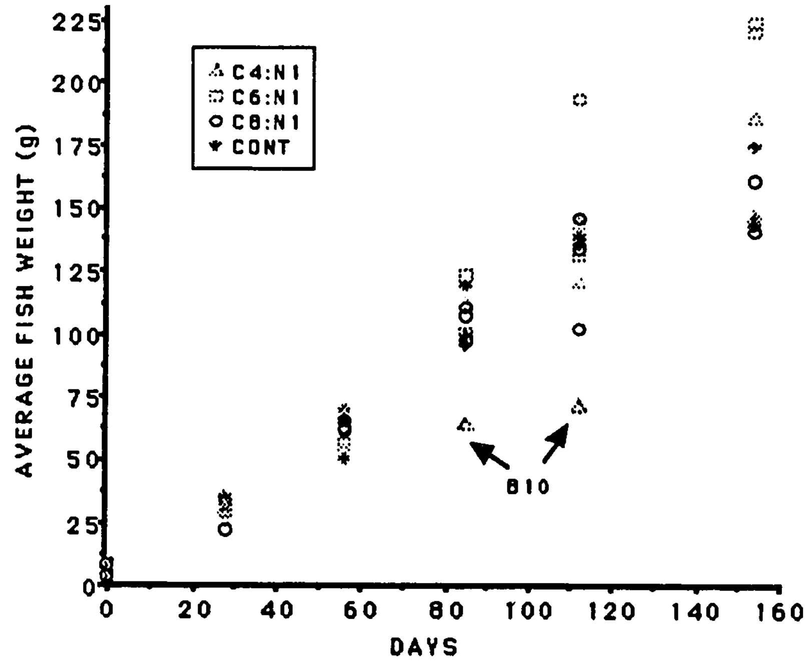

Figure 1. Tilapia growth in ponds fertilized with only chicken litter (C11:N1, control), or chicken litter with supplemental urea to maintain C:N ratios at 8:1, 6:1, or 4:1.

Table 2. Summary (± SE) of fish production and water quality variables in ponds fertilized with only chicken litter (C11:N1, control), or chicken litter with supplemental urea to maintain C:N ratios at 8:1, 6:1, or 4:1.

Treatment	C11:N1 (control)	C8:N1	C6:N1	C4:N1
Gross fish yield (kg/ha per 154 d)	2825 ± 97.1	2764 ± 192.9	3685 ± 94.1	2709 ± 508.8
Mean weight (g)	154 ± 10.1	150 ± 10.1	222 ± 1.49	166 ± 19.5
Secchi disk visibility (cm)	14.3 ± 0.56	13.7 ± 3.35	12.6 ± 2.10	11.9 ± 0.85
Organic N (mg N/L)	3.69 ± 0.12	3.82 ± 0.16	3.86 ± 0.27	4.03 ± 0.22
Total ammonia (mg NH3-N/L	0.06 ± 0.009	0.08 ± 0.002	0.14 ± 0.057	0.48 ± 0.053
Oxidized N (mg NO_3-N plus NO_2-N/L	0.036 ± 0.002	0.045 ± 0.003	0.025 ± 0.010	0.045 ± 0.004
Total P (mg PO_4-P/L)	3.91 ± 0.34	3.93 ± 0.23	3.65 ± 0.42	3.65 ± 0.10
Filterable orthophosphate (mg PO_4-P/L)	2.39 ± 0.28	2.36 ± 0.45	2.34 ± 0.72	2.32 ± 0.01

blue-green algae were not apparent. A blue-green algae scum developed to a much lesser extent on pond B5 (treatment C6:N1), but was not encountered on other ponds in this treatment. These were the first persistent blooms of blue-green algae recorded at El Carao during the PD/A CRSP. Blue-green blooms also occurred at some of the field test sites where urea was applied weekly at 35 kg N/ha. High nitrogen input apparently promotes blue-green algae growth.

Of the water quality variables measured (Table 2), only total ammonia was significantly correlated with increasing levels of supplemental nitrogen fertilization (Figure 2). Total ammonia began the season at high levels in the two lowest C:N ratios, but decreased rapidly as phytoplankton density increased to absorb the inorganic nitrogen. However, total ammonia increased again in the C4:N1 ratio as nitrogen input exceeded nitrogen utilization by plankton. Mean chlorophyll *a* and net primary productivity were not correlated with nitrogen input, but they were slightly correlated to total ammonia (Figure 3, Table 3). The correlation was substantially improved when only data corresponding to total ammonia less than 0.2 mg/L were included (Figure 3). These data corroborated preliminary work (Teichert-Coddington et al. 1990), and indicated that nitrogen fertilization that results in total ammonia concentrations greater than 0.15 to 0.20 mg/L was wasted. Excessive nitrogen fertilization may even be detrimental by promoting profuse growth of blue-green algae. Mean fish yield showed a tendency to increase with increasing chlorophyll *a* and primary productivity, but correlations were not significant.

Maintaining the C:N ratio at 6:1 resulted in significantly greater net income compared with the control. Assuming a price (Lempiras/kg; $1 US = L. 5.40, Oct. 1991) of L. 4.40 for fish and L. 1.50 for urea, L. 1,009/ha in urea was used to produce an additional L. 3,784/ha of fish flesh, which resulted in a gain of L. 2,775/ha. Using more or less supplemental nitrogen than necessary to maintain a C6:N1 ratio resulted in net economic losses compared with using only chicken litter.

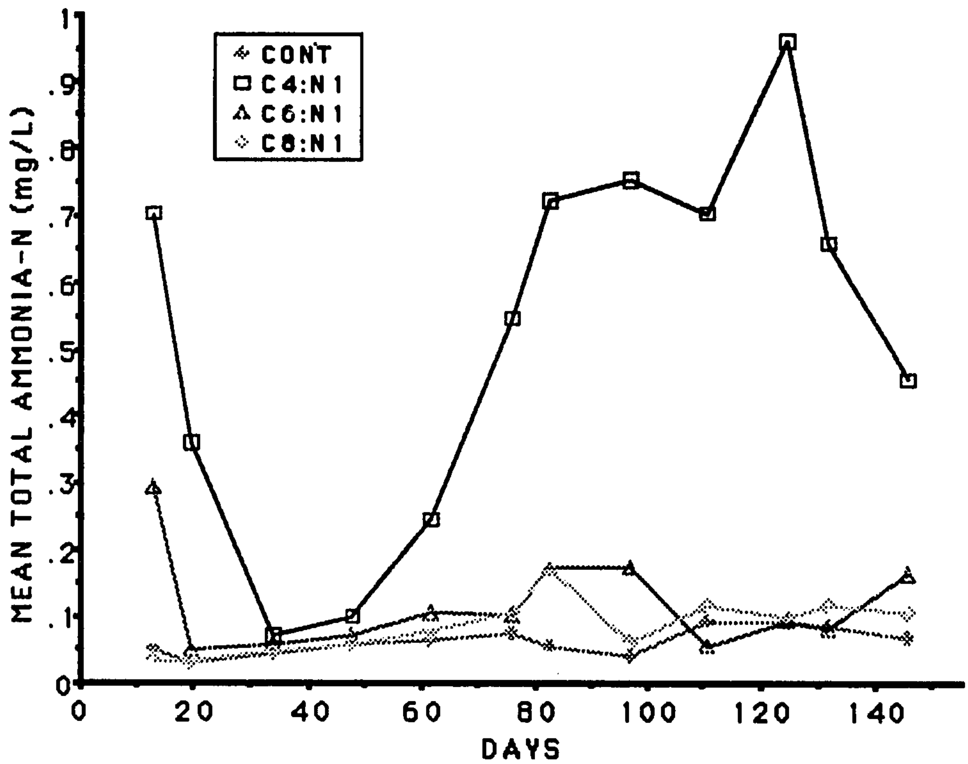

Figure 2. Mean total ammonia-nitrogen in ponds fertilized with only chicken litter (C11:N1, control), or chicken litter with supplemental urea to maintain C:N ratios at 8:1, 6:1, or 4:1.

Table 3. Mean primary productivity and chlorophyll *a* in ponds fertilized with only chicken litter (C11:N1, control), or chicken litter with supplemental urea to maintain C:N ratios at 8:1, 6:1, or 4:1.

Treatment	Primary productivity (mg O_2/l per day)			Chlorophyll *a*
	Net	Respiration	Gross	(µg/l)
C11:N1 (control)	12.1 ± 0.54	16.9 ± 0.45	20.5 ± 0.77	450 ± 29.6
C8:N1	13.2 ± 0.58	17.4 ± 1.70	21.9 ± 1.44	603 ± 53.3
C6:N1	13.2 ± 0.76	17.6 ± 0.66	22.0 ± 1.13	549 ± 132.1
C4:N1	13.9 ± 0.68	18.0 ± 0.70	23.0 ± 1.04	650 ± 26.9

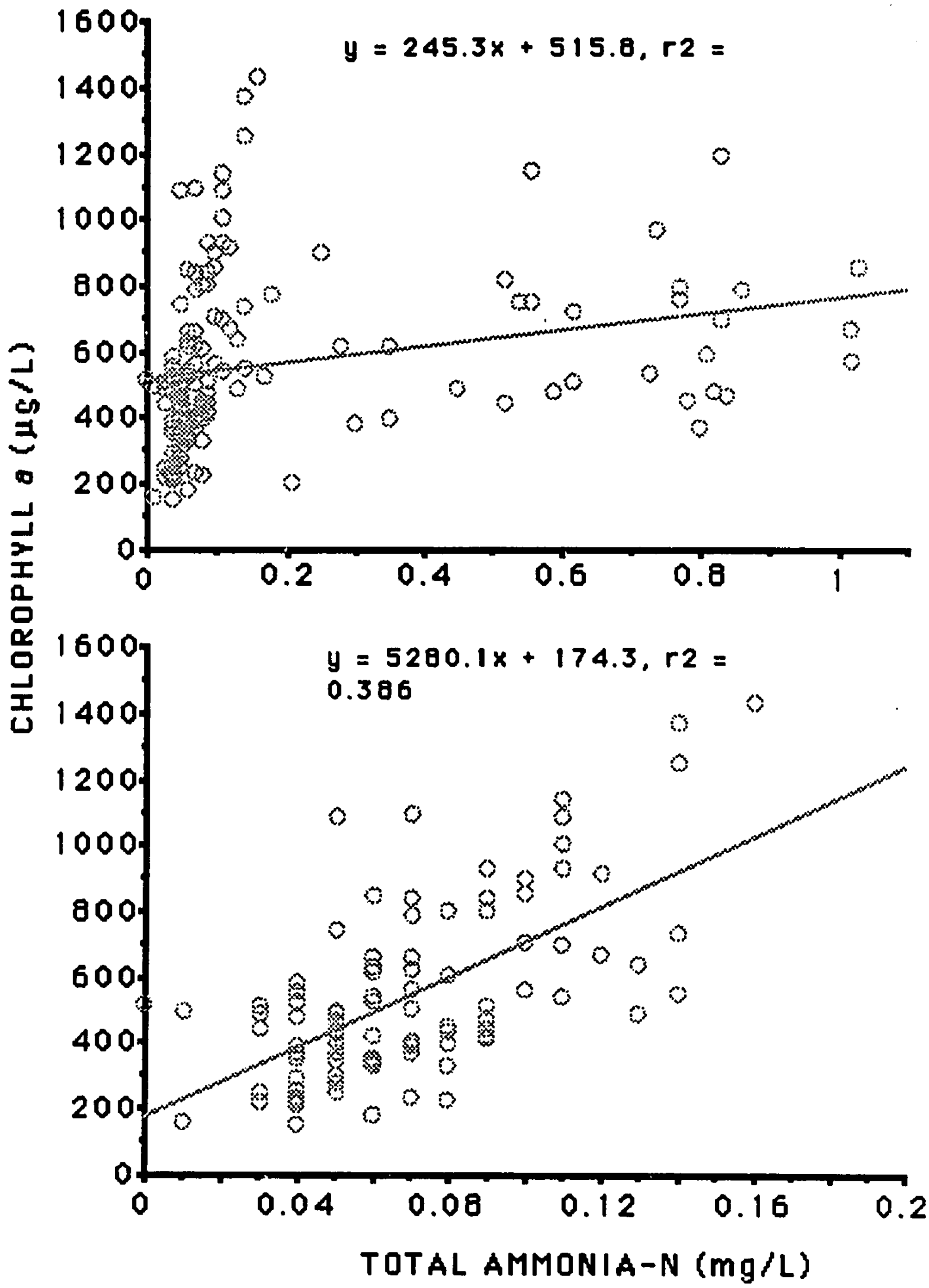

Figure 3. Relationship between chlorophyll *a* and total ammonia-N. The lower graph represents a subset of data (total ammonia-N < 0.016 mg/l) from the upper graph.

Anticipated Benefits

Correct application of supplemental nitrogen with high rates of chicken litter resulted in more profitable fish production compared with only chicken litter. Under- or over-fertilization resulted in less net income. Excessive use of nitrogen promoted blooms of blue-green algae which are known to produce fish toxins and chemicals that result in off-flavor of fish. Additional work to refine the profitable use of supplemental nitrogen fertilization is underway.

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Reproduction of Guapote Tigre in Earthen Ponds: Female to Male Stocking Ratios

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Introduction

Guapote tigre (*Cichlasoma managuense*) is a piscivorous cichlid native to Honduras and other Central American countries. It is sought after by artisanal fishermen, and has been used for some time in population control of tilapia (Dunseth and Bayne 1978).

The reproductive characteristics of guapote are not well documented. Guapote is a nest breeder and can begin reproducing in ponds at a few months of age. Number of fry produced per female appears to be high; however, yields from reproduction ponds are many times lower; probably because of predation on larvae by parents or older fingerlings. Reproduction may also be affected by stocking rates and ratios of male and females, or by environmental variables such as temperature.

The El Carao National Aquaculture Research Station began promoting the use of guapote in tilapia ponds at the end of 1988, but because guapote were being produced only sporadically and ineffectively, the demand for fingerlings quickly outpaced supplies. The need for baseline research on guapote reproduction became apparent. The objective of this study was to document effects of male:female stocking ratios and temperature on the number of fry harvested from reproduction ponds.

Materials and Methods

Twelve trials were conducted at the El Carao National Aquacultural Research Center, Comayagua, Honduras, between 28 September 1990 and 26 August 1991. Two 0.05-ha earthen ponds, each equipped with a 9 m^2 concrete harvest basin, were used for each trial. Two treatments (1 Female:1 Male and 3 Females:1 Male) were randomly assigned to ponds in each trial. Guapote were stocked in each pond on the same day. Maximum-minimum thermometers were suspended in each pond at a depth of 0.5 m, and temperatures were recorded five days per week. Fish were fed a commercial fish or shrimp ration 5 days/week at 1% of total adult biomass. After 25 days, ponds were completely drained and harvested. Outlets were covered with 1 mm square-mesh screen. Fry were harvested from the catch-basin with dipnets, and then weighed to the nearest gram on an electronic balance. A sample of 500 fry was weighed to determine the average larval weight. Total number harvested was calculated from the average larval weight and harvest weight. Data were pooled and analyzed using an unpaired t-test and regression analyses. Differences were declared significant at an alpha level of 0.10.

Results

There was no reproduction during the first 5 trials which occurred during the cold season, except for a few hundred fry harvested during the second month (Figure 1). Reproduction did not occur below mean monthly temperature of 24.5°C, and was independent of temperature above 24.5°C. The number of fry, fry per female, and fry per gram of female harvested from the 1F:1M ratio was significantly greater than that of the 3F:1M ratio (Table 1). Lower harvest numbers at the 3F:1M ratio was probably related to greater predation pressure on the fry by parents. After reproduction started in March 1991, harvest number decreased with an increase of female biomass ($P < 0.05$). Current studies concentrate on increasing successful recruitment by manipulating stocking densities and duration of reproduction cycles.

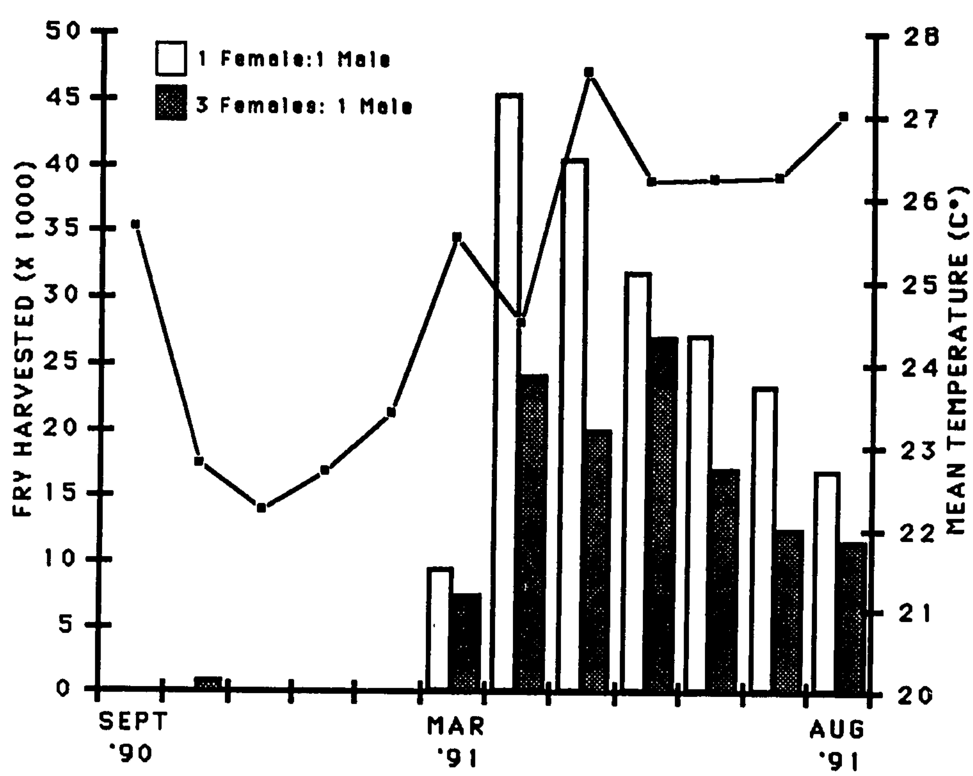

Figure 1. Number of fry harvested and mean average temperature during reproduction of guapote tigre at two female:male ratios from September 1990 to August 1991.

Table 1. Stocking and harvest of guapote tigre at two female:male ratios during seven reproduction trials between March 1991 and August 1991.

Variable	Treatment 1F:1M	3F:1M
Female no.	102	225
Female wt. (g)	121	115
Male no.	102	75
Male wt. (g)	171	164
No. fry	27887	17077
Fry/m2	55.8	34.2
Fry/female	298	80
Fry/g female	2.5	0.7

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RWANDA TECHNICAL REPORTS

Effect of Temperature on Growth of *Oreochromis niloticus*

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Introduction

Tilapia are among the most widely cultured fish in the world. Ideal for tropical areas, tilapia are hardy, omnivorous, fast-growing and easily spawned. However, many tropical areas include highland regions where average water temperatures are thought to remain too low for adequate growth of tilapia. Rwanda is a high altitude equatorial African country in which tilapia culture is practiced in ponds at 1,300 to 2,500 m elevation. Despite the predicted limitations on growth, some Rwandan fish farmers have achieved tilapia yields of over 2,500 kg/ha/yr. This production together with the relative culture advantages of tilapia when compared to other species have created interest in the role of water temperature on tilapia growth.

Temperature is a critical aspect of the pond environment, affecting survival as well as growth, rate of development, activity, and reproduction in tilapia (Balarin and Hatton 1979). Most tilapia have a decrease in growth rate below a temperature range of 17.2-19.6°C (Bishai 1965). The upper temperate range is 38-40°C. For *Oreochromis niloticus*, the upper lethal limit appears to be 41°C.

The effects of temperature on digestion and evacuation rate have been examined in other fishes: brown trout, *Salmo trutta* (Elliott 1972); channel catfish, *Ictalurus punctatus* (Shrable et al. 1969); rainbow trout, *Oncorhynchus mykiss* (Brocksen and Bugge 1974). Studies done using tilapia have not been extensive. Soderberg (1990) determined the effect of temperature on the growth of blue tilapia (*Tilapia aureus*). Some work has been done on the ability of the fish to acclimate to and withstand low water temperatures (Chervinshi and Lahau 1976). Cauiton (1975) observed the diurnal movement and temperature preferences of *Tilapia rendalli* in lakes. *T. rendalli* appeared to prefer warm waters during the day and then to migrate to cooler waters at night. The present study evaluated the effect of temperature on the appetite and growth of tilapia (*O. niloticus*) in laboratory conditions.

Materials and Methods

Oreochromis niloticus, 5.1 g average weight, were stocked into 110-liter aquaria, 20 fish per tank. The treatments consisted of four constant temperatures, 16, 20, 24, and 28°C. Each treatment was replicated five times.

The aquaria had constant aeration and were flushed twice daily to remove wastes. Water for the experiment was city water that was passed through a chlorine filter. Temperatures were regulated with heaters or a water chiller (Frigid Unit Model D1-33). Oxygen, ammonia, pH, and chlorine were monitored. The light-dark photoperiod was 14:10.

The fish were fed twice a day to satiation. The feed used was a commercial catfish diet (32% protein), which was ground and repelleted to an appropriate size for the fish. Daily feed consumption for the fish in each aquarium was measured and the fish were weighed every two weeks.

<u>Results and Discussion</u>

Weight gains in the fish grown at the different temperatures were significantly different. Fish grown at the highest temperature had the best growth ($P<0.05$). The average weight gain of the fish at the various temperatures per sample period is illustrated in Fig. 1.

Of the water quality parameters measured, ammonia was the most difficult to control, ranging as high as 0.5 mg/L. Because of this problem the decision was made to flush the tanks twice a day and thereby maintain an ammonia level

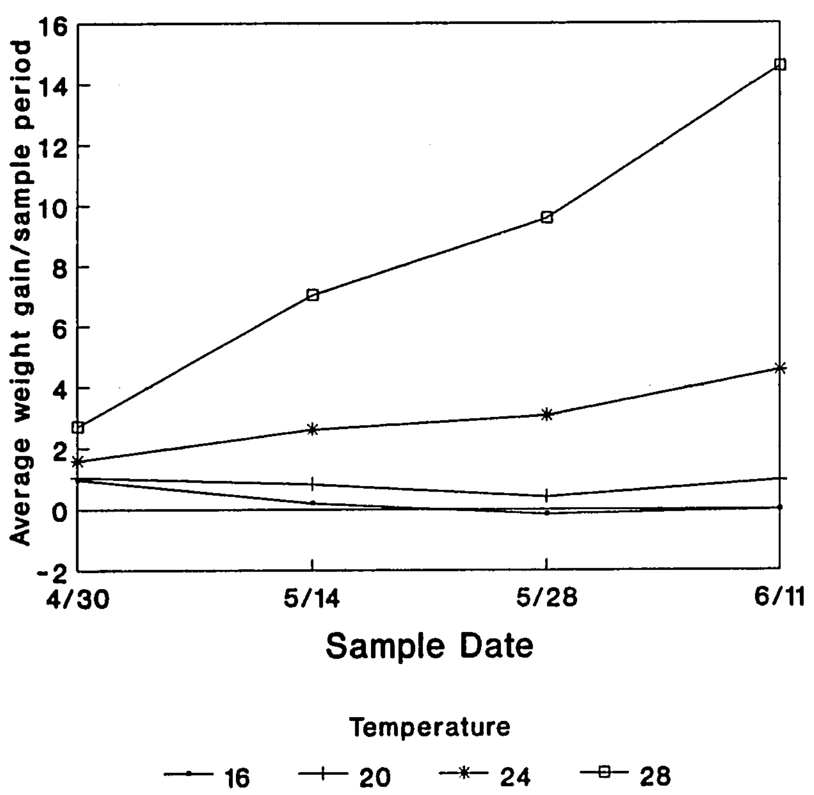

Figure 1. Average weight gain/sample period of *O. niloticus* grown at various temperatures.

within the 0.0 – 0.3 mg/L range. The oxygen level ranged from 6 to 10 ppm, pH 6.5 to 8.0, and chlorine 0.0 to 0.1 ppm.

The results of this experiment were as anticipated: as the temperature increased, the growth increased. Data from this study will be used as baseline data for a second study in which *O. niloticus* will be grown in one of two diel temperature regimes. One regime will have a temperature range of 16° to 24°C with daily average of 20°C and the other will have a temperature range of 20° to 28°C with a daily average of 24°C. These regimes mirror the temperature variations that occur in Rwanda (Hanson et al. 1988). The data from these studies will provide information about how tilapia respond to these various temperatures and perhaps give insight into management practices.

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Production and Growth of Supplementally Fed *Oreochromis niloticus* Males Stocked at Three Densities in Fertilized Ponds

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Introduction and Objectives

In the Rwandan countryside, low densities (67 fish per are) are used in the culture of mixed-sex *Oreochromis niloticus* (1 are = 100 m^2). At the Rwasave Fish Culture Station, stocking has traditionally been 100 fish per are in monosex male culture. This experiment was designed to investigate the optimal fish stocking density for monosex culture at moderate fertilization and feeding rates.

Materials and Methods

The 192-day experiment employed six ponds for three replicated stocking rates. The ponds had a surface area of 3.3 ares and were protected against predation by pelicans and fish eagles by wires supported 20 cm above the surface. *O. niloticus* males, weighing about 80 grams were stocked at densities of 100, 200, and 300 fish per are. Ponds were fertilized with freshly cut green grass and 1.1 kg/are/week of chicken litter. Fish were fed rice bran at 5 grams per fish per day supplemented with fresh outer cabbage leaves.

Every four weeks at least 30 fish were counted and weighed. Growth, mortality, production, food conversion, and cost per return were compared for each stocking density.

Results

Mean daily growth rate for fish stocked at 100, 200, and 300 per are was 0.61, 0.51, and 0.52 grams per day, respectively. Mortalities were 2.7, 4.1, and 3.9%. The mean net yields were 1810, 2620, and 3881 kg/ha for the 192-day experiment. Net productions were 3441, 4981, and 7378 kg/ha/yr, respectively. The high production occurring at the highest density exceeded the maximum production documented for *O. niloticus* in Rwanda. Feed conversion efficiency (FCR) was higher for the lower fish densities, apparently because of greater availability of natural food in those ponds. FCR was 5.6, 7.6, and 7.7 for low, medium, and high fish densities.

Profitability was compared by analysis of the values of inputs verses outputs by the method of comparative benefits. Variables included were the values of fish stocked, rice bran fed, and the value of harvested fish. Gross income at the low stocking rate was FRw 495,600/ha (75 FRw = 1$US). Net returns were 32 and 94% higher at medium and high fish densities, respectively, than at the low fish density.

Anticipated Benefits

This study has shown that commercial tilapia production is economically feasible at the relatively high elevations found in Rwanda (1625 meters at Rwasave). Higher stocking densities (300 fish/are) were shown to be more profitable than lower densities in monosex culture with moderate fertilization when using a rice bran feed. Supplemental feeding with rice bran resulted in double to triple the yields normally obtained with composting only.

On-Farm Production of Mixed Sex *Oreochromis niloticus* at Different Elevations (1370 to 2230 m)*

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*Fifth Work Plan, Experiment 3

Introduction

The upper elevation limit for tilapia production has been reported to be 1500 m (Balarin 1987). Using data from Malawi and Madagascar, Balarin indicated that 1500 m was the 0 - intercept for tilapia production. However, Rwandan farmers have been producing tilapia at elevations above 2000 m. Yields at the higher elevations had been inferior to yields from ponds at less than 1700 m, but extension specialists observed that management practices were also less intense at the higher altitudes.

Objective

The objective of this study is to examine the effects of elevation on the production of tilapia in farmers' ponds enriched with a standardized compost and managed with the same strategy.

Materials and Methods

At least five ponds were selected at each of five elevation zones (1370 m, 1570 m, 1770 m, 1970 m, and 2200 m, elevation ± 30 m) for similar water alkalinity, soil and other physical characteristics, and for farmer willingness and ability to collaborate. Five ponds at 1625 m (Rwasave Station) and three ponds at 1900 m (Kanama Commune) were also included to represent intermediate elevations. All ponds were stocked at 1 fish/m^2 with *Oreochromis niloticus* mixed-sex fingerlings from the same source. Ponds were fertilized weekly at 500 kg dry weight/ha/wk with *Cyperus* sp., a grass common to all sites. The input was supplemented with urea and triple-super phosphate to bring the total application of N to 16 kg/ha/wk and P to 4 kg/ha/wk.

Farmers measured secchi disk visibility weekly and noted water color according to a color-coded scale provided by the researchers. Farmers also noted days on which water was added, and measured total length of any dead fish observed. Rwasave Station staff took monthly water samples for chlorophyll *a*, alkalinity, hardness, pH, dissolved oxygen, and conductivity determinations. Phytoplankton counts were made by genera for pond water samples from each pond. Fish were sampled approximately monthly and average weights for each sex were determined. Recording thermometers were installed in one pond per elevation zone, except for Zone 3. However, not all recorders functioned throughout the experiment. Temperature was monitored at 25 cm below the surface.

Ponds were drained when fish reached an average weight of 100 g or when fish growth approached zero. Ponds in the same zone were drained within a three-day period.

Results

Total alkalinity, the major water quality parameter used to set selection criteria for ponds and other parameters varied between zones (Table 1). All ponds in Zone 1, the lowest elevation zone, had very high total hardness and conductivity in relation to total alkalinity although they were located in three valleys and thus different watersheds. High levels of manganese were measured at one of the sites. Because of the unusual water quality and the slow fish growth observed in all Zone 1 ponds, ponds in this zone were not included in subsequent analyses.

Ponds in Zones 3 and 4 were low in alkalinity throughout the experiment, only surpassing the minimum of 20 mg/L as $CaCO_3$ after the first month (Table 1).

Total fish recovered at harvest was relatively low for most ponds. Fish deaths were recorded throughout the experiment and numbers of fish seined monthly

Table 1. Average pond water quality characteristics (± SD) by zone during the experiment.

Zone	Avg. pond temp. (Jan)	Total akalinity	Total hardness	Conduct	Uncorr. chl *a*	Secchi disk
Meters ASL	°C	mg/L $CaCO_3$	mg/L $CaCO_3$	µmhos/cm²	mg/m³	cm
1. 1370±30	23.8	65±26	195±33	732±41	58±33	23±7
2. 1570±30	23.6	54±11	34±6	128±16	100±34	24±5
Rwasave* 1625	23.8	41±4	40±3	143±6	340±207	20±5
3. 1770±30		19±5	17±2	59±7	229±104	25±5
Special 1900		71±10	72±13	171±21	41±29	33±3
4. 1979±30	20.5	18±8	27±5	36±7	399±138	17±2
5. 2200±30	19.1	50±34	38±5	148±153**	192±47	24±2

* Rwasave Fishculture Station
** caused by one pond with conductivity at 525 µmhos/cm.

sometimes exceeded numbers of fish harvested at draining, suggesting losses occurred over time rather than at stocking. Predation by birds during early morning periods of low oxygen was the most likely cause of losses for most ponds. Theft is suspected for three ponds. Loss of large fish late in the experiment would have greater impact on pond production estimates than for losses at stocking.

Time to first reproduction was one of the most apparent differences between fish in different zones. Eggs were observed in females' mouths after 1 month at low elevations and after 4 months at the highest elevations. In zones where reproduction did occur, the contribution to total production was highly variable. No progeny were observed at draining for ponds in the highest zones (4 and 5), although females brooding embryos had been observed for more than three months prior to draining. The ratio of average weight of males to females decreased as elevation increased (Figure 1) apparently because of the reduction in male weight gain at higher elevations (Table 1).

Weekly secchi disk visibility measured by farmers was more highly correlated with monthly chlorophyll measures (r= -0.75) than monthly secchi disk measurements made by laboratory personnel (r= -0.58). Weekly secchi disk measurements were good predictors of net fish production. Net fish production (including fingerlings) was negatively related to uncorrected chlorophyll *a* (r= -0.45) for ponds both within and among zones.

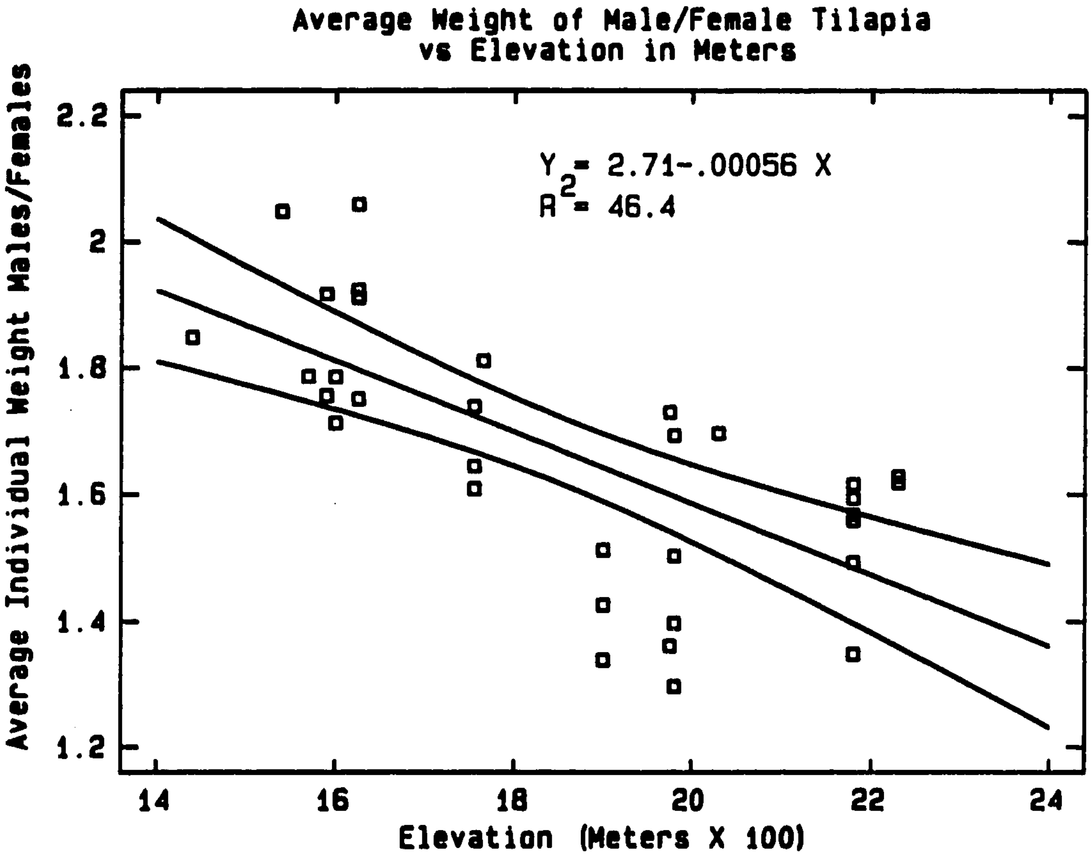

Figure 1. Male to female average individual weight as a function of elevation.

Multiple regression was used to generate a model to predict net annualized fish production using easily measured parameters. Only elevation and secchi disk values were significant environmental parameters, giving an adjusted R^2 of 0.55. Fish recovery rate was also a highly significant factor in predicting fish production. A model using elevation, percent fish recovered, and secchi disk visibility could account for 75% of the variation in pond productivity (Figure 2). If chlorophyll *a* (a parameter more difficult to measure) was substituted for secchi disk visibility in the model, the R^2 would increase from 0.55 to 0.75 for this factor. The model giving the highest correlation used weight of progeny produced, recovery rate, alkalinity, chlorophyll *a*, hardness and secchi disk visibility (in order of importance) providing an adjusted R^2 of 0.88. Further development of this model is planned including a test of its predictive value on a data set not used in selecting the present parameters and in determining values of constants.

Anticipated Benefits

This experiment contributes data necessary for the formulation of optimal pond management practices appropriate for different elevations. Results suggest farmers at elevations below 1700 m employ monosex culture or use short grow-out times, stocking with young fingerlings. High-elevation tilapia farmers will have to overcome the problem of producing sufficient fingerlings for restocking.

Fertilization rates need to be adjusted to compensate for the relatively shallow ponds found in rural areas.

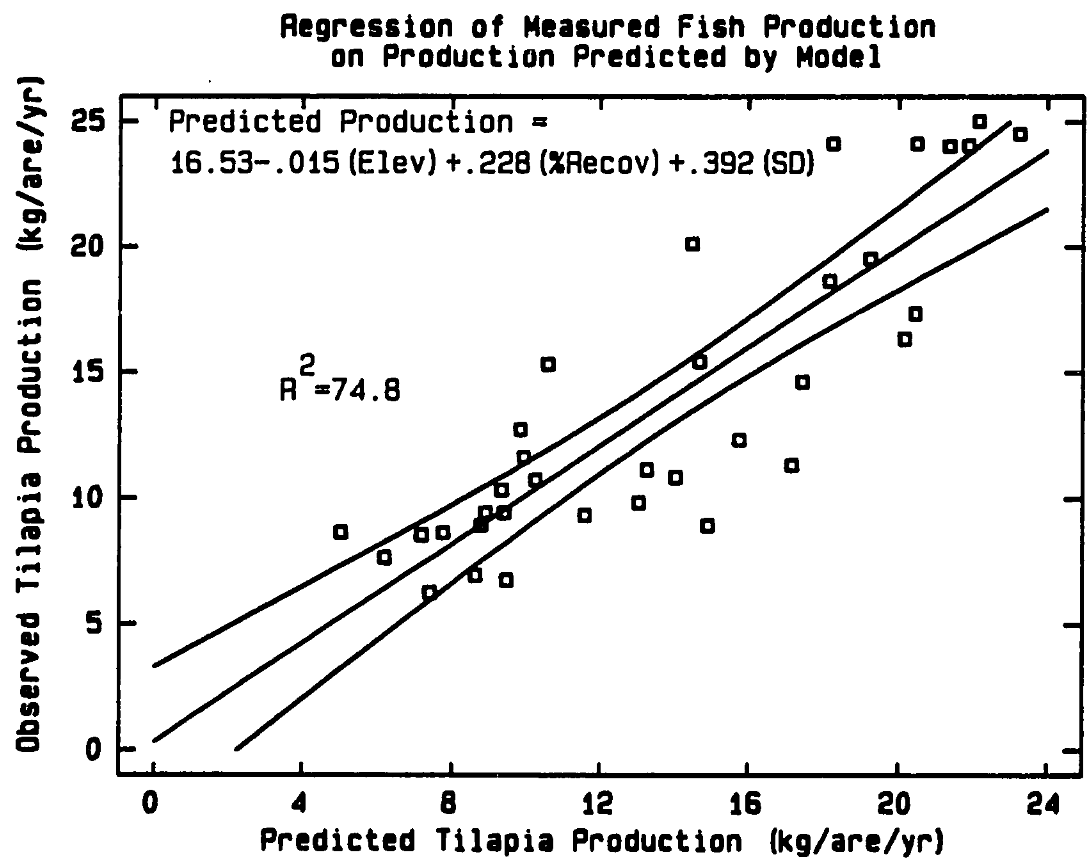

Figure 2. The regression of measured tilapia production (including fingerlings) on tilapia production predicted by a model employing elevation, % recovery, and secchi disk as variables.

Table 2. Average fish production statistics by zone. Ponds with less than 50% fish recovery rate are not included. Zone 1 ponds are not included as explained in text.

Zone	Ponds harvested	Cycle length	Wt. gain males	Wt. gain females	Reproduction wt.	% harv. as reprod	Total prod w/o reprod	Total prod w reprod	Recovery rate
meters		days	g/day	g/day	kg/are	%	kg/are/y	kg/are/yr	%
2. 1570±30	6	185	0.76	0.36	3.31	27.9	11.51	18.04	64.0
Rwasave 1625	5	185	0.71	0.29	1.85	13.7	16.45	20.12	88.9
3. 1770±30	4	236	0.47	0.24	3.40	31.4	7.03	12.48	67.9
Special 1900	3	210	0.69	0.45	0.02	0.16	12.69	12.71	68.7
4. 1970±30	7	192	0.50	0.29	0	0	8.61	8.61	70.1
5. 2200±30	8	245	0.58	0.34	0	0	10.15	10.15	68.0

The high level of farmer participation and interest demonstrated during the study, despite the uncertain political situation at this time, is indicative of the extension value of on-farm trials. Continual effort to control variability is necessary to capitalize on the opportunity to utilize farmer ponds to investigate the influence of elevation on pond productivity.

This study also corroborates observations made by Engle et al. (1990) on the relative contribution of tilapia reproduction to overall pond productivity and to possible net returns to labor.

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Digestibility of Food Consumed by *Oreochromis niloticus* in Fertilized Ponds*

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* Fifth Work Plan, Experiment 6

Introduction

The principal food source for tilapia in enriched ponds in developing countries is naturally occurring organisms. The energy content of these natural foods may be insufficient for the optimum utilization of available protein for fish growth. Supplementary feeding with inexpensive, high-energy feedstuffs could improve protein utilization efficiency. In order to select appropriate feeds or agricultural by-products for supplementing natural foods, data are needed on the relative abundance of digestible protein and energy in food organisms cultured under different conditions. Determinations of digestibility for natural foods occurring in these ponds is underway but not yet complete.

Objectives

The objective of this study is to determine the digestibility of the protein and energy in the natural food organisms ingested by tilapia in ponds enriched by selected inorganic and organic fertilizers. Additionally the fertilizer treatment that is most deficient in digestible energy will be chosen for use in a subsequent experiment.

Materials and Methods

Twelve 7-are ponds were used, two at each of the following fertilization regimens:
1) (N+P), 8.1 kg N and 1.6 kg P per ha/wk as urea and TSP;
2) (GGrass+N+P), freshly cut grass from pond levees added at 500 kg/ha/wk plus N and P as in (N+P) above;
3) (*Cyperus*+N+P), Freshly cut sedge (*Cyperus* sp.) added at 500 kg/ha/wk plus N and P as in (N+P) above;

4) (Pig), pig manure with bedding included added at 500 kg/ha/wk;
5) (Chicken), chicken manure with bedding (wood chips) included added at 500 kg/ha/wk;
6) (GGrass), freshly cut green grass from levees added at 500 kg/ha/wk.

All ponds were stocked with juvenile male *Oreochromis niloticus* at the rate of 350 kg/ha on 26 April 1990, excepting the ponds receiving the green grass treatment, which were stocked at the end of August. The green grass (GGreen) treatment was added because of the apparent similarity of the phytoplankton blooms in existing treatments. After three months, four lots of 10 fish each were removed from each pond at 1600 hours for analysis of the contents of the stomach and lower 5% of intestine (feces). After an additional two months, four lots of 15 fish each were taken from each pond for analysis. Fish were killed immediately and iced. At each sampling period stomach and intestinal contents for each lot were combined to form composite samples.

Analyses of stomach contents and feces included determinations of ash, Kjeldahl-nitrogen, gross energy, chromogens, and for stomach contents only, relative abundance of plankton by genera (dominant=3, frequent=2, present=1).

Results

Stomach contents for individual fish and for lots of fish from the same pond varied greatly, but some generalizations may be made with respect to treatment. Blue-green algae especially *Microsystis* and also *Syncchococcus* sp. made up the major portion of stomach contents of fish in the chemical fertilizer treatments (Table 1). Plant debris containing mineral crystals was also common. Zooplankton (rotifers and copepods), detritus and *Microsystis* were common in the chicken manure treatment with zooplankton dominating. Stomach samples from fish in ponds receiving grass plus chemical fertilizer or *Cyperus* plus chemical fertilizer contained frequent *Microsystis*, plant debris, and rotifers. The pig manure treatments resulted in samples dominated by blue-greens and zooplankton. Green grass inputs resulted in samples high in detritus and vegetable matter: *Oscillatoria* was frequent in many samples and diatoms often appeared (Table 1).

Net annualized fish production was highest for ponds receiving pig and chicken manure (Table 2).

Digestibility of ingested materials has not yet been calculated as noted above.

Anticipated Benefits

From values of digestible energy a food supplement can be selected to provide sufficient energy to save scarce protein for growth rather than for meeting energy requirements. Naturally produced protein would be used more efficiently resulting in higher yeilds. Supplemental feeds recommended would be inexpensive, high-energy types, minimizing additional costs.

Table 1. Description based on analysis of frequency indices and direct observation of contents of tilapia stomachs for four lots of 10 fish each for each pond.

Pond	Treatment	Description of Stomach Contents
C1	N+P	Plant debris with mineral crystals, also *Microsystis* sp.
C2	N+P	Cyanophytes dominate, represented by *Microsystis* and Synochococcus sp. Few rotifers, some plant debris with mineral crystals.
C4	GGrass+N+P	Mostly plant debris with crystals. Dominant phytoplankter is *Microsystis*. Some samples show significant rotifer numbers.
C5	GGrass+N+P	Plant debris with crystals dominate in two lots, *Microsystis* dominates in the other two lots.
C6	*Cyp.*+N+P	Zooplankton dominates, especially rotifers *Brachionus*, *Asplanchna*, *Keratella*. Also present *Microcystis* and *Phacus* (Euglenophyte).
C7	*Cyp.*+N+P	*Microsystis* dominates. Some rotifers present.
C8	Pig Manure	Zooplankton dominates, especially rotifers and cladocera. Some samples dominated by *Microsystis*.
C9	Pig Manure	Much detritus (may be pig feed). Some rotifers and *Lyngbya* sp. (Cyanophytes).
D1	Chicken Man.	Detritus and zooplankton (rotifers and copepods) both common. One lot with many *Trachelomonas* (Euglenophyte).
D5	Chicken Man.	*Microcystis* dominates in some lots, rotifers and copepods in others.
D4	GGrass	Vegetable debris and detritus dominate. Also Cyanophytes as *Calothrix* sp., *Gonatozygon* and *Rivularia*. One lot with much *Pinnularia* (diatom). For the replicate, Oscillatoria was predominate.
D6	GGrass	Vegetable debris and detritus dominate. *Microcystis* and *Calothrix*, *Rivularia* (all Cyanophytes) and some *Pinnularia* present. For the replicate, Oscillatoria and *Anabaena*. Some diatoms.

Table 2. Net tilapia production in kg/are/yr and percent survival for each treatment.

Pond	Treatment	Net Production (kg/are/yr)	Percent Survival
C1	N+P	15.6	96.4
C2	N+P	16.6	96.2
C4	GGrass+N+P	18.3	95.1
C5	GGrass+N+P	13.9	96.9
C6	*Cyp*+N+P	18.5	97.4
C7	*Cyp*+N+P	11.7	92.6
C8	Pig Manure	22.7	91.5
C9	Pig Manure	30.1	96.9
D1	Chicken Man.	24.2	95.1
D5	Chicken Man.	23.8	94.9
D4	GGrass	15.8	81.8
D6	GGrass	22.8	97.7

THAILAND TECHNICAL REPORTS

Tilapia and *Clarias* Polyculture

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Introduction

Clarias are commonly cultured in Thailand using earthen ponds and supplemental feed. Nutrients from such ponds, as well as surplus feeds which remain uneaten, are wasted in this culture. In an earlier experiment, we found that *Clarias* could be stocked in cages in tilapia ponds, and in such a system the *Clarias* can eat supplemental feed, while waste products will increase primary production and tilapia growth. The development of tilapia and *Clarias* polyculture can substantially increase yields and use nutrients more efficiently than monoculture of either species. The purpose of this study was to further refine the polyculture system.

Clarias are also used in polyculture systems, as a predator to limit natural reproduction in ponds. Restraining *Clarias* in cages negates such an effect, but allows for more efficient use of supplemental feed.

Objectives

The purpose of this study is to examine the role of *Clarias* and tilapia in polyculture systems. To accomplish this, four treatments were tested:

(1) *Clarias* in cages and tilapia in ponds, with supplemental feed for the caged fish;
(2) *Clarias* and tilapia at large in ponds, with similar supplemental feeding;
(3) *Clarias* and tilapia at large in ponds with only fertilizer application;
(4) *Clarias* in open ponds with supplemental feed, tilapia in separate ponds with catfish pond effluents.

Materials and Methods

Experiments were conducted at AIT with deep ponds (150 cm) for treatments 1 to 3, and shallow ponds (100 cm) for treatment 4. Each treatment was triplicated. Tilapia were stocked on 9 May, *Clarias* on 14 May. Stocking and harvest rates are given in Table 1. Treatment 3 included fertilization at 250 kg chicken manure per ha each week, with nutrient supplements to 2N:1P ratios.

Table 1. Stocking and harvest data for *Clarias* and tilapia in each treatment.

Treatment	Species	Biomass (kg)	Number	Size (g)
		at stocking		
1	*Clarias*	12.1	1120	10.8
	tilapia	10.1	800	12.6
2	*Clarias*	11.5	1120	10.3
	tilapia	10.1	800	12.6
3	*Clarias*	8.7	400	21.8
	tilapia	9.8	800	12.3
4	*Clarias*	2.2	1200	1.8
	tilapia	7.2	800	9.0
1	*Clarias*	139.3	504	276.0
	tilapia	90.7	720	125.9
2	*Clarias*	261.3	1022	256.0
	tilapia	53.3	659	81.0
3	*Clarias*	18.1	370	49.0
	tilapia	80.8	748	108.0
4	*Clarias*	198.7	473	420.1
	tilapia	69.6	732	95.1

Supplemental feeding was initially at 10% BW/d for *Clarias* and gradually declined to 3%/day by harvest. Water chemistry analyses were conducted weekly. Ponds were harvested on 27 September 1990 (140 days).

Results

Growth, survival, and yield in each treatment are summarized in Table 2. Tilapia showed relatively consistent survival between replicates of a treatment under most conditions (Table 3). However, yield varied significantly among replicates (the lowest yields were 45 to 55% of the highest yields in a treatment). *Clarias* data were somewhat more predictable with survivals and yields reasonably consistent among replicates, but with large differences between treatments. Due to the great variability in tilapia data, this experiment is being repeated.

In spite of variation among replicates of a treatment, there were still significant differences between treatments. Treatment 1 (supplemental feed and caged *Clarias*) produced the best growth, survival, and yield of tilapia. *Clarias* survival and yield was highest in treatment 2 (no cages, supplemental feed), while growth was highest in treatment 4 (no tilapia in pond, supplemental feed). Supplemental feed resulted in high *Clarias* growth, but variable survival. Tilapia growth was not correlated to use of supplemental feed.

Table 2. Average growth, survival, and yield of *Clarias* and tilapia in each treatment.

Treatment	Growth (g)	Survival (%)	Net Yield (kg)
		Clarias	
1	265.2	45	127.2
2	245.7	91	249.8
3	27.2	93	9.4
4	418.3	59	196.5
		Tilapia	
1	113.3	90	80.6
2	68.4	82	43.2
3	95.7	94	71.0
4	86.1	92	62.4

Anticipated Benefits

This project, while yielding somewhat variable results, still provided interesting outcomes for pond management. The first was that *Clarias* grew much better with supplemental feed than without it. Growth in supplementally fed systems was good, and yield was better in ponds where the fish were not caged. Reasons for this are unclear, as survival was better in uncaged groups with tilapia, but survival was limited and growth excellent in uncaged monoculture.

Tilapia results were hard to interpret. Tilapia growth was highest when *Clarias* were caged, and lowest with *Clarias* at large. Combined yields were maximum when both were in separate ponds. It does not appear that *Clarias* ate tilapia to a great degree when they were in open polyculture, because *Clarias* growth was average and tilapia survival near average.

All of these results, along with future runs, can be used to fine tune these polyculture systems.

Table 3. Numbers and weights stocked and harvested for each replicate of *Clarias* and tilapia in polyculture.

Treatment	Number Stocked	Number Harvested	Weight at Stocking (g)	Weight at Harvest (g)
		Clarias		
1	1120	572	11.4	119.5
1	1120	412	12.2	183.5
1	1120	529	12.7	114.8
2	1120	1047	10.9	259.7
2	1120	972	11.5	286.2
2	1120	1049	12.1	238.2
3	400	375	8.3	19.8
3	400	378	8.2	19.9
3	400	358	9.6	14.6
4	1200	587	2.3	235.1
4	1200	455	2.3	196.6
4	1200	379	2.1	164.5
		Tilapia		
1	800	788	10.7	65.5
1	800	699	9.9	64.5
1	800	672	9.7	29.1
2	800	759	9.2	110.1
2	800	642	10.0	102.4
2	800	575	11.2	60.1
3	800	838	9.4	103.3
3	800	662	10.1	82.2
3	800	746	10.0	56.9
4	800	783	7.3	80.0
4	800	722	7.2	56.0
4	800	692	7.2	72.9

A Systematic Approach to Maximizing Nutrient Efficiency and Growth of Nile Tilapia (*Oreochromis niloticus*) Under Semi-intensive Pond Culture

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Pond management strategies have been developed in Thailand to optimize use of nutrients in fertilizers for high and predictable yields of Nile tilapia. Application of concepts dealing with phosphorus:nitrogen:carbon ratios required in fertilized ponds and research with fish stocking strategies have led to the highest yields ever reported for Nile tilapia under semi-intensive culture. We obtained mean net fish yields of over 50 kg/ha/day in 75 days, and 32 kg/ha/day with 150 day growout. Ponds had high concentrations of dissolved inorganic carbon (DIC). DIC at dawn was 20 to 30 g/m^2. Ponds were stocked with 3 fish/m^2. They were fertilized at a rate of 1 g dry weight chicken manure/m^2/day (70 kg/ha/wk) and supplemental urea and triple superphosphate to give a nitrogen (TN) input of 0.5 g/m^2/day and a TN:TP ratio of 4:1. Ammonia was adequately cycled in ponds to eliminate concern for adverse influences of un-ionized ammonia on fish growth. Artificial aeration of ponds was not required. Mean dissolved oxygen at dawn was near 3.0 mg/L.

Chicken Manure as a Source of Carbon in the Production of *Oreochromis niloticus*

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Introduction

The role organic fertilizers may play in pond culture of Nile tilapia (*Oreochromis niloticus*) is still not universally agreed upon. Manures are frequently applied to fish ponds because they release soluble nitrogen (N) and phosphorus (P) which promote algal production, the primary food source for planktivorous fish (Wohlfarth and Schroeder 1979; Colman and Edwards 1987). In waters with low alkalinities, manure decomposition may also be an important source of dissolved inorganic carbon (DIC) for algae (McNabb et al. 1990; Knud-Hansen et al. 1991a). Several studies have suggested that the particulate component of organic fertilizers may be also be consumed directly or as manure-derived detritus after heterotrophic microbial activity (Colman and Edwards 1987; Green et al. 1989; Knud-Hansen et al. 1991a). Recent research by Schroeder et al. (1990), however, suggested that organic matter from manure contributed very little to growth of common carp, silver carp, grass carp, and tilapia hybrids grown in polyculture.

Whether a farmer should use organic and/or inorganic fertilizers depends on relative environmental and economic efficiencies of transferring soluble and particulate nutrients into fish biomass. Choice of organic inputs must be made carefully as there are several inherent problems with its use, including 1) promotion of early morning deoxygenation, 2) labor intensiveness with regards to transport and application, and 3) rapid filling of ponds. In Thailand the use of chicken manure is also a poor economic choice. Although urea and triple superphosphate (TSP) are 10 and 20 times more expensive than chicken manure, respectively, the unit cost of available N is nearly seven times less expensive with urea while the cost of available P is almost three times less expensive with TSP. Recent research at AIT indicated that if chicken manure does have additional benefits for tilapia production, then it is quite limited (Knud-Hansen et al. 1991b). The following experiment was designed to evaluate the utility of chicken manure as a source of carbon for Nile tilapia production under conditions of high inorganic N and P inputs.

Objectives

This experiment examined whether chicken manure provides particulate organic carbon as manure-based detritus for tilapia, dissolved inorganic carbon for algal productivity, neither, or both. The factorial design allowed examination of possible interactions between different types of carbon sources on net fish yield (NFY).

Null Hypotheses:

1. Chicken manure does not increase NFY by providing particulate organic carbon for consumption either directly or as detritus.
2. Chicken manure does not increase NFY by providing inorganic carbon for stimulating algal productivity.

Materials and Methods

Research was conducted at the Bang Sai Freshwater Fisheries Station of the Royal Thai Department of Fisheries located approximately 60 km northwest of Bangkok, Thailand (14.2°N 100.5°E). Twelve 0.028-ha earthen ponds were stocked with sex-reversed male Nile tilapia at a density of 3.1 fish/m^2 on 25 October 1990. Fish weight ranged from 2 to 6 g at the time of stocking. Methyl-testosterone (Buddle 1984) was used for sex reversal. Fish were harvested after a 147-day growout period on 21 March 1991.

Four treatments consisted of 1) fresh layer chicken manure added at 59 kg dry wt/ha/week, 2) inorganic carbon added at 9.2 g C/m^2/day as $NaHCO_3$, 3) both chicken manure and $NaHCO_3$ added at the rates given in the first two treatments, and 4) no organic (chicken manure) or inorganic ($NaHCO_3$) added. Urea and TSP (45% P_2O_5) were added to all ponds to give a nitrogen input of 0.4 g N/m^2/day and a N:P ratio of 4:1 by weight. In calculating loading rates it was assumed that chicken manure releases through leaching and decomposition 50% of its total carbon, 40% of total N, and 20% of total P as solutes available for phytoplankton uptake. The factorial design allowed examination of possible interactions between different types of carbon sources on NFY. There were three replicates per treatment; treatment allocation to ponds was completely random.

Water quality measurements were made biweekly as described by Egna et al. (1987). Integrated samples were collected by vertically lowering and capping a pre-rinsed, 5-cm (i.d.) PVC tube. Water temperature and dissolved oxygen were measured *in situ* with a Yellow Springs dissolved oxygen (DO) meter Model 54A. Total alkalinity was analyzed potentiometrically using 0.02N HCl to titrate the sample to pH 5.1 (APHA et al. 1985). Net primary productivity (NP) was estimated from diurnal changes in DO measured before dawn (≈ 0600 hours) and at 1600 hours at pond depths of 25, 50, and 75 cm.

ANOVA and regression analyses presented here were done according to Steel and Torrie (1980) using the Statgraphics v.4™ statistical software package.

Results

NFY ranged between 19.3 and 38.4 kg/ha/day for all ponds. There were no significant differences in mean NFY between treatments (Table 1), however, suggesting that neither particulate organic carbon nor DIC additions benefited tilapia production. There were also no significant interactions (non-linear effects) on NFY between the two sources of carbon. These results support conclusions of Schroeder and Buck (1987), Schroeder et al. (1990), and Knud-Hansen et al. (1991b) that manure-derived detritus was at best a minor influence in tilapia production.

Table 1. Treatment means and standard errors (S.E.) for net fish yield (NFY, kg/ha/day), net primary productivity (NP, mg O^2/L/10 hours), and total alkalinity (mg $CaCO_3$/L). No treatment means were significantly different from each other for each variable.

Treatment	NFY Mean	NFY S.E.	NP Mean	NP S.E.	Alkalinity Mean	Alkalinity S.E.
No Carbon Added	30.5	1.5	11.8	0.7h	98.7	22.1
Sodium Bicarbonate	25.6	4.9	11.7	2.5	83.4	35.4
Chicken Manure	24.3	2.0	10.1	0.5	47.3	8.0
Chicken Manure + Sodium Bicarbonate	30.6	5.7	13.7	1.0	99.4	18.7

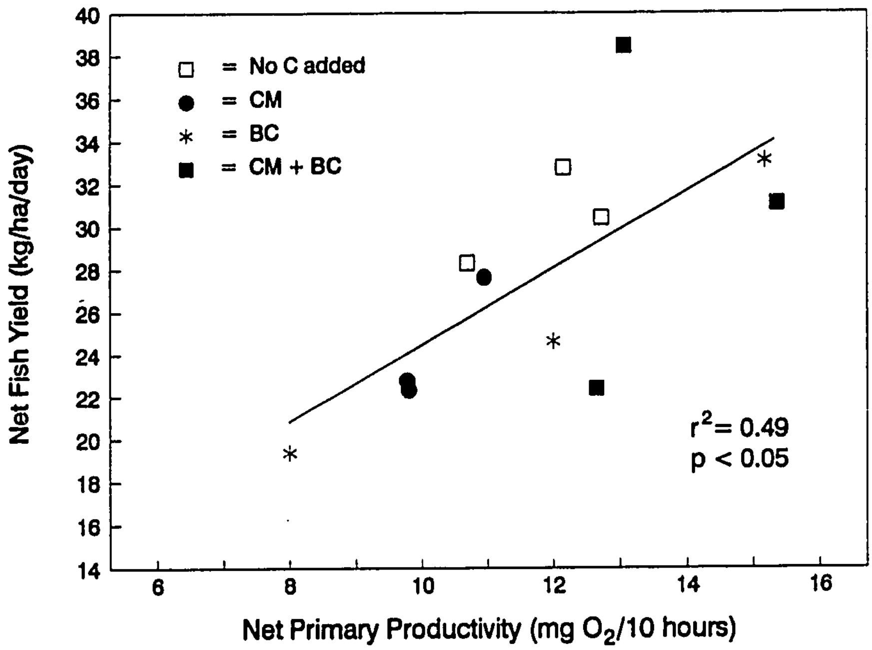

Figure 1. Relationship between net fish yield (kg/ha/day) and mean net primary productivity (diurnal changes in dissolved oxygen as mg/L/10 hours) for all treatments and ponds. Treatment designations are: No C added = no carbon added; CM = chicken manure added; BC = bicarbonate added, and; CM + BC = chicken manure and bicarbonate added.

The apparent contradiction with opposite conclusions by others (Noriega-Curtis 1979; Oláh et al. 1986; Colman and Edwards 1987; Green et al. 1989; Knud-Hansen et al. 1991a) may be related to phytoplankton abundance and productivity. Although variations in NP were not related to treatment differences (Table 1), NFY was significantly linearly correlated to net primary productivity ($r^2 = 0.49$, $P < 0.05$) (Figure 1), similar to McConnell et al. (1977) and Knud-Hansen et al. (1991b). When DIC availability, light (due to inorganic turbidity or discoloration from dissolved organic matter), or relatively low soluble N and P inputs restrict algal production beyond dietary requirements for fish growth, tilapia may be forced to feed on manure-derived detritus.

Since carbon inputs showed no significant influence on NFY or NP (Table 1), what was responsible for variations in NP which in turn were related to NFY (Figure 1)? The apparent answer was DIC availability as reflected in total alkalinity. Initial alkalinities in all ponds were 101 mg $CaCO_3$/L. By the end of the experiment alkalinities ranged from 25 to 175 mg $CaCO_3$/L in individual ponds. There was a significant linear correlation ($r^2 = 0.81$, $P < 0.001$) between mean alkalinity and mean NP (Figure 2), and therefore between mean alkalinity and NFY (Figure 3). Analysis of variance indicated that alkalinity differences between ponds accounted for 57% and 82% of the observed variation in NFY and NP, respectively. McNabb et al. (1990) demonstrated that chicken manure can supplement the DIC pool increasing algal productivity in fish ponds with low alkalinities (20-30 mg $CaCO_3$/L). Changes in alkalinity, however, were not related to treatment (Table 1), fertilizations from previous experiments, or spatial distribution of ponds.

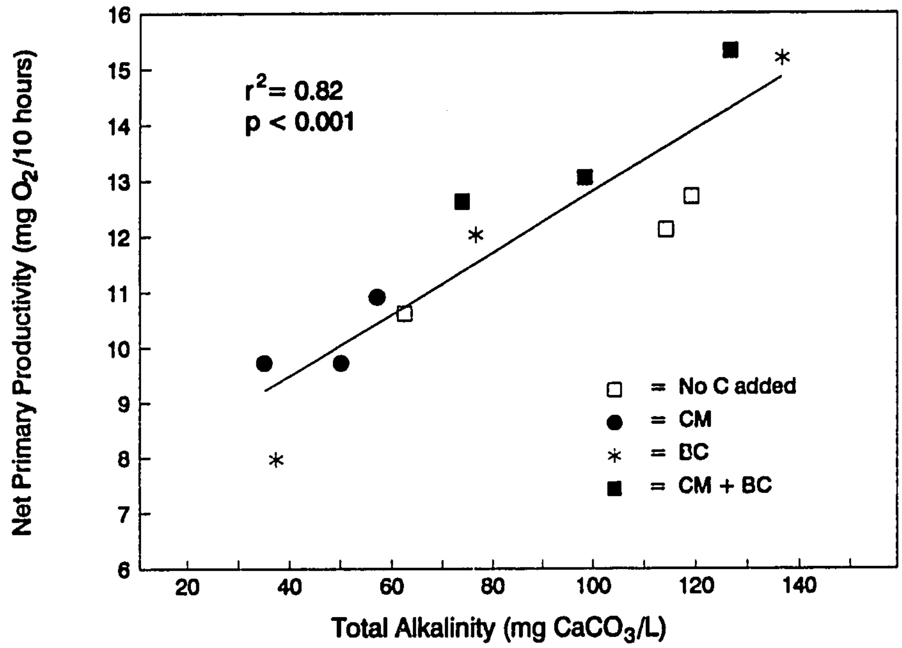

Figure 2. Relationship between mean net primary productivity (diurnal changes in dissolved oxygen as mg/L/10 hours) and total alkalinity (mg $CaCO_3$/L) for all treatments and ponds. Treatment designations are: No C added = no carbon added; CM = chicken manure added; BC = bicarbonate added, and; CM + BC = chicken manure and bicarbonate added.

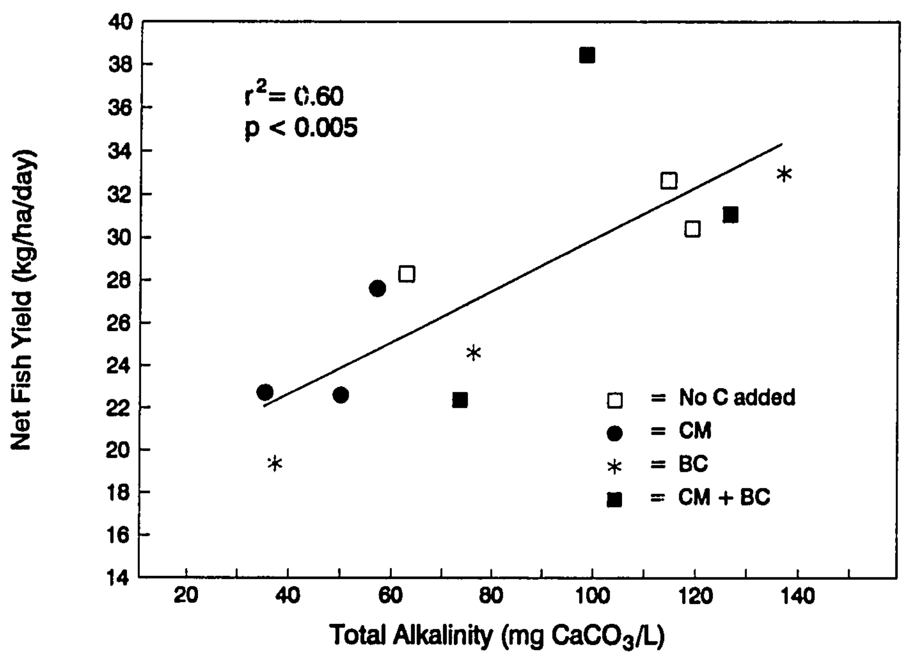

Figure 3. Relationship between net fish yield (kg/ha/day) and mean total alkalinity (mg $CaCO_3$/L) for all treatments and ponds. Treatment designations are: No C added = no carbon added; CM = chicken manure added; BC = bicarbonate added, and; CM + BC = chicken manure and bicarbonate added.

A likely candidate for affecting alkalinity may be snails, which after draining the ponds were found on sediments in varying amounts. Some ponds had only a few snails while other pond bottoms were nearly 100% covered. Although only qualitative estimates of snail biomass were made at the time, there was a distinct inverse relationship between snail coverage and alkalinity. It seems highly plausible that incorporation of $CaCO_3$ into snail shells greatly influenced DIC dynamics and limited its availability for algal uptake. Although snail activity may have obscured actual beneficial effects of additional carbon inputs, further analysis did not suggest this. Treatment differences explained even less variation in NFY when a second ANOVA was conducted using mean pond alkalinity as a covariate.

Anticipated Benefits

Results showed that neither chicken manure nor sodium bicarbonate provided additional benefits towards increasing algal and tilapia productivities in ponds fertilized at high levels of urea and TSP. This is very useful to the farmer in that adding manure to ponds degrades water quality, fills in ponds, is labor intensive, and is a more expensive source of N and P than urea or TSP, respectively.

This study, nevertheless, suggested the importance of DIC availability in regulating phytoplankton and fish productivities in ponds with relatively low alkalinities. If snails are capable of reducing DIC concentrations, then polyculture with a mulluscivore such as black carp may be a way of increasing tilapia yields without increasing nutrient inputs.

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Assessment of Nutrient Limitation in Fertilized Fish Ponds by Algal Assay

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Abstract

A provisional technique for field algal assay procedure was devised using either a 125-ml Erlenmeyer flask or a 70-ml test tube as an incubation vessel with a 25- or 30-ml sample covered with a loose fitting aluminum cap. Samples are incubated under a shade cloth for 3 to 4 days at ambient air temperatures and the incubation vessels are shaken three times daily.

An algal assay methodology for determining the limiting nutrient (carbon, nitrogen, or phosphorus) for fertilized fishponds using the above technique and indigenous algal cultures was devised and tested. Results indicated full agreement between assay results and nutrient limitation for prepared algal growth media. Tests of pond waters showed a good agreement between assay responses and nutrient ratios of the waters tested.

Visual assessment of assay responses were evaluated; I found that over 90% of people involved (n = 15) could distinguish between chlorophyll *a* differences of <10 mg/m^3 for a 100 ml sample filtered onto a Whatman GF/C filter.

Algal yield dose response patterns to phosphorus spiking of phosphorus-limited cultures followed an asymptotic relation ($r^2 > 0.86$, $p < 0.001$ for six trials). Analysis of the regression slopes showed a significant correlation ($r^2 = 0.85$, $p < 0.01$) between the slopes and the initial dissolved inorganic nitrogen (DIN) of the culture media. This lends support to the underlying theories for assessment of DIN through algal assays. Dose response experiments showed a significant and relatively close correlation ($r = 0.68$, $p < 0.001$) between initial DIN and visually assessed spike saturation levels (the amount of spike needed to make DIN limiting) for phosphorus-limited algal cultures.

Investigations by algal assay of pond and tank waters used for fish culture at the Asian Institute of Technology, Bangkok, showed a dominance of nitrogen limitation (six out of nine cases). From these results a pattern of increased algal yield (measured as % over control) was determined as C:N ratio increased and N:P ratio decreased.

Effects of Circulation in Deep Ponds*

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* Fifth Work Plan, Studies 5 and 6

Introduction

Tilapias are grown successfully in waste-fed ponds in warm climates, despite characteristic pond conditions that would be unsuitable for other species. Warmwater ponds tend to exhibit daytime density stratification, which creates the potential for severe depletion of dissolved oxygen (DO) particularly near the bottom (Boyd 1990), but tilapia generally suffer little or no mortality in such ponds. Growth may nonetheless be inhibited under suboptimal oxygen regimes.

Stratification may affect photosynthetic production of organic matter, an important source of the cultured animals' food, positively or negatively under different conditions.

We have observed that 1) in earthen ponds of depths ranging 0.6 - 1.5 m, yields of *Oreochromis niloticus* were proportional to total stocking and fertilization inputs (Szyper et al. 1991); and that 2) daytime pond mixing by internal water circulation can conserve DO during the day and improve nighttime concentrations near pond bottoms (Szyper and Lin 1990). Because ponds produced yields proportional to inputs, deeper ponds produced more fish per unit area, despite being more frequently and severely stratified. It was therefore reasonable to ask whether mixing might enhance production in deeper ponds by ameliorating conditions of low DO and potential nutrient-limitation of primary production.

Objectives

1. To determine the effects of circulation within deep ponds on fish yield, water quality, and system efficiency during the wet season.
2. To determine if previous dry-season high yields in deep ponds stocked and fertilized in proportion to volume can be obtained in a wet season.

Materials and Methods

Nine earthen ponds of about 370 m^2 surface area were maintained at depths of 0.9 and 1.5 m, at the Asian Institute of Technology. Triplicate ponds for each of three treatments were stocked with hormonally sex-determined juvenile male *O. niloticus* of 10-13 g individual weight, and fertilized weekly with chicken manure, urea, and TSP (triple superphosphate) as in earlier experiments.

Stocking and fertilization rates (3 fish per m^3 and 5 g N/m^3/week, respectively) were proportional to pond volume.

Three ponds were maintained at 0.9 m depth and never mixed mechanically; three deeper ponds (1.5 m) were also left unmixed. Three 1.5 m deep ponds were mixed from 1500 - 1700 hours each day. An 0.5 hp (373 W) submersible pump took water in from 80 cm depth (below the thermocline) and discharged it horizontally at 10 cm, from a pipe of 6.4 cm diameter.

Water samples consisting of three pooled 90-cm water column samples were taken every two weeks from each pond and analyzed for total ammonia, oxidized nitrogen (nitrate plus nitrite), total Kjeldahl nitrogen, orthophosphate (soluble reactive phosphorus), total P, chlorophyll *a*, total suspended solids (TSS), and total volatile solids (TVS). Biweekly diel sampling programs determined DO and temperature at 3 depths (25 cm below surface, midwater, and 25 cm above bottom) at six times during the diel cycle. Gross photosynthetic oxygen production was estimated from each biweekly diel observation series (n = 14 dates), according to the DAST's modification of the free-water method of Hall and Moll (1975).

Fish were sampled monthly for length and weight; total crop weight was taken at harvest. A short-term study of diel cycles of temperature and DO was conducted during the latter half of the trial using an automated monitoring system (Szyper and Lin 1990). Statistical analyses were performed as described by Sokal and Rohlf (1981). Significance is referred to as $\alpha = 0.05$ unless otherwise stated.

Results

Yields were statistically indistinguishable among treatments, averaging 5.4 t/ha/yr in three ponds of 1.4 m depth whose water was mixed for two hours each day, 6.7 t/ha/yr in three similar but unmixed ponds, and 6.9 t/ha/yr in three unmixed ponds of 0.9 m depth. Survival was significantly lower in the deep mixed ponds (72% compared with 91-93%). The mixed ponds had poorer primary production and lower average concentrations of dissolved oxygen during the first half of the growth period, though final treatment means were similar. Differences in fish growth were apparent in early samples; final individual weight was greatest in the shallow unmixed ponds.

Daily mixing produced higher nighttime bottom oxygen concentrations through 2300 hours, but did not change overnight minima. No treatment-related differences in ammonia concentrations or other water-quality parameters were found.

The oxygen-conserving effect of mixing was not effective in enhancing production of this species, which grows and survives well in unmixed ponds, tolerating or avoiding waters of low oxygen content. Mixing and aeration strategies must be examined carefully for both detrimental and beneficial effects.

Anticipated Benefits

Although the results were negative (null hypothesis of no difference among treatments is supported), these results point to improved strategies in further experimental attempts to enhance production by circulation. Literature contains both positive and negative outcomes of such attempts. This work also suggests features of ecosystems (e.g., primary production) to be regarded carefully in these and other manipulations of waste-fed ponds.

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Maintenance of Minimum Dissolved Oxygen Concentrations*

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* Fifth Work Plan, Study 10

Introduction

The Thailand CRSP Project, like the one in Honduras, has a dat.. logger system available for automated monitoring of pond water quality. The system is also capable of automated control of aerators or other electrically-powered devices in response to the sensor readings of the monitoring part of the system. The Honduras Project has completed a study of the effects of automated aeration. This one in Thailand was of similar design. Differences included the Thailand electrical supply and the aerators available at AIT.

Objective

To quantify the effects of aeration on tilapia growth, primary production, and water quality.

Materials and Methods

Ponds were stocked, managed, and sampled as were the 0.9 m deep ponds in the experiments described in the preceding paper, *Effects of Circulation in Deep Ponds*. The logger system was set to activate aerators when DO fell to 50% saturation in three ponds, to 10% in three more, with three control ponds operated without aeration.

Results

The ponds were harvested in summer of 1991. Data have not been sufficiently reduced and analyzed to permit description or discussion of results. It appears that the aerators used were too large for the pond areas of 394 m^2. The logger data show rapid dramatic effects on stratification; visual observations of bottom-stirring and high turbidity suggest that primary production may have been harmed by the aeration treatments.

Anticipated Benefits

If effects on productivity can be analyzed, the data from this experiment may be used with those described above to relate productivity to fish production, and to design better mixing and aeration treatments.

V. UNITED STATES RESEARCH COMPONENT OF THE GLOBAL EXPERIMENT

Introduction

Title XII of the International Development and Food Assistance Act of 1975 implies that CRSP research activities should be mutually beneficial to developing countries and the United States. In planning this CRSP, the 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 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.

The CRSP Technical Committee selects projects of high technical merit and relevance to overall goals of the CRSP for funding under the U.S. Research Component. 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 weighs 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 management, analysis, and modeling of data collected from the overseas CRSP sites is critical to unifying the research at diverse locations into a global experiment. 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 U.S. universities who check the data sets and forward them to the Program Management Office. The data sets are then electronically translated into a standardized format and sent back to the principal investigators for verification. (Data entry already is standardized through the use of templates 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 Work Plans IV and V, 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 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 different treatments will allow farmers to adapt 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.

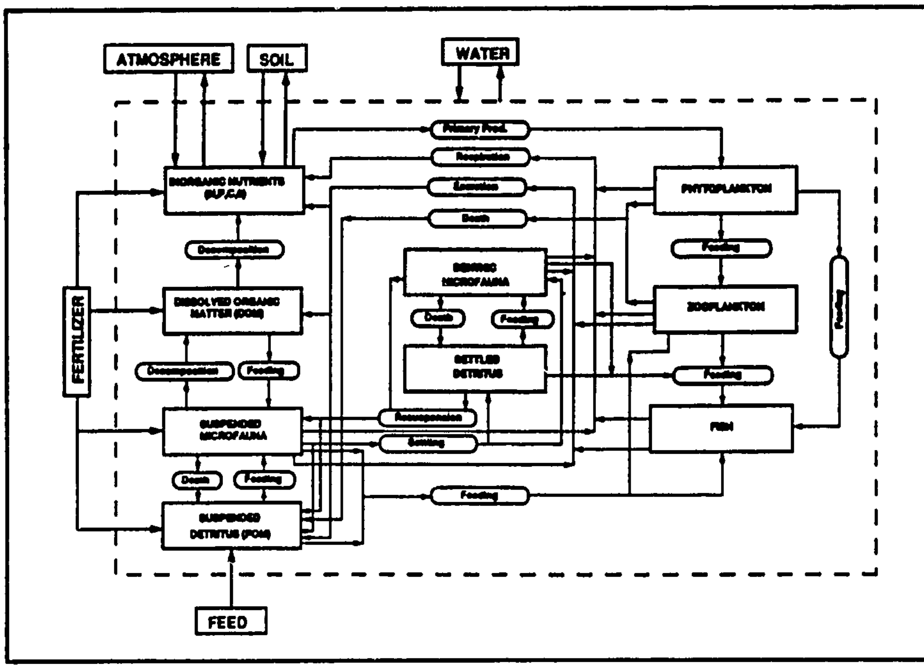

Figure 1. A CRSP conceptual model of an aquaculture pond. The arrows connecting the model's components represent the paths for movement of mass in the system. The system includes both biological and non-biological components. The strictly biological components are phytoplankton, zooplankton, and fish, 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, and phosphorus, and 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.

Data Analysis and Synthesis Team
Annual Report 1990-1991

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The Data Analysis and Synthesis Team (DAST) currently consists of two members, and their efforts are focused on the following areas of activity:

1. Pond classification techniques and pond management guidelines (Lannan).
2. Analysis and modeling of pond dynamics (Piedrahita).

During this period, a computerized pond classification and management technique was developed and distributed to CRSP members for their review and comments. The technique constitutes a significant breakthrough that incorporates recent findings in all aspects of water quality management and fish yield prediction in ponds. The computerized guidelines are designed for use by persons with diverse technical training (e.g., farmers, extension agents, researchers) and with various informational needs (e.g., planning, management, research). Other developments during this period were related to the study of primary production and respiration processes and of the physical environment in ponds. Primary production dependence on light intensity and changes in water column respiration rates over diel cycles were investigated. In addition, a simplified model of temperature stratification has been developed and is being tested.

Analysis and Modeling of Water Quality in Ponds

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Introduction

The focus of the UCD component of the DAST during the 1990-91 year has been the analysis of pond primary productivity, including phytoplankton photosynthesis and respiration rates. Additional work was undertaken in the analysis of pond stratification and in the development of a simplified model to simulate temperature stratification in ponds. The calculation of fish growth parameters and of primary production efficiencies reported in the previous annual report has continued as new data sets are received. A summary of the updated results is presented here.

Information derived from the various models and experiments has been circulated to CRSP participants by means of a quarterly newsletter initiated in March 1990. One issue of the newsletter (July 1991) was devoted to a survey of opinions and expectations for the Data Base and the Data Reports.

Objectives

Activities at UC Davis during the 1990-91 year relate to two of the DAST goals and objectives as stated in the Fifth Work Plan:

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

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

DAST Study 2: Ecosystem Model

1. To identify general topics requiring further field research.

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 under the various DAST studies have been presented in the DAST Newsletters. General descriptions of the findings and progress under each of the relevant DAST studies are presented below. The DAST work in the areas of data analysis and computer modeling is ongoing, and some topics currently being pursued will not be discussed in detail in this Annual Report. Presentations on these topics will be made through the DAST Newsletter as significant milestones are reached, and will be included in future Reports. Some specific areas of ongoing work that will not be discussed in detail in this report are: 1) Fish growth calculations using the model described in the previous annual report. These calculations are being continued as new data are received for the latest experimental cycles. Information on nutrient inputs to the ponds is being incorporated into the results for a more complete analysis of factors determining the parameters that describe fish growth with the model proposed. 2) The calculation of primary production efficiency also is a continuing area of emphasis. It is expected that efficiency of primary production will serve as an indicator of phytoplankton "condition." Efficiency values will be analyzed to determine the degree to which they might be predictable based on weather conditions, water quality, and input or fertilization rates.

Modification of a Temperature Model for Stratified Ponds*

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*Fifth Work Plan, Study 2

Introduction

The importance of stratification events in the functioning of aquaculture ponds has been recognized by Pond Dynamics / Aquaculture (PD/A) CRSP participants. Several experiments have been conducted to investigate the extent of stratification in ponds, and to examine methods that may be used to destratify ponds (e.g., Szyper and Lin, 1990). In addition, standardized data collection for all projects are generally carried out at three depths to obtain some information on the degree of thermal and chemical stratification in the ponds. In an effort to develop practical methods for predicting stratification events in aquaculture ponds, the UC Davis DAST group has undertaken the revision of a model previously developed at UC Davis (Losordo and Piedrahita 1991; Losordo 1988). The modified stratification model will serve as the basis for revising the existing Ecosystem Model so that some variables may be simulated at more than one depth. The model modifications being carried out by the UC Davis DAST are designed to simplify the date requirements of the previous model to make it useable with data sets such as those currently being collected in the PD/A CRSP.

Previous DAST pond models have been constructed with the assumption that the water column did not show marked vertical stratification of thermal or biochemical parameters. The assumption made in all previous models was that of a spatially homogeneous water column. While useful for identifying areas for further study, these models have not been appropriate for modeling diurnal variations as actually encountered in stratified ponds at CRSP or non-CRSP study sites. The current "Ecosystem Model" studies at UC Davis are part of an ongoing effort to develop and refine models which will more closely mimic these diurnal stratification events, as well as use CRSP field-generated data in their verification and calibration.

Objectives

The general objectives proposed for the DAST Study 2 in the Fifth Work Plan were:

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

The specific objectives for the work being reported here may be restated as:

To simplify the data requirements of an existing temperature stratification model and test the model with non-CRSP and CRSP data sets.

Methods

A previously developed temperature stratification model (Losordo 1988) has been simplified to run on data sets comparable to those generated by CRSP field studies. Simplification of the model, written in STELLA®, a dynamic modeling language available for Macintosh™ computers (High Point Systems, Inc. Hanover, NH.), was carried out by reviewing initial energy-balance representations, and making changes to allow more generic inputs for data requirements. The principal model revisions are:

- Energy- and mass-balance relationships are based on a three volume-element characterization of the water column, as opposed to six volume-elements (i.e., the number of depths at which temperatures are calculated).
- Data input requirements for solar irradiance, wind speed, wind direction, air temperature, and relative humidity have been reduced from 20-minute intervals to hourly intervals.

- Light extinction coefficients previously obtained from underwater measurements of photosynthetically active radiation (PAR) have been replaced by Secchi disk depth estimations.

- Relative wind directions and pond orientation in geographic space have been incorporated into the model, reducing data modification prior to input.

- Pond depth (and therefore volume-element size) is now a variable input, in order to accommodate ponds of depths different from 1.0 meter.

Perhaps most importantly, the modified model has been constructed in as flexible a manner as possible, increasing the range of questions the user may ask of it. While the original model has proven to be quite accurate in prediction of thermal stratification, it does not yield readily to "what if" kinds of simulation runs. It has been our aim to retain in the current model as much predictive accuracy as possible, simplify the input data requirements to reflect current CRSP data collection schedules, and increase the ways in which the model can be used to investigate pond water quality dynamics. Of particular current interest are the studies proposed for evaluation of methods for destratification (Pond Dynamics/ Aquaculture CRSP 1991). Accurate modeling of these events could prove helpful in subsequent analysis of the effectiveness of the alternatives under consideration. The model also is expected to be useful in predicting sites at which pond stratification is likely to be particularly severe, and also water quality characteristics that are likely to reduce the extent of stratification.

Additional changes to the model will be made as energy- and mass-balance relationships are more clearly defined and updated with more recent findings (see CRSP Sixth Work Plan), and as the model is tested with current CRSP data sets.

Results

To date, the UC Davis DAST has simplified and tested with non-CRSP data sets a model for pond temperature stratification which has resulted in the simulated temperature profiles shown (Figures 1, 2, and 3). Figure 1 shows the measured and simulated temperatures at three depths for a fully stratified pond at a farm in California on Julian date 224, 1987. Figure 2 shows the similar measurements and a simulation for a wholly mixed pond at a different California farm on Julian date 173, 1987. The simulations carried out to generate the data for Figures 1 and 2 use data inputs obtained with the revised model for one-hour intervals in the data inputs. Figures 3 compares results of simulations carried out with the revised model (hourly inputs) with those of the older model (20-minute inputs) for the fully mixed pond in Figure 2. As is shown, there is little loss of model resolution with this data input frequency reduction, and the difference between the two simulations is negligible. Similarly, simulations for the stratified pond of Figure 1 using 20-minute and one-hour intervals for data input resulted in identical temperature profiles.

Ongoing refinement and calibration of this model and its coupling to a dissolved oxygen model is planned for the Sixth Work Plan.

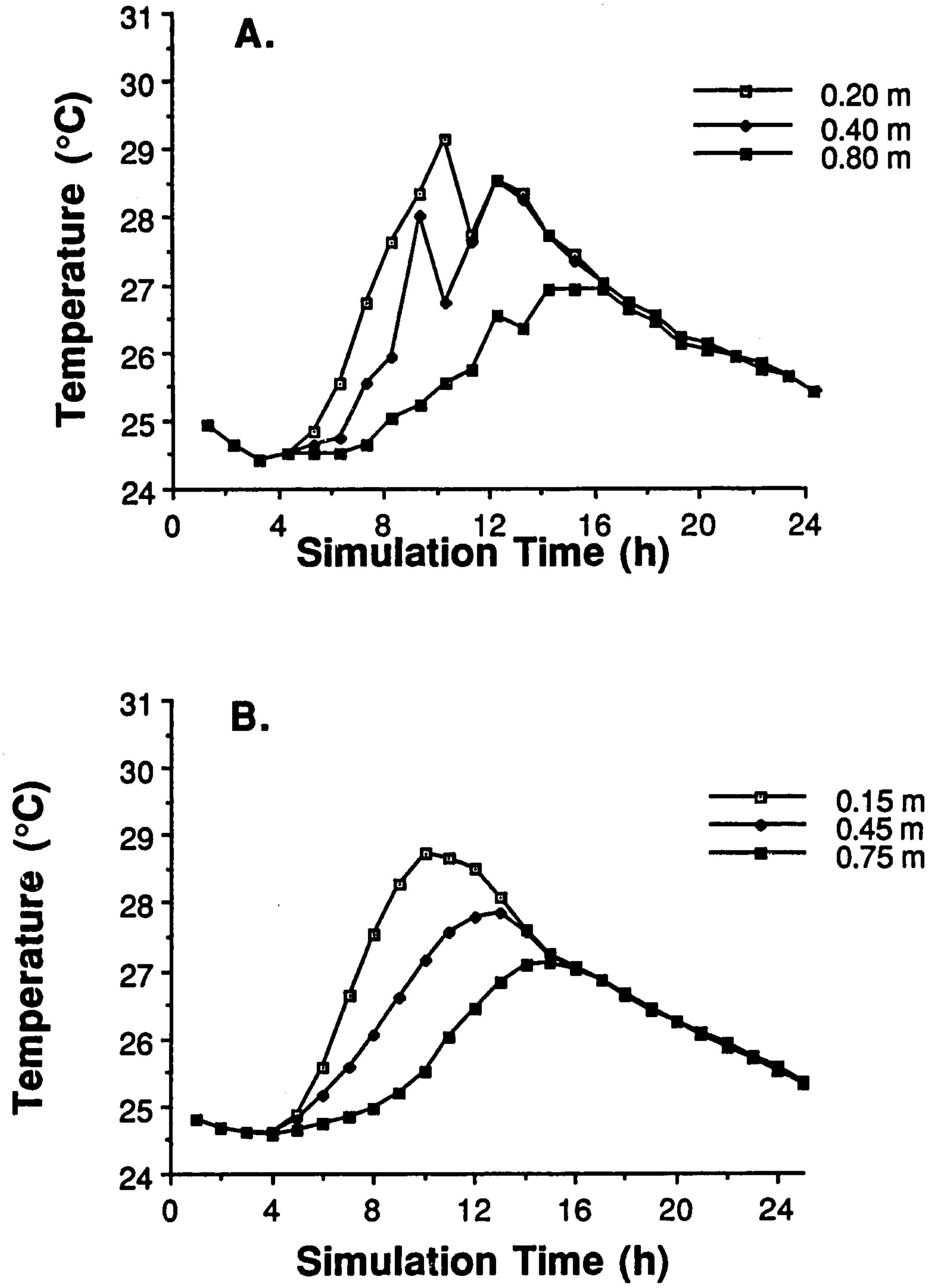
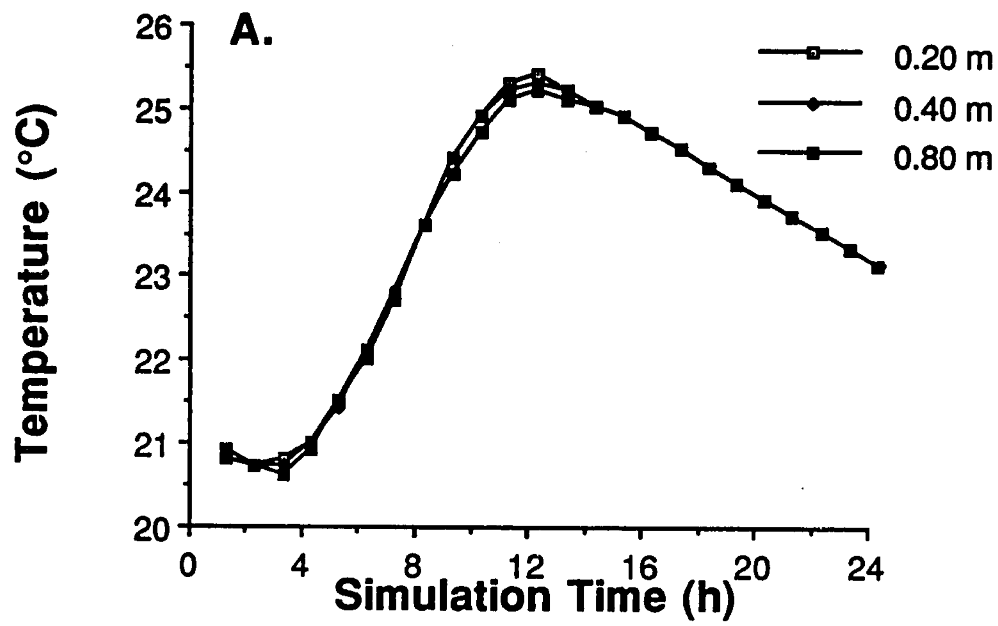


Figure 1. Comparison of measured (A) and simulated (B) temperatures in a stratified pond at a California farm on Julian date 224, 1987. The simulation has been carried out with the modified model using hourly data inputs. Note that the depths for the measured and simulated values are not equal.



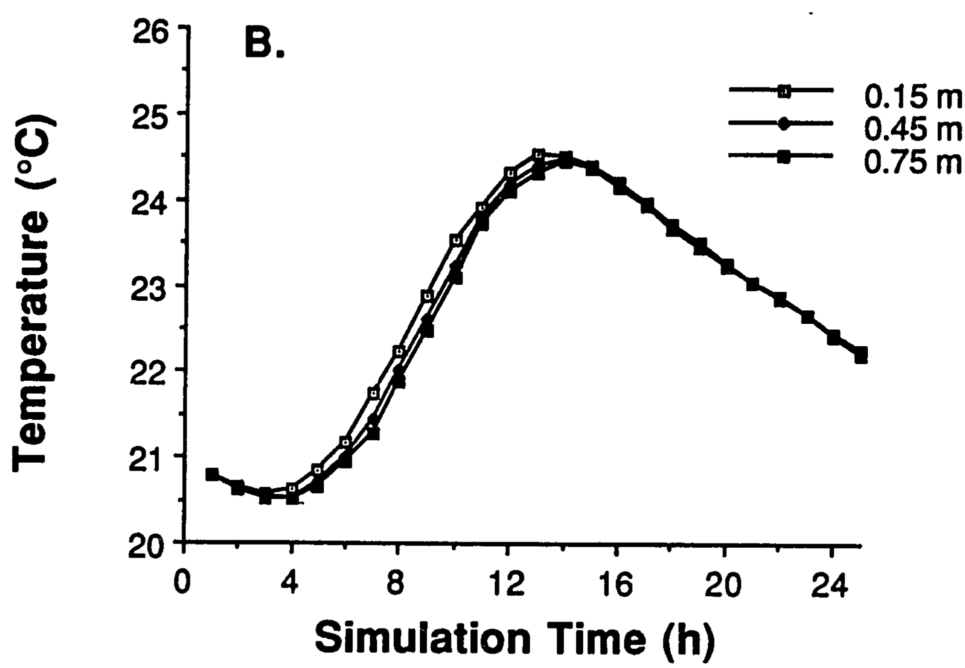


Figure 2. Comparison of measured (A) and simulated (B) temperatures in a fully mixed pond at a California farm on Julian date 173, 1987. The simulation has been carried out with the modified model using hourly data inputs. Note that the depths for the measured and simulated values are not equal.

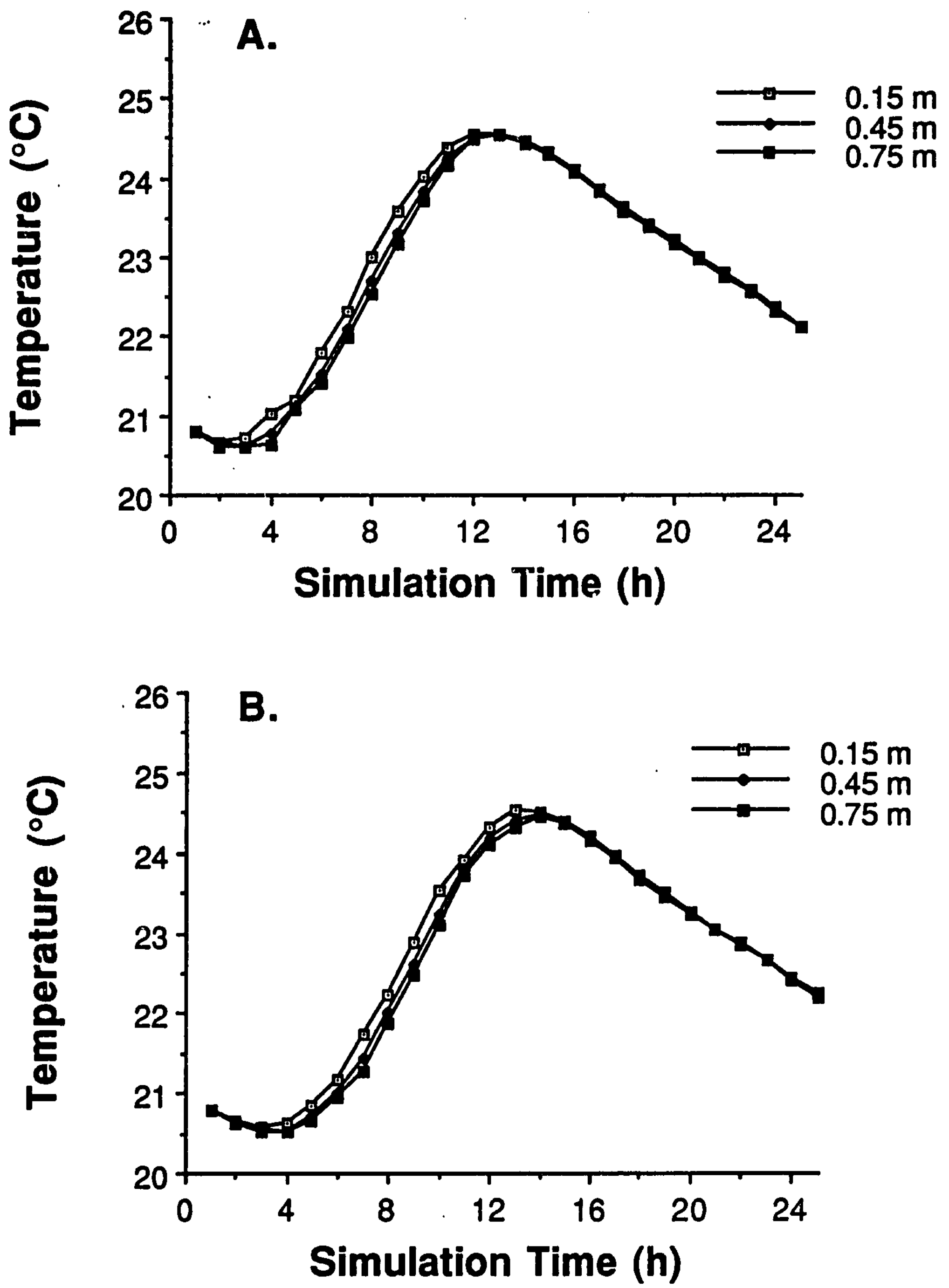


Figure 3. Comparison of simulated temperatures using data inputs at 20 minutes (A) and one hour (B) intervals for the same pond as in Figure 2.

Anticipated Benefits

The proposed model refinement will provide researchers with a more accurate analytical tool with which to study aquaculture pond dynamics – both their characterization and their prediction. If the accuracy of the older, previously developed models of temperature stratification can be retained or improved during modification, the subsequent ability to use the CRSP Data Base for input variables will provide ample opportunity for study of how management, climate, and local water quality effect temperature and dissolved oxygen regimes in production ponds, and in turn, what these regimes mean in terms of overall system performance. The models also will be useful tools for planning and designing aquaculture systems that meet certain specified criteria for allowable stratification.

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Procedures for Estimating Water Column Respiration Rates*

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*Fifth Work Plan, Study 3

Introduction

A major component of the UC Davis DAST research effort has dealt with the investigation of diel studies of water quality parameters in aquaculture ponds to develop procedures for more efficient pond design and management. Primary productivity is vital to the functioning of non-fed pond systems, as it is the basis for both the food chain and for dissolved oxygen for respiration by fish and other organisms present. Therefore, only through monitoring and optimizing the operation of a pond's primary production system, can the maximum yield of a pond be achieved. An important tool in this monitoring effort involves the use of dissolved oxygen mass balances, for isolating particular processes of interest.

Much work has already been done in the theoretical determination of optimum depths and turbidities for particular light intensities (Pond Dynamics/ Aquaculture CRSP Eighth Annual Administrative Report 1991). However, there is a major gap in our ability to quantify certain critical processes, and this lack of knowledge has prevented the development of workable analytical tools to monitor the internal functioning of aquatic primary producers. One current focus of research by the UC Davis DAST is improving the reliability and practical application of analyses of diel oxygen cycles by focusing on the accuracy of information available for the oxygen mass balance. It has become apparent that our lack of understanding of the dynamics of respiration by organisms suspended in the water column is a major factor affecting the utility of dissolved oxygen models already developed. Therefore, efforts by the UC Davis DAST are aimed at developing consistent and practical methods for the determination of diel pond respiration rates, and to use this information to improve our understanding of overall water quality dynamics. This ongoing research is a direct continuation of research from the Fifth Work Plan, and extends into the following work plan.

Background

It is apparent from previous work by the DAST that water column respiration cannot be described accurately by empirical temperature dependent functions. Equally inaccurate are data derived from the common practice of extrapolating nighttime pond respiration rates to daytime periods (Hall and Moll 1975). How respiration processes are affected during the daylight hours is the subject of some speculation; however, previous studies have indicated that the light respiration rate appears to be related to the photosynthetic production rate (Falkowski et al. 1985; Graham 1980; Harris and Piccinin 1977; Burris 1977). If this is the case, extrapolation of nighttime respiration rates over the diel period would cause a significant underestimation in total pond respiration, which would then result in significant underestimation of gross primary production. It has been suggested that the underestimation of gross primary production could be as high as 40% (Burris 1977). It is therefore critical to the understanding of diel primary productivity that the processes controlling light respiration rates in a pond be examined, so that accurate estimates of gross primary production can be made.

Objectives

The objectives of the UCD DAST in the continued development of the dissolved oxygen simulation models are threefold. First, the research is aimed at developing a consistent and convenient methodology for the determination of hourly rates of community light and dark respiration in aquaculture ponds over a diel period. This objective represents our current primary objective, and is being addressed in a two-phase research plan. The first phase is laboratory testing of equipment components, and the second phase involves field testing.

Secondly, a future objective is to examine how these respiration rates change over the diel period and establish relationships between light and dark respiration rates and environmental factors. This objective will be addressed once techniques for diel field determination of pond respiration have been worked out.

Finally, this knowledge will be used to provide improved measurements of pond primary production systems for use in the CRSP Pond Efficiency and Optimization Models. These models will then form the basis of analysis of various experimental pond treatments and provide ongoing objective criteria for evaluation of pond system performance.

Materials and Methods

Phase 1

Phase 1 has focused on investigating the feasibility of measuring light respiration with dissolved oxygen probes. Recent studies have shown that light-enhanced mitochondrial respiration contributes a significant portion of total algal respiration, and that these light enhanced rates are maintained for at least 5 minutes after illumination is discontinued (Weger et al. 1989). Previous studies have noted similar declines in post-illumination respiration. Harris and Piccinin (1977) attributed post-illumination respiration rate increases to photorespiration and noted a rate decline after 5 minutes of darkness of 60-80%. In addition, Falkowski et al. (1985) characterized the rate of decline as an exponential function with a first order rate constant of 0.003 s^{-1}.

To test the feasibility of measuring changing respiration rates during diel cycles, a simple apparatus has been developed to measure the change in dissolved oxygen concentration in the dark of phytoplankton exposed previously to light. Dissolved oxygen microprobes with a fast response time (less than 20 sec) were used in preliminary experiments to track the dissolved oxygen concentration changes in laboratory cultures during the transition from light to dark. These measurements were carried out for plankton at various stages in their light-dark cycle. Subsamples (≈ 100 mL) from a plankton culture (≈ 10 L) in a lighted chamber were monitored for the rate of change of dissolved oxygen with a Microelectrodes MI-370 Micro-Oxygen Electrode connected to a picoammeter, and a Campbell Scientific CR-21X Micrologger recording averaged data at either 15 or 30 second intervals. The samples were then darkened and the measured millivolt outputs, corresponding to transient oxygen concentration changes, were recorded. These data were then used to obtain rates of oxygen consumption and gross primary production. The initial rate of oxygen consumption was interpreted as the sum of the light enhanced phytoplankton respiration rate plus non-algal respiration.

Calibration and preliminary testing of the microprobes served to establish relationships between probe output and dissolved oxygen concentration (e.g., mv/ mg/L). The correlation between the rate of change of sample DO, as measured with both Winkler titrations and YSI oxygen probes, and microprobe output, was consistent and accurate. The probes were found to have a tendency to loose calibration easily, but the millivolt to milligram per liter ratio was found to be very stable and remained constant. Therefore, microprobe outputs are shown in millivolts, and rates of DO change are calculated directly.

Phase 2

Based on the work in Phase 1, a methodology was developed to measure pond respiration rates over the diel period at half-hour intervals in the field. Using a respiration sampling system constructed by co-investigator Dr. Jim Szyper at the Hawaii Institute of Marine Biology (HIMB), field testing was conducted at the Mariculture Research and Training Center (MRTC), during the month of September 1991. The system has been tested for sampling at three depths in the water column, at 30 min intervals, for several continuous 24-hour diel cycles. The system was set up to measure water column respiration within 10-minute intervals. In addition, diel pH, temperature, chlorophyll *a* fluorescence and underwater light quanta were recorded at 30-minute intervals. Results from that work are currently being analyzed, and a paper is currently being prepared for publication.

Results

The work done in Phases 1 and 2 confirm the applicability of the techniques described for nearly simultaneous measurement of net primary production and pond respiration over diel cycles in field applications. In Phase I testing, phytoplankton cultures subject to a light period followed by a dark period showed consistent patterns of enhanced respiration, immediately after being darkened, which gradually declined after the first 5 to 10 minutes. Figure 1 shows a typical plot of the millivolt output from the microprobe reading during two illuminated and darkened periods. The laboratory tests confirmed the applicability of the technique, and provided parameters necessary for the design of a field apparatus to sample respiration rates in ponds.

Preliminary analysis of the data collected in Phase 2 indicates that there is a marked difference between respiration rates at different pond depths, and that the respiration rates appear to follow a diurnal cycle with maxima occurring around dusk. Figure 2 shows water column respiration rates calculated over a diel period from the averages of 7 points over a 10-minute dark cycle for water samples at 10, 30, and 40 cm depths. Secchi disk depth was measured at approximately 45 cm. The extent to which dissolved oxygen concentration affects the measured respiration rates is unclear. These preliminary results are consistent with expectations based on previous laboratory studies done by UCD CRSP and by authors cited above.

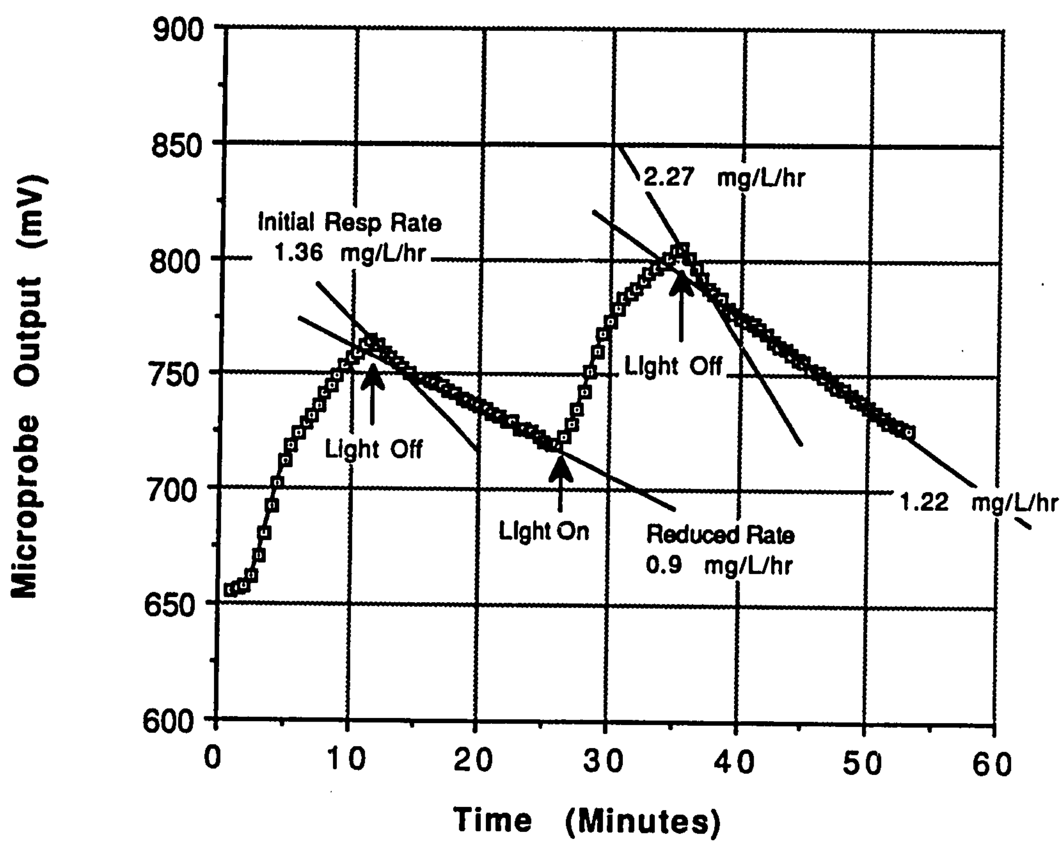

Figure 1. Output of dissolved oxygen microprobe measuring response of phytoplankton culture to two consecutive periods of light and dark, showing initially high rate of respiration followed by a lower rate of oxygen utilization. Light source is 1100 lumens full spectrum fluorescent.

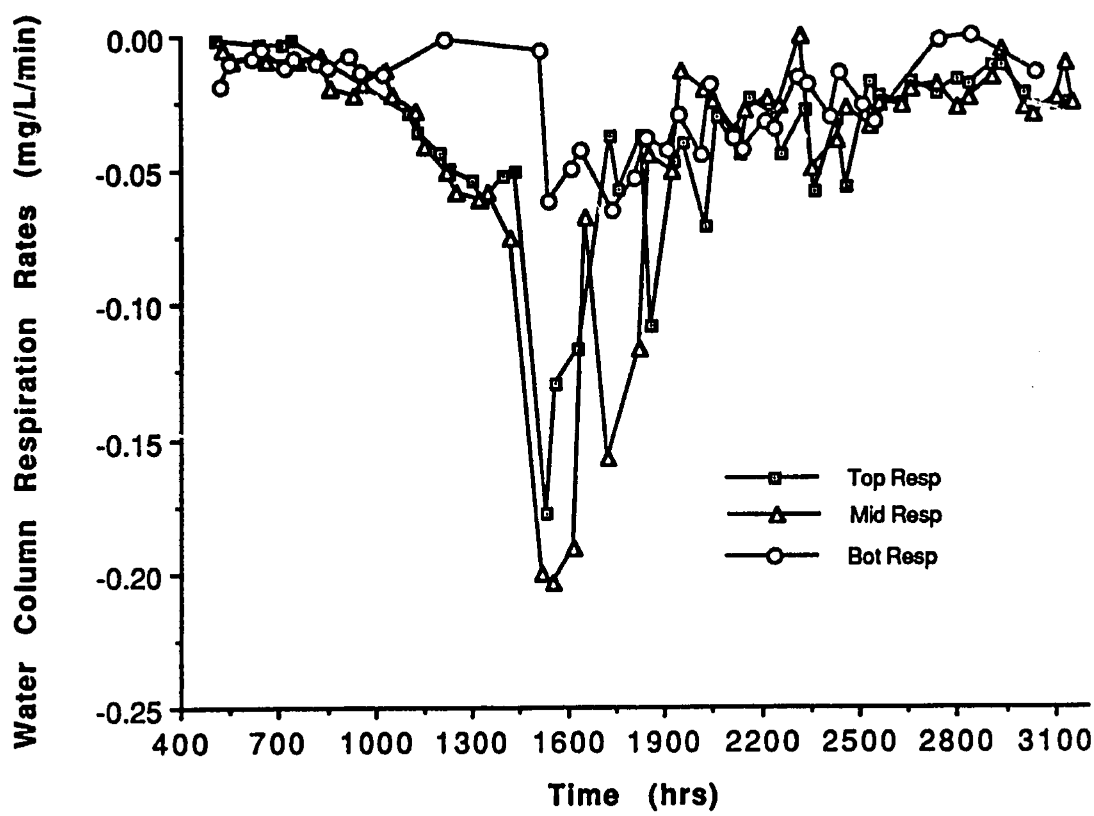

Figure 2. Respiration rates calculated over a diel cycle from 10, 30, and 40 cm depths. Data from research tilapia pond at the Mariculture Research and Training Center, Sept. 14 - 15, 1991.

Anticipated Benefits

These and future results will serve to improve the predictive ability of dissolved oxygen models, and the design of management practices to ensure optimum oxygen regimes within the physiological limitations of phytoplankton. In particular, the ability to estimate gross primary production rates over a diel period will enable researchers to examine how these rates are changing in response to management variables, and will allow the efficiency of a pond system to be monitored over time. Without being able to isolate diel gross primary production rates it is impossible to determine whether changes in net primary production rates (and in dissolved oxygen concentration) are due to respiration rate changes or due to changes in gross primary production rates. Ultimately, the improved ability to monitor phytoplankton processes can be used in conjunction with measurements of nutrient concentration and other water quality parameters, and with light intensity measurements, to determine changes in the efficiency of resource utilization by the phytoplankton, and therefore its "condition". This research also supports the development of specific application models that focus on the optimization of the oxygen regime in a pond system.

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Guidelines for Fertilizing Aquaculture Ponds

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One of the goals of the CRSP is to translate research findings into practical guidelines for improving the efficiency and reliability of aquaculture ponds. The Oregon State University (OSU) component of the DAST is directed toward this goal, with work focusing on the preparation of a manual of guidelines for fertilizing aquaculture ponds. The first version of this manual, *Provisional Guidelines for Fertilizing Aquaculture Ponds*, was completed prior to this reporting period, and is described in the CRSP Eighth Annual Administrative Report.

The manual is in the form of an expert system—a computer program that evaluates information provided by the user about a specific pond—and estimates the most cost efficient fertilizer application for optimizing fish yield based on quality and local costs of available fertilizers. Versions of the manual have been written for IBM-PC[1] and Apple Macintosh[2] personal computers. Documentation which accompanies the computer program describes the underlying theory, computational methods, and operating instructions.

During this reporting period, our goal was to refine the manual and associated software through the processes of peer review and revision into a form suitable for distribution to interested audiences. This process has proven to be a formidable task, and has resulted in the project falling behind schedule.

It was intended that the manual receive peer review at two levels. The first level is an informal review conducted by CRSP participants and colleagues familiar with the CRSP. This review was coordinated by the project staff, and completed during this reporting period. The informal reviews of the expert system program and associated documentation were conducted separately but concurrently. The second level of peer review is to be conducted by impartial reviewers who are not affiliated with the CRSP. This review will be coordinated by the CRSP Program Management Office.

CRSP researchers and selected aquacultural scientists not affiliated with the CRSP were provided with a copy of the computer program, brief operating instructions, and a questionnaire. Each reviewer was asked to complete the questionnaire to describe his or her overall reaction to the program, any problems encountered in operating the program, and any suggestions s/he might have for improving the program. Fourteen copies (11 CRSP and three external reviewers) of the Macintosh version were distributed for review. Completed questionnaires were received from four reviewers (one CRSP, three external) of the IBM PC version, and from five (three CRSP, two external) reviewers of the Macintosh version. Additionally, four reviewers sent letters expressing their reaction to the program, but did not complete the questionnaire. Although the number of responses received was disappointing, it is understandable. It was anticipated that a minimum of four to six hours would be required to review the program.

As might be expected, reactions of the reviewers to the expert system varied, ranging from enthusiastic support to skepticism. All of the reviewers felt that expert systems represent an excellent means of communicating this type of technical information. Although a majority of reviewers felt the approach was technically feasible, a few were skeptical about whether the expert system could provide reliable guidance for actual on-farm situations. The skepticism is based in the fact that the expert system represents a departure from the traditional method of providing constant amounts of fertilizers at regular intervals. On the other hand, the expert system assumes that fertilizer requirements of a pond

1 IBM PC is a registered trademark of IBM Corp.

2 Apple Macintosh is a registered trademark of Apple Computer, Inc.

would be expected to fluctuate in response to climatic conditions, carryover of nutrients from prior fertilizer applications, and other factors. Thus fertilization rates should be continuously adjusted to current pond conditions. Fertilizing at constant rates is likely to result in nutrient limitations at some times, and wasting fertilizer by providing an excess at other times. In both cases the efficiency of fish production, expressed in terms of cost per unit fish yield, is compromised. Although this departure from the traditional approach has been verified experimentally, some elements of the aquacultural community, including some researchers, will be reluctant to accept change. The ultimate test of the guidelines will be to apply the expert system to real production situations.

Several reviewers provided thoughtful suggestions for improving the program. The suggestions included improving the format for program output, and a more user-friendly method for creating data files.

Reviewers also encountered some technical difficulties related to hardware incompatibilities, most (but not all) of which were specific for the IBM PC version. In developing the program prototype, it was not possible to test the program operation on many combinations of personal computers, printers, and peripherals. To some degree, the informal peer review was intended to test the program on a wider range of hardware than could be conducted by project staff. In this sense, the reviewers assistance in identifying problems provided the opportunity to expand the application of the program to a greater variety of hardware.

One reviewer reported "fooling" the program into providing unrealistic expected fish yields by manipulating selected pond variables. In designing the program code, we overlooked placing limits on permissible ranges of values for certain variables. The program code has been revised to prevent recurrence of this misleading output.

Concurrent with distributing the review copies of the program, drafts of the documentation were distributed to a different set of reviewers. These manuscript reviewers were asked to react to the program design concept described in the text, and on the scientific merit of the approach. This was a consensus of the manuscript reviewers that the conceptual approach and computational methods used in the computer program are technically sound. No substantive criticism of the design concept was received. The reviewers provided helpful suggestions for improving the clarity of presentation of specific points, and for improving the organization of the text in several places.

In summary, the informal peer review served to identify opportunities for improving the computer program and documentation, and also identified discrepancies in the program code that had gone undetected. The next step in preparing the manual for general distribution was thus to revise the program code to resolve technical problems and improve program operation, and to incorporate suggestions of the manuscript reviewers into the text.

Revision and testing of the Macintosh version has been completed. Trouble shooting the PC version has been difficult, but the sources of the problems have now been determined, and revision and testing of the program code is underway.

Similarly, text revision is nearly complete, although the text cannot be finalized until the program coding is completed. There is always a possibility that it may become necessary to modify program operation to correct technical difficulties.

We anticipate that completion of the program and text revision will require approximately one additional month of work. The formal, external peer review can commence at that time.

VI. SPECIAL TOPICS RESEARCH IN THE HOST COUNTRIES AND UNITED STATES

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 toward 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.

HONDURAS SPECIAL TOPICS

Comparative Growth of Communally Stocked Red and Wild-Type Tilapia

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Introduction

The red tilapia is rapidly becoming popular as a culture fish in Honduras. El Carao has had two different lines of red tilapia with greatly different appearances and culture characteristics. The first was a line introduced from Mexico, which originated with M. Sipes of Florida. This fish was pink, bred true, but because it grew and handled poorly, its use was discouraged. In 1989, a commercial farm in Honduras imported a red tilapia from south Alabama, which apparently originated with L. L. Behrends at the National Fertilizer Development Center in Muscle Shoals, Alabama. This fish was the result of several generations of backcrossing of the red offspring with *Oreochromis niloticus* parents. The original red color also came from the M. Sipes red tilapia. The Alabama red did not produce 100% reds, but its growth and rusticity were superior to the Mexican line. Before recommending its use, though, we wanted to test its production characteristics against the El Carao line of normal colored *O. niloticus*, which was the objective of this study.

Materials and Methods

Three 0.1-ha ponds at the El Carao National Aquaculture Research Center were communally stocked with 500 red and 500 normal colored male tilapia. Red and normal fingerlings weighed 8.3 and 7.3 g, respectively. Ponds were fertilized only with chicken litter at 1000 kg total solids/ha per week for the first two months of growth. Thereafter, fish were fed a commercial shrimp ration (20% crude protein) 6 days per week at 3% of fish biomass. All ponds received equal quantities of inputs. After 148 days, ponds were completely drained, and fish were counted and weighed. Data were analyzed by one-way ANOVA and differences were declared significant at alpha level 0.05.

Results

Mean yield of normal colored tilapia (1133 kg/ha per 148 days) was significantly greater than mean yield of red tilapia (456 kg/ha per 148 days). However, mean weight at harvest of normal (252 g) was not different than that of red tilapia

(253 g). Yield for red tilapia was less than that of normal colored tilapia because of significantly lower survival. Survival for red and normal tilapia was 37 and 83%, respectively. Red tilapia survival was low primarily because of predation by ospreys. Daily visits by several ospreys were observed, and most ospreys left with red tilapia in their talons. The pond farthest away from human activity suffered the poorest survival. These results indicated that growth potential of red tilapia was similar to that of normals, but that the red tilapia's color provides birds of prey a much easier target for predation.

Relationship Between Wind Speed and Reaeration in Small Aquaculture Ponds*

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Abstract

Two 1,000 m^2 ponds at the El Carao National Aquaculture Research Center at Comayagua, Honduras were deoxygenated by treatment with sodium sulfite and cobalt chloride, and biological activity was suppressed by formalin and copper sulfate application. Wind speed and the change in dissolved oxygen concentration and the wind speed were monitored with a data logger system during the reaeration period. Standard oxygen transfer coefficients (K_La_{20}) were related to wind speed and measured at 3 m height by the equation:

$$K_La_{20} = 0.017X - 0.014; r^2 = 0.88$$

where K_La_{20} = standard oxygen transfer coefficient at 20°C (h^{-1}) and X = wind speed ($m\ s^{-1}$). A method for computing pond reaeration rate from the standard oxygen transfer coefficient is presented.

* This is an abstract of a paper accepted for publication in Aquacultural Engineering.

RWANDA SPECIAL TOPICS

Comparison of Organic Carbon Analytical Techniques and Determination of Sample Size for Studies Involving Organic Carbon for Pond Soils in Rwanda

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Objectives

I. To compare the modified Mebius and organic carbon analyzer methods.
II. To determine the variability within ponds and among ponds for estimating sample size.

Methods

I. Organic carbon determination.

In the modified Mebius method, organic matter is oxidized by $K_2Cr_2O_7$ and H_2SO_4 with external heating. The sample is placed in a flask, the flask is attached to a West condenser, and heat is applied with a hot plate for 30 minutes. A Leco Corporation "Carbon Determinator EC-12" was used. This machine provides dry combustion of the organic matter at high temperature (about 1,500°C) in an induction furnace in the presence of pure oxygen.

II. Variation of organic carbon concentration between and within ponds.

Between and within pond variation for organic carbon was considered for ponds in Rwanda. Samples were taken from six ponds (D6, D7, D8, D9, D10, and D11). Pond bottoms were divided into 50 quadrants, and one sample of the 0-5 cm layer was taken from each quadrant with a small shovel. Samples were air dried and pulverized with a mortar and pestle to pass a 60 mesh screen. Samples were analyzed in duplicate by the carbon analyzer method at laboratory in Auburn, and by modified Mebius method in Rwanda. Variability was estimated by analysis of variance.

Results

I. Comparison of modified Mebius and carbon analyzer methods.

Relationships between carbon concentrations on 50 samples from each of six ponds in Rwanda are shown in Table 1. The modified Mebius method provided greater concentration ($p<0.05$) of carbon for all samples than the carbon analyzer. On average, the modified Mebius method overestimated values by

13%. The relationship between organic matter analyses by the modified Mebius method to those of the carbon analyzer for one pond is described by the equation $Y = -0.108 + 1.142\ X$, where Y is percent carbon according to the modified Mebius method and X is percent carbon according to the analyzer.

II. Variation within pond and among ponds.

There was high variability within and between ponds as shown in the analysis of variance table:

Source of variation	df	SS	MS	F
Ponds	5	615.43	123.09	35.17
Samples	289	1010.70	3.50	350.00
Determinations	295	3.76	0.01	

For use in future experiments variance components were used to compute the number of samples and ponds required to detect a given difference in soil carbon concentration at $p<0.05$. The equation for computing detectable differences follows:

$$C \geq 2\sqrt{\frac{s^2_D}{dsp} + \frac{s^2_S}{sp} + \frac{s^2_P}{p}}$$

C = Approximate change in percent carbon to be detectable in an experiment at $p<0.05$.
where, s^2_D = variance component for determinations.
s^2_S = variance component for samples.
s^2_P = variance component for ponds.
d = number of determinations per sample.
s = number of samples per pond.
p = number of ponds per treatment.

Table 1. Comparison between mean carbon values obtained by the carbon analyzer and modified Mebius methods for soil samples from Rwanda. The SD was pooled over pond samples and laboratory determinations.

Pond	Mean percent carbon		
	Analyzer	Mebius	r
D6	2.03+1.538	2.22+1.850	0.989
D7	2.42±1.014	2.76±1.108	0.920
D8	3.81±1.084	4.23±1.266	0.971
D10	2.40±1.054	2.76±1.251	0.948
D11	4.85±1.585	6.65±2.980	0.853

Effect of *Oreochromis niloticus-Clarias gariepinus* Polyculture on Production of Market-size Fish and Fingerling Tilapia

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Introduction

Clarias gariepinus is often used in African countries as a predator to control tilapia reproduction (Balarin 1979). Recommended stocking ratios vary between 1:10 and 1:20, predator:prey. Total elimination of tilapia recruitment is of questionable value, however, in areas where tilapia reproduction may sometimes be insufficient. Excessive predation can be avoided by manipulating size of each species at stocking, stocking rates, and length of grow-out cycle.

Previous experiments on polyculture of clarias with Nile tilapia (*Oreochromis niloticus*) conducted at Rwasave Fish Culture Station focused on the predatory capabilities of *C. gariepinus* and on the possible competition for food between *O. niloticus* and *C. gariepinus*. Small *C. gariepinus* were found to feed largely on bottom organisms and broken rice (Verheust et al. 1991), a somewhat different feeding strategy than used by young Nile tilapia. When *C. gariepinus* become piscivorous their growth rates jump to as high as 15g/fish/day. They could conceivably grow large enough to eat market-size tilapias, thus limiting tilapia yield.

Objectives

Current research at Rwasave seeks to increase total output of market-size fish yet produce enough tilapia recruits during the production cycle for restocking the pond. A relatively high density of clarias stocked at a small size would allow for the first groups of tilapia recruits to escape predation. If the clarias reached weights of over 150 g they would be of market size and add to the value of the harvest.

Within this larger objective, the objectives of the two experiments described below are 1) to test the effect of *C. gariepinus* stocked at a relatively high ratio to tilapia on the resultant tilapia recruitment and on the production of market-size fish; and 2) to test the possible effects of a longer tilapia reproductive period on yield and recruitment. In the latter experiment, older tilapia were stocked and cultured over a longer period than in the first experiment. In both experiments clarias fingerlings were stocked two months after the tilapia to conform to typical practice.

Materials and Methods

Experiment I: six 7-are ponds were each stocked with 700 *O. niloticus* fingerlings (mixed sex) averaging 25 g each. Two months later, three of the ponds were stocked with 233 *C. gariepinus* fingerlings averaging 3.6 g each, bringing the total stocking rate to 1.33 fish per m² for treatment "POLY". The three remaining ponds received no additional fish (treatment "MONO"). Fish were fed at 10% of body weight per day up to a maximum of 5 g per fish per day based on total tilapia weight and numbers.

Each month at least 30 fish were separated by species and sex (adults) and weighed. Ponds were drained 175 days after first stocking. Floating graders were used to separate tilapia fingerlings into groups of ≤4 g, 4 to 20 g, and >20 g. These groups corresponded roughly to the three major size classes observed.

Experiment II: six 3.3-are ponds were stocked at 1 fish per m² with mixed sex *O. niloticus* juveniles averaging 51.2 g. Two months later, each of three ponds received 165 *C. gariepinus* fingerlings averaging 3.4 g, bringing the total stocking rate to 1.5 fish per m². All ponds in both experiments were fertilized every 2 weeks with a mixture of freshly cut grass and chicken manure.

Ponds were drained 210 days after first stocking. Tilapia progeny were separated into two groups: fry of less than 4 g, and fingerlings greater than 4 g.

Results

In both experiments, net fish production did not differ between treatments (Table 1). However, for market-size fish, polyculture treatments in both experiments resulted in significantly greater yields than the monoculture

Table 1. Net production and yield data for Experiments I and II. For each experiment, letters in parentheses denote significant differences at the 95% confidence level.

Experiment	Trt	Cycle	Net Prod Adults	Yield O. n.	Yield C. g.	Yield Market Size	Yield O. n. Fing.	% of Yield as Repro.
		Days/yr	kg/are	kg/are	kg/are	kg/are	kg/are	%
1	POLY	175	32.3	10.2	3.7	13.9(a)	4.2	23(a)
1	MONO	175	34.3	10.2	0	10.2(b)	8.7	46(b)
2	POLY	210	41.3	15.0	5.5	20.5(a)	8.0	28(a)
2	MONO	210	33.6	11.7	0	11.7(b)	12.6	51(b)

treatments (Figures 1 and 2). The increase in yield due to clarias compensated for the lower yield of tilapia fingerlings (4.5 kg/are and 4.6 kg/are for Experiments I and II, respectively).

All polyculture ponds contained one or two clarias surpassing 1 kg individual weight. All other clarias were considered market size, averaging 174 and 143 g for Experiments I and II, respectively.

A simple analysis of comparative benefits showed that for market-size fish of both species the polyculture treatment resulted in 22% (Experiment I) and 56% (Experiment II) greater revenues than monoculture. Considering the market value of fish of all sizes, less the cost to restock the pond, the comparative benefit of polyculture falls to -18% for Experiment I and to +14% for Experiment II.

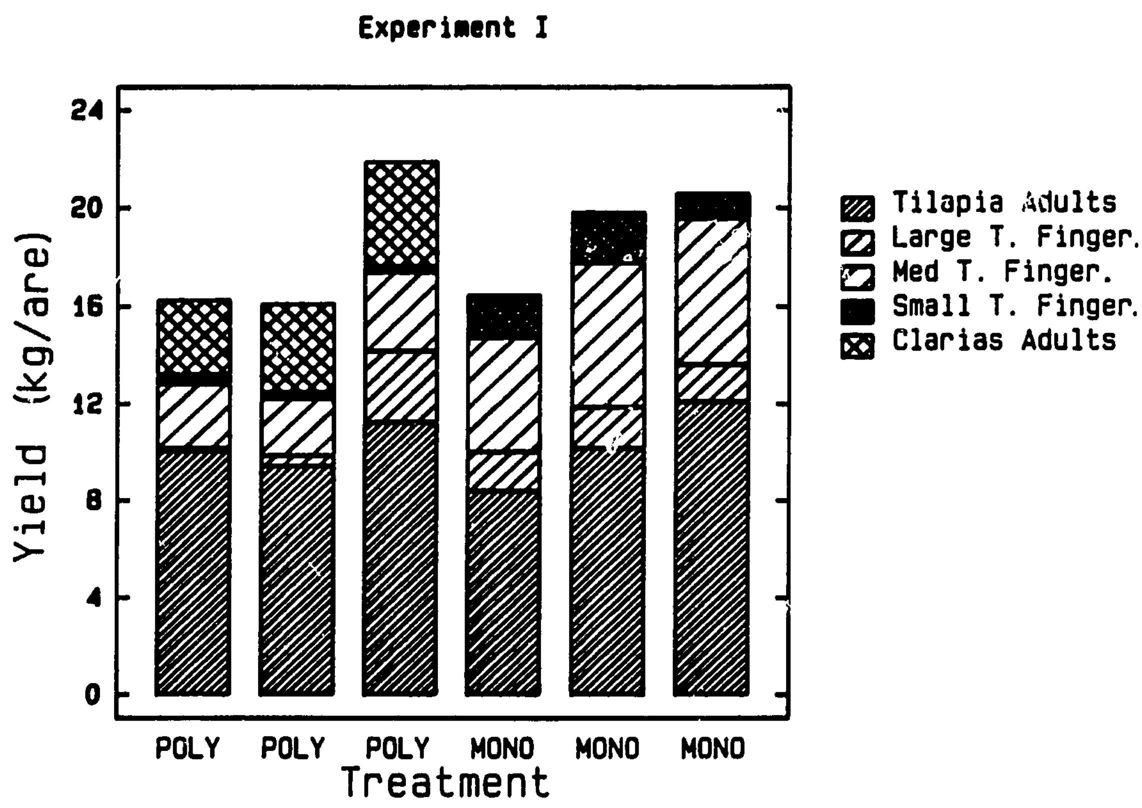

Figure 1. Distribution of yield (kg/are) for Experiment I.

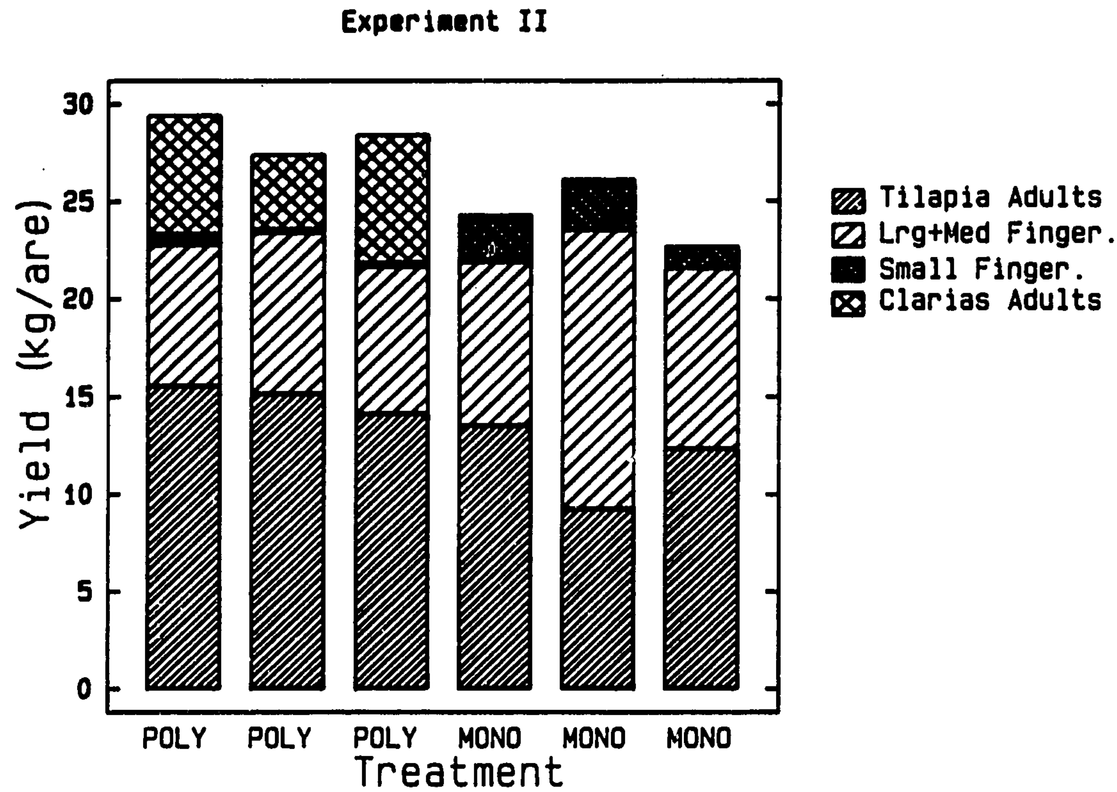

Figure 2. Distribution of yield (kg/are) for Experiment II.

Anticipated Benefits

These results may assist fish culturists in making correct management decisions appropriate to elevation-induced temperature effects on tilapia reproduction and growth. In zones of the central African highlands where there is a ready market for *O. niloticus* fingerlings, the addition of *C. gariepinus* must be considered with caution. However, Rwandan ponds situated at elevations less than 1700 meters produce more than sufficient fingerlings for restocking, resulting in a saturated market. The addition of *C. gariepinus* can therefore enhance profitability of fish culture in these areas. Clarias-tilapia polyculture may also reduce the tendency of farmers to retain excess fingerlings, resulting in a cycle of poor growth due to over-stocking.

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THAILAND SPECIAL TOPICS

Role of Urea in Fertilizing Fish Ponds

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Abstract

The objective of this study was to determine what happens to urea that is applied to ponds. To attain the objective of this study three experiments were conducted.

Urea, dissolved in pond water at an initial concentration of 4 mg urea-N/L in 75-L aquaria and exposed to light in outdoor tanks, disappeared at a rate of 249 ± 14 (1 SE) μg urea-N/L/day. When covered from light, the bacterial decomposition was 90 ± 10 (1 SE) μg urea-N/L/day. Chemical hydrolysis in distilled water exposed to light was insignificant. Urea, applied at a fertilization rate of 21 kg N/L/week (approximately 2.1 mg urea-N/L in water) in tanks, was gone after one week.

Toxicity of urea was tested. The median lethal concentration (LC_{50}) of urea to sex-reversed male Nile tilapia (*Oreochromis niloticus*) fingerlings (mean weight = 7.1 g) at 24-hr and 96-hr exposures were 19,700 and 16,800 mg urea-N/L, respectively. The 24-hr LC_{50} for silver barb (*Pontius gonionotus*) fingerlings (mean weight = 11.1 g) was 17,000 μg urea-N/L. The 24-hr LC_{50} of urea to tilapia and silver barb were significantly different ($p>0.05$). No mortality was recorded for either species when exposed to 14,000 mg urea-N/L or less.

Urea was compared to three types of inorganic fertilizers (ammonium sulfate, potassium nitrate, and NPK 14-14-14) as fertilizers inputs. After 90-day culture of sex-reversed male tilapia (mean weight = 12.2 g), the net fish yield of urea-fertilized tanks was 1.4 ± 0.1 (1 SE) $g/m^2/day$ which was higher than ammonium sulfate [1.2 ± 0.1 (1 SE) g/m2/day] and potassium nitrate [0.8 ± 0.4 (1 SE) $g/m^2/day$], but lower than NPK [2.0 ± 0.1 (1 SE) $g/m^2/day$] fertilized tanks. Fertilization did not give significant difference in chlorophyll *a* concentration, as an estimate of phytoplankton abundance, between urea and inorganic fertilizers ($p<0.05$).

Urea was slowly decomposed in ponds by bacteria and was utilized by plankton. The low decomposition rate of urea in water can provide nitrogen for plankton in a pond for a longer period because of this characteristic. It has low toxicity and a normal fertilization rate should not result in fish kills.

Strategies for Stocking Nile Tilapia (*Oreochromis niloticus*) in Fertilized Ponds (of 280 m²)

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Abstract

A 149-day growout experiment tested the effects of stocking density, partial harvesting and intermediate stocking on net fish yield (NFY), and harvest size of Nile tilapia (*Oreochromis niloticus*). Tilapia were raised in 280 m^2 earthen ponds, which received 8 kg dry weight chicken manure/ha/day with a urea and triple superphosphate supplement to give a total fertilization rate of 4.0 kg N/ha/day and 1.0 kg P/ha/day. The five treatments were three stocking densities of 0.8, 1.6, and 2.4 fish/m^2, fish stocked at 0.8 fish/m^2 with an additional 0.8/fish m^2 added after 2.5 months, and fish stocked at 1.6 fish/m^2 with 50% of fish removed after 2.5 months.

Stocking density significantly affected fish yield ($r^2 = 0.57$, $p < 0.02$); extrapolated mean NFY in ponds stocked at 0.8, 1.6, and 2.4 fish/m^2 were 14.2, 19.2 and 26.7 kg/ha/day respectively; mean weights were 335, 230 and 214 g/fish, respectively. Mean NFY for the first 2.5 months exceeded 39.0 kg/ha/day in ponds stocked at 2.4 fish/m^2. Although treatments were not significantly different, partial stocking gave higher mean total NFYs than partial harvesting, or 21.7 kg/ha/day compared to 18.0 kg/ha/day. Additional stocking did not significantly affect fish growth of the originally stocked fish. Mean harvest weights of fish stocked at 0.8 fish/m^2 were similar to the first stocked fish in the treatment receiving an additional 0.8 fish/m^2 after 2.5 months. Results suggest a partial intermediate stocking and partial harvesting strategy may produce annual tilapia yields of 30 kg/ha/day with mean weights over 300 g/fish.

Effects of Pond Depth and Mechanical Mixing on Production of *Oreochromis niloticus* in Manured Earthen Ponds*

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Abstract

An experiment to assess effects of water mixing on production of Nile tilapia in fertilized earthen ponds was performed at the Asian Institute of Technology in Thailand.

Sex-determined male fingerlings stocked at 3 fish/m^3 grew to final weights of 106 - 233 g in 173 days in nine ponds of approximately 370 m^2 surface area.

Yields were statistically indistinguishable among treatments, averaging 5.4 t/ha/yr in three ponds of 1.4 m depth whose water was mixed for two hours each day, 6.7 t/ha/yr in three similar but unmixed ponds, and 6.9 t/ha/yr in three unmixed ponds of 0.9 m depth. Survival was significantly lower in the deep, mixed ponds (72% compared with 91-93%). The mixed ponds had poorer primary production and lower average concentrations of dissolved oxygen during the first half of the growth period, though final treatment means were similar. Differences in fish growth were apparent in early samples; final individual weight was greatest in the shallower unmixed ponds.

Daily mixing produced higher nighttime bottom oxygen concentrations through 2300 hours, but did not change overnight minima. No treatment-related differences in ammonia concentrations or other water-quality parameters were found.

The oxygen-conserving effect of mixing was not effective in enhancing production of this species, which grows and survives well in unmixed ponds, tolerating or avoiding waters of low oxygen content. Mixing and aeration strategies must be examined carefully for both detrimental and beneficial effects.

* This paper is under review for inclusion in the proceedings of the International Symposium of Tilapia in Aquaculture III.

Production of *Oreochromis niloticus* (L.) and Ecosystem Dynamics in Manured Ponds of Three Depths*

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Abstract

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

Depth showed no direct effect on fish yields of 0.9 to 6.3 t/ha/yr, on survival rates of 66 to 98%, nor on final individual weights of 96 to 313 g/fish. Greater yields were obtained from deeper ponds when they received proportionally greater stocking and fertilizer inputs. Inputs per unit area were the most important factor accounting for yield variation.

Temperature, dissolved N and P, and suspended solids showed little or no relation to depth treatments. Time-averaged chlorophyll concentrations and photosynthetic production of dissolved oxygen were greater in treatments receiving greater inputs of nitrogen per unit pond volume.

Deeper ponds produced the greatest areal yields of fish, when fertilized in proportion to their volumes. Shallow ponds produced fish and dissolved oxygen at least as efficiently per unit input as did deep ponds, which is consistent with models of photosynthesis/depth relations.

* This paper was published in Aquaculture and Fisheries Management, 1991, 22:169-180.

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 minutes with a modest-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 two-hour period or two one-hour periods) produced potentially important differences in temperature and DO distribution.

* This paper was published in Aquacultural Engineering, 1990, 9:151-165.

Bias in Seine Sampling of Tilapia*

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Abstract

Seine sampling of fish populations in ponds is well-known to produce upwardly-biased estimates of average size. Aquaculturists may therefore ignore size estimates made in this way during growth periods, and use only final size data. Fisheries biologists have developed methods for quantifying the bias and using this information to correct seine sample data.

Data from 86 ponds in three countries (Thailand, Rwanda, Indonesia) showed a mean positive bias of +7.0% (± 0.8% = SE) for seine samples compared with harvest measurements taken the following day. There was no significant effect of country, sample size, or fish size in this data set.

At least within PD/A CRSP experiments conducted in this way, size estimates from intermediate seine samples may be corrected by this factor, and used for analyses of growth.

* In press. Journal of the World Aquaculture Society.

UNITED STATES SPECIAL TOPICS

Growth of *Oreochromis niloticus* in the Presence of Un-ionized Ammonia

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The 96-hour LC_{50} for un-ionized ammonia was 2.3 mg NH_3-N/L for Nile tilapia (*Oreochromis niloticus*) fingerlings (11 g/fish) incubated at both 23°C and 33°C. Acute toxicity tests also showed that 3 g fish were more susceptible to un-ionized ammonia than 45 g fish. Fish weighing six grams were used to assess the chronic effect of sub-lethal concentrations of un-ionized ammonia on growth. Growth during the 35-day experiment was depressed linearly over the range of 0.08-1.40 mg NH_3-N/L ($y = 70.4x - 4.1$, $r^2 = 0.89$, where y = percent decrease in fish weight gain relative to controls, and x = un-ionized ammonia concentration in mg NH_3-N/L). Extrapolating from this equation, no effect on growth would be expected at $\leq$ 0.08 mg NH_3-N/L, and no weight gain by fish would be expected at $\geq$ 1.48 mg NH_3-N/L. The effect of sub-lethal concentrations on growth of Nile tilapia under field conditions was examined by first finding the correlation of net fish yield (NFY) and algal primary productivity based on three years of pond-culture data collected in Thailand. Residuals (expected minus observed yields) from analysis of variance were then plotted against measured concentrations of un-ionized ammonia. Comparisons were made between laboratory and field results.

Free-water Estimates of Pond Photosynthesis and Respiration: Examination by Short-Interval Monitoring*

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Abstract

Free-water methods for examination of diel cycles of dissolved oxygen (DO) and dissolved inorganic carbon (DIC) can provide good estimates of daytime net primary productivity, community respiration, and total diel net productivity in

earthen ponds. Changes in DO and DIC produced similar estimates for most components of diel cycles. Automated monitoring at short time intervals gave the most accurate estimates, but reasonable approximations for routine monitoring can be derived by manual sampling six or seven times per day, including a sampling time near midnight. Dawn-dusk 3-point methods preclude good diffusion corrections and so yield low-biased production estimates.

Assessment of gross primary productivity requires estimation of daytime respiration from uncertain assumptions. Frequent-interval monitoring produced higher estimates of these quantities than less-frequent sampling, because small-scale features of diel curves were important, and were missed in the latter case.

Nighttime respiration rates during 30 minute intervals were positively correlated with DO concentrations above 6 mg/L, but not below this level. The "slope-at-DO-saturation" estimate of respiration may differ substantially from the mean of frequent observations. The manured ponds sampled for this work exhibited daytime net productivity (1.4-2.5 g C/m^2/day) similar to other manured ponds, negative total diel net production for the water column, and photosynthetic and respiratory quotients of reasonable mean values but with extremes beyond those reported for cultured phytoplankton.

* This paper has been submitted to Aquaculture for review.

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 and computation of each of the growth rates in an effort to encourage aquaculturists to use only growth rates which correspond to their data.

* This paper has been accepted with revisions by the Journal of the World Aquaculture Society.

Instantaneous Mortalities and Multivariate Models: Applications to Tilapia Culture in Saline Water*

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Abstract

The "percent mortalities" commonly used by aquaculturists do not allow separation of the different components of fish mortality between stocking and harvesting in aquaculture experiments. It is shown that "instantaneous" or exponential mortalities as used in fish population dynamics, have the properties required for such separation, especially when used in conjunction with a multiple regression model. Examples drawn from tilapia experiments conducted in seawater tanks in Kuwait and brackish water ponds in the Philippines are presented.

* In Press. *Multivariate Methods In Aquaculture Research: Case Studies of Tilapias Experimental and Commercial Systems.* In: M. Prein, G. Hulata, and D. Pauly (eds.). ICLARM Studies and Reviews No. 20.

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 have arisen for providing support to scientific research institutions for training and for extending CRSP research results to the people of these countries. 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 is the premier water quality analysis laboratory in Rwanda. The station attracts funding from outside sources, including the European Economic Community, which will fund several construction projects at the station. Despite war-related shortages and communications difficulties, construction of ten new research aquaria proceeded, and eight more aquaria are planned for the new hatchery room. Surveying has begun for the construction of additional ponds. Twelve new 6-are research ponds are under construction, and twelve additional ponds of 4-5 ares each are planned. This will bring the total number of ponds available for research to 51, with surface area ranging from 3.3 to 7 ares per pond. The laboratory and research facilities of the Rwasave Station were critical to Rwandan students after courses at the University of Rwanda were suspended because of civil war. The CRSP was able to employ some students left without financial support, providing them with practical lab and field experience while they helped conduct CRSP research activities. The importance of the research station to Rwanda was demonstrated by the level of support given CRSP researchers to carry out these lab and field studies at a time when many other activities within the country were severely constrained.

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.* Nearly half of the students enrolled in the course were from disciplines other than aquaculture. Kevin Hopkins lectured at the Asian Institute of Technology on the culture of tilapia under marginal conditions.

Karen Veverica, the US field scientist in Rwanda, taught short courses at Kigembe to trainees of the National Fish Culture Service on the design of storerooms for feed and equipment, and on the hanging and repairing of seines. 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 is also a resource to fish culture extension agents, who meet with CRSP researchers for advice and planning. In Honduras, the CRSP offers short courses and intensive seminars when appropriate. Claude Boyd conducted a seminar on water quality management in brackish water ponds for the shrimp producer association in Choluteca during his visit to Honduras to initiate the pond soil respiration study. Bart Green conducted a course on principles of aquaculture for fish farmers and extensionists who are participating in the on-farm trials in Honduras. Course topics included requirements for aquaculture, water quality, fertilizer calculations, and reproduction in tilapia, Chinese carp, and tambaqui. A third of the course was dedicated to production systems and economics of aquaculture, including the development of production system enterprise budgets.

Raul Piedrahita, Data Analysis and Synthesis Team PI from UCD, traveled to Cartagena, Colombia to present a one-week course on Aquacultural Engineering and Water Quality Management. He also prepared a 120 page handbook for the course.

A handbook of analytical methods used in the CRSP was prepared by the Technical Committee. This new handbook includes detailed methods from standard reference manuals of 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 400 individuals have benefited from informal training activities since the beginning of the program; at least 75 individuals received training during this reporting period. 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).

Table 1. List of Participating Institutions

Asian Institute of Technology (Thailand)
Agricultural University of Bogor (Indonesia)
Auburn University
Catholic University of Chile
Central Luzon State University (Philippines)
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

Prior to this reporting period at least 95 degrees (B.S., M.S., and Ph.D.) were awarded, and during this period another 10 were completed (Table 2).

Over 70 theses have been completed under the direction of CRSP researchers. Theses completed during this period are:

- Pautong, Ambuton K. 1991. Role of urea in fertilizing fish ponds. M.S. Thesis, Asian Institute of Technology, Bangkok, Thailand.
- Guttman, Hans. 1990. Assessment of nutrient limitation in fertilized fish ponds by algal assay. M.S. Thesis, Asian Institute of Technology, Bangkok, Thailand.

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

- Qifeng, Y. 1991. Nutrient budget and water quality in integrated walking catfish-tilapia culture. M.S. Thesis, Asian Institute of Technology, Bangkok, Thailand.
- Muthuwam, V. 1991. Nutrient budget and water quality in intensive marine shrimp culture ponds. 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.

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.

In Rwanda, the CRSP has advised the USAID/Kigali Mission and the Natural Resources Management Project (a USAID-sponsored project) on natural resource issues. The US Ambassador to Rwanda, Mr. Robert Flaten, toured the Kigembe Fish Station with CRSP staff to discuss the economic and social feasibility of fish culture for industry and for small farmers. CRSP staff in Rwanda attended by invitation a seminar sponsored by the FAO for the development of a national strategy for fisheries and aquaculture. The CRSP's success in supporting women in fish farming has attracted additional funding to study women's participation. WID/PPC and the Kigali Mission are supporting the study; the results will help improve and extend support services to women fish farmers. The EEC also has made major contributions to the station for the construction of ponds and facilities.

In Honduras, researchers serve as consultants for Peace Corps volunteers on the formation of a computerized data base for recording and analyzing the 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. Land Use Productivity Enhancement Project (LUPE) is also interested in cooperating in the on-farm testing. 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 and Economic Concerns (BIFADEC), Washington, D.C.
- CARE, Honduras
- Catholic University of Leuven (CUL), Belgium, Rwanda
- Central Luzon State University, Freshwater Aquaculture Center, 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. 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 are 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 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 efficient utilization of these agricultural by-products to enhance production in ponds, and to contribute to sustainability by recycling farm materials.

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 research in integrated agriculture-fish culture systems has been undertaken with Belgian researchers and with the International Development Research Centre (IDRC).

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 research geared toward increasing food production using indigenous fish species. For example, in Honduras researchers have included *Cichlasoma maculicauda*, a native cichlid, in studies of feeding rations and aeration. In Thailand researchers have 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. Other polyculture studies are underway in Rwanda and Honduras.

Women in Development

Women's involvement in aquaculture can have profound effects on the environment and the economy of a country, as improved nutrition from fish can help provide family food security. A first step in involving women in aquaculture is to provide training. 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. Twenty-eight women received training at overseas locations, and eleven studied at U.S. institutions. Training included 17 non-degree activiues (short courses, etc.), and 26 degree-related efforts (19 B.S., 4 M.S., and 3 Ph.D. degrees). During this reporting period, 9 women either completed degrees or other training activities, or continued work on degree programs. This constitutes approximately one-third of all those receiving some form of training during the period.

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 funded by 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 will explore ways of increasing extension support to include post-harvest issues, and will 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. The El Carao Research Station in Honduras has also become almost completely self-supporting through the sale of fingerlings to local fish farmers. The shortage of fingerlings in the area, though problematic in the short run, indicates the enthusiasm with which aquaculture is being embraced by local farmers.

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 (LDCs) 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

The Bean/Cowpea CRSP funded economic studies of aquaculture operations in Thailand. This study drew on previous economic studies in Rwanda, and focused on the economic rate of return for three different fertilization regimes in small-scale aquaculture operations in northeast Thailand. The results reinforce conclusions reached by CRSP researchers, demonstrating the efficacy of the chicken manure fertilization regime both economically and biologically.

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.

- Nine CRSP participants attended the annual meeting of the World Aquaculture Society held in San Juan, Puerto Rico, in June 1991. Cal McNabb presented the paper "A systematic approach to maximizing nutrient efficiency and growth of Nile tilapia (*Oreochromis niloticus*) under semi-intensive pond culture." Jim Szyper presented the paper "Free-water estimates of pond photosynthesis and respiration: Estimation by short-interval monitoring."

- Kevin Hopkins attended the BOSTID-ICLARM Aquaculture Workshop for PSTC/CDR scientists in Manila, 6 to 10 August 1991. Participants represented 15 countries and were partially supported by USAID funds. The two main areas of research emphasized were aquaculture and bilharzia control. Both topics are subjects of research in the CRSP proposal to begin research in Egypt.

- Two CRSP researchers from Rwanda attended the International Aquaculture and Trade Show in Dublin, Ireland, where they presented a slide show entitled "Fish culture in Rwanda, a high altitude developing country in central Africa," and a poster presentation entitled "*Oreochromis niloticus* culture in Rwanda: Optimal density and feeding ration in earthen ponds."

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 is part of OSU International Fisheries at OIRD, which is composed of 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 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 Assistant Vice President for International Research and Development. 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:

- Hillary S. Egna, Director (1.0 FTE)
- Marion McNamara, Assistant Director (1.0 FTE)
- Hilary Berkman, Data Base Manager (0.4 FTE)
- Jim Bowman, Graduate Research Assistant (0.4 FTE) through 30 June 1991
- Naomi Weidner, Secretary (0.5 FTE)

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 BIFADEC/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:

- Preparation of CRSP budgets and subcontractual modifications for extending funding and performance periods;
- Negotiation and implementation of a 20% funding increase, including preparation of new budgets and subcontracts;
- Continued efforts to establish a collaborative aquaculture research site with Egypt under the National Agricultural Research Project (NARP);
- Site visit to the Asian Institute of Technology in Bangkok;
- Site visit to the El Carao Research Station in Honduras;
- Visit to the Indonesian USAID Mission to discuss re-institution of CRSP research;
- Visit to Panama USAID Mission to discuss institution of CRSP field-testing;
- 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 eleven data reports;
- Organization of the ninth annual CRSP meeting in Auburn, Alabama on 7-9 March 1991 and participation in attendant Board Meetings and Technical Committee meetings;
- Coordination and publication of the Sixth 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 R&D/AGR through participation on CRSP Council;
- Participation in CRSP Council presentations to Congress, the World Bank, USAID, and environmental groups, 19-21 March 1991;
- Participation in CRSP Council Socioeconomic Studies Report Workshop, Detroit, Michigan 3 November 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, 29 October to 2 November 1989.

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. Special committees are convened as needed. The Technical Committee convened an Executive Panel to recommend proposals to be funded by the 20% funding increase, and a Data Base Evaluation Committee to recommend future directions of the CRSP Central Data Base. In both cases, recommendations were made to the Board of Directors. In an effort to improve continuity, the Technical Committee changed the term of the Technical Committee Chair from one year to two. The membership of the Technical Committee and subcommittees is presented in Table 1.

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, Chair from March 1991;
- Dr. Philip Helfrich, University of Hawaii (CIFAD institution), Chair from May 1989 to March 1991;
- Dr. R. Oneal Smitherman, Auburn University;
- Mr. Chris Jones, NMFS, IPA to R&D/AGR , Ex-Officio Member to March 1991;
- Dr. Lamarr Trott, NMFS, IPA to R&D/AGR, Ex-Officio Member from March 1991;
- Ms. Hillary Egna, Oregon State University, CRSP Director, Ex-Officio Member.

Table 1. Membership of the Technical Committee and subcommittee assignments.

Name	Institution	Subcommittees[1]
Principal Investigators (Voting Members)		
Ted Batterson	Michigan State University	EP*, B*, D
Claude Boyd	Auburn University	M
Jim Diana	University of Michigan	T*
Peter Edwards	Asian Institute of Technology, Thailand	
Carole Engle	University of Arkansas at Pine Bluff	
Kevin Hopkins, Chair	University of Hawaii	EP, M
Evariste Karangwa	National University of Rwanda	W
Jim Lannan	Oregon State University	T
Raul Piedrahita	University of California, Davis	EP, M*, D
Tom Popma	Auburn University	EP, W, D*
Ivan Rodriguez	Directorate of Renewable Natural Resources	B
Wayne Seim	Oregon State University	B
Non-Voting Members		
Hilary Berkman	Oregon State University, Management Entity	D
Bryan Duncan	Auburn University	M
Bart Green	Auburn University	W*
Sompong Hiranyawat	National Inland Fisheries Institute, Thailand	
Chris Knud-Hansen	Michigan State University	
Kwei Lin	University of Michigan and AIT, Thailand	T
Cal McNabb	Michigan State University	W
Eugene Rurangwa	National University of Rwanda	
Bill Shelton	University of Oklahoma	W
Jim Szyper	University of Hawaii	M
David Teichert-Coddington	Auburn University	M
Sompote Ukkatawewat	National Inland Fisheries Institute, Thailand	
Karen Veverica	Oregon State University, Auburn University	M
At-large Members		
Donald Garling	Michigan State University	
George Tchobanoglous	University of California, Davis	
Ex-officio Members		
Hillary Egna	Oregon State University, Management Entity	
Chris Jones (to March 1991)	S&T/AGR, U.S. Agency for International Development	
Lamarr Trott (from March 1991)	S&T/AGR, U.S. Agency for International Development	

[1] W=Work Plans; B=Budgets; T=Technical Progress; M=Materials and Methods; D=Data Base Evaluation; EP=Executive Panel

* Subcommittee Chairpersons

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

- 18 January 1991 Telephone Conference Call
- 9 March 1991 Auburn University, Alabama
- 5 April 1991 Telephone Conference Call
- 19 June 1991 San Juan, Puerto Rico

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;
- Review of proposals for 20% funding increase;
- Annual meeting agenda input and approval;
- Advice on international travel procedures;
- Guidance on efforts to strengthen the program; and
- Participation in the ninth annual program meeting in March 1991.

External Evaluation Panel

The External Evaluation Panel (EEP) is composed of impartial senior aquaculture scientists. During this reporting period, two seats on the External Evaluation Panel have become open, and await appointments by the Board of Directors and approval by AID. Dr. Homer Buck, Illinois Natural History Survey, continues to serve on the EEP.

Other members of the External Evaluation Panel who served during this reporting period were Dr. Kenneth Chew, University of Washington, Seattle, Washington, and Dr. Herminio Rabanal, Aquaculture Consultant, the Philippines.

The External Evaluation Panel reviewed the technical plan for continuation of the Global Experiment from 1990 to 1995. Dr. Homer Buck attended the ninth annual meeting in Auburn, Alabama in March 1991.

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.

The two publication series that were launched in 1987 have attracted many new readers. Over 300 people in more than 35 countries now receive our publications. 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 eight years. 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 B.

Administrative Reports

Annual Administrative Report

Pond Dynamics/Aquaculture CRSP, Program Management Office. February 1991. Eighth Annual Administrative Report. Office of International Research and Development, Oregon State University, Corvallis, Oregon. 166 pp.

CRSP List of Publications

Pond Dynamics/Aquaculture CRSP, Program Management Office. February 1991. Office of International Research and Development, Oregon State University, Corvallis, Oregon. 49 pp.

CRSP Work Plan

Pond Dynamics/Aquaculture CRSP, Program Management Office. August 1991. Sixth Work Plan. Office of International Research and Development, Oregon State University, Corvallis, Oregon. 71 pp.

Directory

Pond Dynamics/Aquaculture CRSP, Program Management Office. 1991 CRSP Directory. Office of International Research and Development, Oregon State University, Corvallis, Oregon.

The CRSP Directory was updated twice during this reporting period, in October and April. 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* is an occasional publication. It serves to inform CRSP participants and others of program activities that are not of a technical nature. *Aquanews* contains information on meetings, travel of CRSP participants, and site visits. The Data Analysis and Synthesis Team publishes a quarterly newsletter with the goal of improving communication between the DAST and the Principal Investigators in the field. 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

Green, B.W., D.R. Teichert-Coddington, R.P. Phelps. 1991. Response of tilapia yield and economics to varying rates of organic fertilization and season in two Central American countries. CRSP Research Reports 91-30, Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon. 1 p.

Hanson, B.J., J.F. Moehl, Jr., K.L. Veverica, F. Rwangano, M. Van Speybroek. 1990. Pond culture of tilapia in Rwanda, a high altitude equatorial African country. CRSP Research Reports 90-28, Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon. 6 pp.

Knud-Hansen, C.F., T.R. Batterson, C.D. McNabb. 1990. Hatchery techniques for egg and fry production of *Clarias batrachus* (Linnaeus). CRSP Research Reports 90-29, Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon. 1 p.

Knud-Hansen, C.F., T.R. Batterson, C.D. McNabb. 1991. Nitrogen input, primary productivity and fish yield in fertilized freshwater ponds in Indonesia. CRSP Research Reports 91-32, Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon. 1 p.

Szyper, J.P., C.K. Lin. 1991. Techniques for assessment of stratification and effects of mechanical mixing in tropical fish ponds. CRSP Research Reports 91-31, Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon. 1 p.

Collaborative Research Data Reports

Diana, J.S., C.K. Lin, T. Bhukaswan, V. Sirsuwanatach, B.J. Buurma. 1991. Thailand: Cycle II of The Global Experiment. Collaborative Research Data Reports, Volume Two, Number Two. Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon. 82 pp.

Diana, J.S., C.K. Lin, T. Bhukaswan, V. Sirsuwanatach, B.J. Buurma. 1991. Thailand: Cycle III of The Global Experiment. Collaborative Research Data Reports, Volume Two, Number Three. Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon. 110 pp.

McNabb, C.D., T.R. Batterson, B.J. Premo, H.M. Eidman, K. Sumatadinata. 1991. Indonesia: Cycle II of The Global Experiment. Collaborative Research Data Reports, Volume Three, Number Two. Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon. 67 pp.

Woessner, J., R.D. Fortes, V. Corre, Jr. 1991. Philippines: Cycle I of The Global Experiment. Collaborative Research Data Reports, Volume Four, Number One. Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon. 175 pp.

Carpenter, K.E., J. Woessner, R.D. Fortes, A. Fast, P. Helfrich. 1991. Philippines: Cycle II of The Global Experiment. Collaborative Research Data Reports, Volume Four, Number Two. Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon. 531 pp.

Carpenter, K.E., A.W. Fast, J. Carreon, R. Juliano. 1991. Philippines: Cycle III of The Global Experiment. Collaborative Research Data Reports, Volume Four, Number Three. Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon. 297 pp.

Hanson, B., V. Ndoreyaho, F. Rwangano, R. Tubb, W.K. Seim. 1991. Rwanda: Cycle III of The Global Experiment. Collaborative Research Data Reports, Volume Five, Number Two. Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon. 128 pp.

Teichert-Coddington, D.R., M. Peralta, R.P. Phelps, R.P. Malca. 1991. Gualaca, Panama: Cycle I of The Global Experiment. Collaborative Research Data Reports, Volume Seven, Number One. Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon. 129 pp.

Hughes, D., R.P. Phelps, R.P. Malca. 1991. Aguadulce, Panama: Cycle I of The Global Experiment. Collaborative Research Data Reports, Volume Eight, Number One. Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon. 145 pp.

Hughes, D., R.P. Phelps, R.P. Malca. 1991. Aguadulce, Panama: Cycle II of The Global Experiment. Collaborative Research Data Reports, Volume Eight, Number Two. Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development. Oregon State University, Corvallis, Oregon. 144 pp.

Hughes, D., R.P. Phelps, R.P. Malca. 1991. Aguadulce, Panama: Cycle III of The Global Experiment. Collaborative Research Data Reports, Volume Eight, Number Three. Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon. 232 pp.

IX. DATA BASE MANAGEMENT

All data from CRSP experiments are maintained in a centralized data base located in the Program Management Office. This facilitates data analysis by the CRSP Data Analysis and Synthesis Team (DAST), and also provides access to CRSP data by outside researchers. The Central Data Base allows for comparisons between CRSP sites because many variables are required to be reported and data from all sites are standardized. Also, the Central Data Base helps to preserve the global nature of the CRSP.

The Data Base is complete through the Fourth Work Plan. For the first three cycles of experiments there are 128,406 rows of data. For the Fourth and Fifth Work Plans there are 37,229 and 15,179 rows of data, respectively. Fifth Work Plan data are still being received in the Data Base Management Office. There are data for 164 variables for the first three cycles of experiments and 147 variables for the Fourth and Fifth Work Plans, excluding identifying columns, date columns, and extra data columns. Data are reported and stored by category; for example, soil data, fish data, and weather data are all stored in separate tables within the data base. These are referred to as templates. All tables have identifying columns in common with all other tables. Identifying columns include the site, cycle or work plan, season or experiment, dates and pond numbers where appropriate. Data which are reported by a research site but are not required by the Work Plan are added to an appropriate table and are included in the Data Base.

Altogether the CRSP Data Base currently utilizes 34 megabytes of memory; the first three cycles account for 15 megabytes, the Fourth Work Plan data use 15 megabytes, and the Fifth Work Plan data presently use 4 megabytes.

Data for the first three cycles of experiments are stored in R:Base for DOS (R:Base version 2.2) and data from the Fourth and Fifth Work Plans are stored in R:Base version 3.1. Both versions of R:Base allow data to be exported and imported from the following types of files: ASCII delimited, ASCII fixed field, Lotus 1-2-3 (all versions), Symphony, dBase II, dBase III, dBase II PLUS, pfs:FILE, VisiCalc, and Multiplan. The ASCII options make R:Base usable with any other program with ASCII capability. Further, data received by the Data Base Management Office in a Macintosh format can be translated to an IBM format and imported into the Data Base. R:Base allows easy access to the CRSP data either in whole or in part. Data can be retrieved by any of the identifying columns or by values within the variable columns. R:Base also has a few descriptive statistic functions (average, maximum, minimum, standard deviation, and variance) which can be applied to columns to identify outlying values or errors in data entry. Data are provided to CRSP researchers and the public in any format requested; the most commonly used is Lotus 1-2-3 files on 5.25 or 3.5 inch diskettes for IBM and compatible users, and in Excel files for Macintosh users. Data can be sent through electronic mail networks as well, although this option has not been used.

The CRSP Data Base is constantly being refined. Errors in the data are reported to the Data Base Management Office by members of the DAST, other users of the Data Base, or individuals at the research sites as they discover errors in the data. The Data Base Manager makes needed corrections, thus continuously improving the CRSP Data Base.

During this reporting period the CRSP Board of Directors appointed a special committee to review the data base function. Although the results of the evaluation will not be available until the next reporting period, the evaluation has already generated ten requests for CRSP data and further information about the Data Base from outside researchers.

X. STAFF SUMMARY

The Pond Dynamics/Aquaculture CRSP represents the joint efforts of more than 40 professionals and support personnel from U.S. universities. It also represents the collaborative efforts of over 35 scientists, technicians, and graduate students from project sites in our three host 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.

Individuals outside the CRSP have participated in the development of host country projects. For example, fish culture extensionists in Rwanda meet regularly with CRSP researchers for advice and planning, and Peace Corps volunteers in Honduras consult with CRSP researchers and assist in data collection.

The major United States-based research activity, Data Analysis and Synthesis, involves 8 researchers from the University of California at Davis, and Oregon State University. Scientists from Auburn University, the University of Arkansas at Pine Bluff, Oregon State University, and the University of Hawaii also participate in additional 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						
Robert Fridley	Chairman (from 3/91)	X	X	X		Davis, California
Philip Helfrich	Member Chairman (to 3/91)	X		X		Kaneohe, Hawaii
R. Oneal Smitherman	Member	X		X		Auburn, Alabama
AT-LARGE TECHNICAL COMMITTEE						
Donald Garling	Member			X		East Lansing, Michigan
George Tchobanoglous	Member			X		Davis, California
MANAGEMENT ENTITY						
Hillary Egna	Director	X	X	X		Corvallis, Oregon
Marion McNamara	Assistant Director	X				Corvallis, Oregon
Hilary Berkman	Data Base Manager		X	X	X	Corvallis, Oregon
Jim Bowman (2)	Graduate Student (to 5/91)	X	X	X		Corvallis, Oregon
Naomi Weidner	Secretary	X				Corvallis, Oregon
DATA ANALYSIS AND SYNTHESIS TEAM						
DATA ANALYSIS AND SYNTHESIS TEAM - OREGON STATE UNIVERSITY						
James Lannan (2)	Principal Investigator	X		X	X	Newport, Oregon
Shree Nath	Graduate Student		X	X		Corvallis, Oregon
Andy Snow	Graduate Student		X	X		Corvallis, Oregon
Felix Manickam	Student Assistant				X	Newport, 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 TEAM - UNIVERSITY OF CALIFORNIA AT DAVIS						
Raul Piedrahita	Principal Investigator		X	X	X	Davis, California
Steven Culberson	Research Assistant		X	X	X	Davis, California
Philip Giovannini	Post-Graduate Researcher		X	X	X	Davis, California
Zhimin Lu	Post-Graduate Researcher				X	Davis, California
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						
Bryan Duncan	U.S. Principal Investigator	X		X		Auburn, Alabama
Claude Boyd (2)	U.S. Researcher	X	X	X		Auburn, Alabama
David Teichert-Coddington	U.S. Research Associate		X	X		Comayagua, Honduras
Bartholomew Green	U.S. Research Associate		X	X		Auburn, Alabama
Donald Large (2)	Fiscal Officer	X				Auburn, Alabama
HONDURAS - HOST COUNTRY PERSONNEL						
Ricardo Gomez	H.C. Principal Investigator	X		X		Comayagua, Honduras
Luis A. Lopez	H.C. Research Associate			X		Comayagua, Honduras
Nelson Claros	H.C. Chemist		X			Comayagua, Honduras
Sagrario Calix	H.C. Secretary	X				Comayagua, Honduras
Miguel Zelaya	H.C. Lab Technician			X		Comayagua, Honduras
Myra Lara	H.C. Biologist/ Chemist			X		Comayagua, Honduras

(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)
RWANDA						
RWANDA - OREGON STATE UNIVERSITY						
Wayne Seim	U.S. Co-Principal Investigator	X	X			Corvallis, Oregon
Richard Tubb	U.S. Co-Principal Investigator	X	X	X		Corvallis, Oregon
Clem La Cava	Fiscal Officer	X				Corvallis, Oregon
Felicien Rwangano	Graduate Student			X		Corvallis, Oregon
Revathi Balakrishnan	U.S. Principal Investigator (Sociology)					Corvallis, Oregon
RWANDA - AUBURN UNIVERSITY						
Tom Popma	U.S. Principal Investigator	X		X		Auburn, Alabama
Karen Veverica	U.S. Research Associate		X	X		Auburn, Alabama
Claude Boyd (2)	Faculty Cooperative		X			Auburn, Alabama
Mohammed Ayub	Cooperative Researcher		X			Auburn, Alabama
Donald Large (2)	Fiscal Officer	X				Auburn, Alabama
Joseph Molnar	U.S. Principal Investigator (Sociology)					Auburn, Alabama
RWANDA - UNIVERSITY OF ARKANSAS AT PINE BLUFF						
Carole Engle	U.S. Principal Investigator	X		X		Pine Bluff, Arkansas
Ann Gannam	Researcher			X		Pine Bluff, Arkansas
Harold Phillips	Research Assistant			X		Pine Bluff, Arkansas

(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)
RWANDA - HOST COUNTRY PERSONNEL						
Evariste Karangwa	H.C. Principal Investigator	X		X		Butare, Rwanda
Eugene Rurangwa	H.C. Research Associate			X		Butare, Rwanda
Maurice Ntahobari	UNR Rector	X				Butare, Rwanda
Runyinya Barabwiliza	Dean of Faculty of Agronomy	X				Butare, Rwanda
Venantie Mukasikubwabo	UNR Research Associate			X		Butare, Rwanda
Anaclet Gatera	UNR Researcher					Butare, Rwanda
Lieven Verheust	UNR Researcher			X		Butare, Rwanda
Annie Kakuse	UNR Graduate Student					Butare, Rwanda
Pierre Rwalinda	UNR Graduate Student					Butare, Rwanda
Ngoy Kasongo	H.C. Technician		X			Butare, Rwanda
Alfonsine Murekeyisoni	H.C. Technician		X			Butare, Rwanda
Joseph Murangwa	H.C. Computer Technician				X	Butare, Rwanda
THAILAND						
THAILAND - UNIVERSITY OF MICHIGAN						
James Diana	U.S. Co-Principal Investigator		X	X	X	Ann Arbor, Michigan
C. Kwei Lin	U.S. Co-Principal Investigator	X	X	X		Bangkok, Thailand
Tracy Willoughby	Fiscal Officer	X				Ann Arbor, Michigan

(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.	Field(s) of Specialization: Limnology/ Water	Fisheries/ Aquaculture	Data Management	Location of Work (1)
THAILAND - MICHIGAN STATE UNIVERSITY						
Clarence McNabb	U.S. Co-Principal Investigator		X	X		East Lansing, Michigan
Ted Batterson	U.S. Co-Principal Investigator	X	X		X	East Lansing, Michigan
Chris Knud-Hansen	U.S. Research Associate		X	X	X	Bangkok, Thailand
Colleen J. Sober	Fiscal Officer	X				East Lansing, Michigan
THAILAND/PHILIPPINES - UNIVERSITY OF HAWAII						
Kevin Hopkins	U.S. Co-Principal Investigator	X	X	X	X	Hilo, Hawaii
James Szyper	U.S. Co-Principal Investigator	X	X	X		Kaneohe, Hawaii
Gerry Akiyama	Administrative Support	X				Honolulu, Hawaii
Annette Chang	Associate Fiscal Officer	X				Kaneohe, Hawaii
PHILIPPINES - HOST COUNTRY PERSONNEL						
Eduardo Lopez	H.C. Principal Investigator			X		Munoz, Nueva Ecija, Philippines

(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)
THAILAND - HOST COUNTRY PERSONNEL						
Kitjar Jaiyen	H.C. Co-Principal Investigator		X	X		Bangkok, Thailand
Peter Edwards	H.C. Co-Principal Investigator			X		AIT, Thailand
Tanaporn	H.C. Research Assistant			X		Bangkok, Thailand
Wongbathom Konmonrat	H.C. Research Assistant				X	Bangkok, Thailand
Sompote Ukatawewat	H.C. Research Associate	X		X		Ayutthaya, Thailand
Kiengkai	H.C. Research Assistant		X	X		AIT, Thailand
Chintana	H.C. Research Assistant			X		Bangkok, Thailand
Manoj Yomjinda	H.C. Research Assistant		X			AIT, Thailand
Kriengkrai Satapornvanit	H.C. Research Assistant		X			AIT, Thailand
Archin Chamnankuruwet	H.C. Research Assistant			X		AIT, Thailand
Somchai Vaipoka	H.C. Research Assistant			X		Ayutthaya, Thailand
Vorathep Muthuwam	H.C. Research Assistant		X			AIT, Thailand
Ye Qifeng	H.C. Research Assistant				X	AIT, Thailand
SOILS - GLOBAL						
John Baham	U.S. Co-Principal Investigator					Corvallis, Oregon
James Lannan (2)	U.S. Co-Principal Investigator	X		X	X	Corvallis, Oregon
James Bowman (2)	U.S. Research Associate		X	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.

XI. FINANCIAL SUMMARY

This section summarizes the expenditures 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 program budgets and matching support.

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 1990 to 31 August 1991. This is the first year of the third grant, which runs through 31 August 1995, and which provides core funding of $920,000 per year. Table 1 shows the allocation of core funding through the budget year (1 September 1990-30 August 1991) and for the enhancement funds which were allocated for the period of 1 May 1991 to 30 April 1992. Because the budget period for the enhancement funds is not congruent with the core funding budget year, and because funds were not actually available to projects until late summer, the actual expenditures as of 31 August in some cases appear artificially low.

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. 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 and at Oregon State University.

Cost-sharing contributions from the U.S. institutions are presented in Table 1. The Average percentage of funding borne by U.S. universities is 28%, which exceeds the USAID requirement. 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. Cost-sharing contributions from U.S. institutions (in U.S. dollars).

	Core Funds, 1991		Program Enhancement Funds *		Total, USAID	US Cost Sharing		Total, all US funds		Host Country Contribution	
	Budgeted	Cumulative	Budgeted	Cumulative	(As of 31 Aug 91)	1990	Cumulative	1990	Cumulative	1990	Cumulative
Research Program											
Honduras: Auburn	$158,980	$158,980	$10,131	$10,131	$169,111	$29,997	$29,997	$199,108	$199,108	$45,000	$45,000
Rwanda: Auburn	$92,831	$92,831	$4,125	$4,125	$96,956	$18,298	$18,298	$115,254	$115,254		
OSU	$90,418	$90,418	$5,485	$5,485	$95,903	$14,587	$14,587	$110,490	$110,490	$33,093	$33,093
UAPB	$5,000	$5,000	$0	$0	$5,000	$833	$833	$5,833	$5,833		
Thailand: MSU	$77,872	$77,872	$13,349	$13,349	$91,221	$41,342	$41,342	$132,563	$132,563		
UH	$52,874	$52,874	$8,373	$8,373	$61,247	$12,285	$12,285	$73,532	$73,532		
UM	$129,346	$129,346	$0	$0	$129,346	$18,202	$18,202	$147,548	$147,548	$43,000	$43,000
Subtotal	$607,321	$607,321	$41,463	$41,463	$648,784	$135,544	$135,544	$784,328	$784,328	$121,093	$121,093
US Research Program											
DAST											
UCD	$48,641	$48,641	$2,331	$2,331	$50,972	$14,600	$14,600	$65,572	$65,572		
OSU	$45,000	$45,000	$0	$0	$45,000	$19,046	$19,046	$64,046	$64,046		
Special Topics:											
Soil Studies											
OSU	$0	$0	$5,217	$5,217	$5,217	$5,914	$5,914	$11,131	$11,131		
Subtotal	$93,641	$93,641	$7,548	$7,548	$101,189	$39,560	$39,560	$140,749	$140,749		
Management Entity§	$219,038	$219,038	$12,267	$12,267	$231,305			$231,305	$231,305		
TOTAL	$920,000	$920,000	$61,278	$61,278	$981,278	$175,104	$175,104	$1,156,382	$1,156,382	$121,093	$121,093

* Prorated for four months

§Includes the research activities of Data Base Management and Technical Publications. Thus, over 20% of Management Entity expenditures are actually research expenditures.

APPENDICES

Appendix A. CRSP List of Publications through December 1991

AUBURN/HONDURAS

Theses

Berrios, J. In preparation. Growth and survival of hybrid tilapia (*Tilapia nilotica* x *Tilapia hornorum*) 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.)

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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).

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

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<u>Theses</u>

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Guttman, Hans. 1990. Assessment of Nutrient Limitation in Fertilized Fish Ponds by Algal Assay. M.S. Thesis, Asian Institute of Technology, Bangkok, Thailand.

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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.

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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.

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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.

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Curtis, L.R., F.T. Diren, M.D. Hurley, W.K. Seim, and R.A. Tubb. 1991. Disposition and elimination of 17a-methyltestosterone in Nile tilapia (*Oreochromis niloticus*). Aquaculture (in press).

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

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).

Verheust, L, K.L. Veverica, and E. Rurangwa. 1991. Comparative growth and mortality of *Oreochromis niloticus* and *Clarias gariepinus* fingerlings in earthen ponds (Rwanda). p 318-319 In: EAS Special Publication No. 14 (1991). Aquaculture and the environment. N. De Pauw and J. Joyce, eds. 332 p.

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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).

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

Meetings Attended

Karangwa, E., Verheust, L., Veverica, K. Seim, W., Popma, T. and R. Tubb. CRSP Annual Meeting. Auburn, Alabama.

Veverica. K., along with AID officers and others met with the new US Ambassador to Rwanda to brief the Ambassador on agricultural production problems in Rwanda.

Posters Presented

Rurangwa, E. and L. Verheust. 1991. *Oreochromis niloticus* culture in Rwanda: optimal density and feeding ration in earthen ponds. International Aquaculture Conference and Trade Show. Dublin, Ireland. June 10-12.

Rurangwa, E. and L. Verheust. 1991. Comparative growth and mortality of *Oreochromis niloticus* and *Clarias gariepinus* fingerlings in earthen ponds (Rwanda). International Aquaculture Conference and Trade Show. Dublin, Ireland. June 10-12.

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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.

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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.

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Other

Rurangwa, E. and L. Verheust. 1991. Slide presentation: Fish culture in Rwanda: a high altitude, developing country in central Africa. International Aquaculture Conference and Trade Show. Dublin, Ireland. June 10-12.

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.

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.

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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).

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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).

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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/THAILAND

Manuscripts

Szyper, J.P., and K.D. Hopkins. (In review). Effects of pond depth and mechanical mixing on production of *Oreochromis niloticus* in manured earthen ponds. Submitted to Third International Conference on Tilapia in Aquaculture (ICLARM) - accepted for oral presentation.

Szyper, J.P. (In review). Free-water estimates of pond photosynthesis and respiration: examination by short-interval monitoring. Submitted to Aquaculture.

Publications and Reports

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

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Hopkins, K., and A. Yakupitiyage. Bias in seine sampling of tilapia. Journal of the World Aquaculture Society. Accepted for publication.

Hopkins, K.D., J. Bowman and H.S. Egna (eds.), 1991. Collaborative Research Data Reports. Volume 4, Number 3. Philippines Project: Cycle III of the Global Experiment. PD/A CRSP Program Management Office, Corvallis, OR.

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.

Szyper, J., and C.K. Lin. 1990. Techniques for assessment of stratification and effects of mechanical mixing in tropical fish ponds. Aquacultural Engineering 9:151-165.

Szyper, J.P., J. Bowman and H.S. Egna (eds.), 1991. Collaborative Research Data Reports. Volume 4, Number 1. Philippines Project: Cycle I of the Global Experiment. PD/A CRSP Program Management Office, Corvallis, OR.

Szyper, J.P., J. Bowman and H.S. Egna (eds.), 1991. Collaborative Research Data Reports. Volume 4, Number 2. Philippines Project: Cycle II of the Global Experiment. PD/A CRSP Program Management Office, Corvallis, OR.

Szyper, J.P., K. Hopkins, and C.K. Lin. 1991. Production of *Oreochromis niloticus* (L.) and ecosystem dynamics in manured ponds of three depths. Aquaculture and Fisheries Management 22:169-180.

Meetings Attended

K. Hopkins and J. Szyper attended CRSP Annual Meeting at Auburn University, March 1991. Both presented papers; Hopkins chaired the Technical Committee meeting.

K. Hopkins attended the BOSTID-ICLARM Aquaculture Workshop in Manila, August 1991.

J. Szyper attended the World Aquaculture Society annual meeting at San Juan, Puerto Rico, June, 1991, and presented a paper.

J. Szyper and K. Hopkins' paper (see Publications above) was accepted for presentation at the Third International Conference on Tilapia in Aquaculture at Abidjan, Cote d'Ivoire, November 1991.

UNIVERSITY OF MICHIGAN/THAILAND

Theses

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

Buurma, B.J. 1991. The effects of feeding frequency and handling in culture of the walking catfish, *Clarias fuscus*. M.S. thesis, University of Michigan.

Muthuwam, V. 1991. Nutrient budget and water quality in intensive marine shrimp culture ponds. M.S. Thesis, Asian Institute of Technology, Bangkok, Thailand.

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

Qifeng, Y. 1991. Nutrient budget and water quality in integrated walking catfish-tilapia culture. M.S. Thesis, Asian Institute of Technology, Bangkok, Thailand.

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

Publications and Reports

Buurma, B.J., and J.S. Diana. 1992. The effects of feeding frequency and handling on growth and mortality of cultured walking catfish, *Clarias fuscus*. Aquaculture (accepted for publication).

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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., D. J. Dettweiler, and C. K. Lin. 1991. Effect of Nile tilapia *Oreochromis niloticus* on the ecosystem of aquaculture ponds, and its significance to the trophic cascade hypothesis. Can. J. Fish. Aquat. Sci. 48:183-190

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APPENDIX B. LIST OF ACRONYMS AND DEFINITIONS

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
BIFADEC	Board for International Food and Agricultural Development and Economic Cooperation
Bilateral Programs	assistance programs involving arrangements between a single developing country and a single donor country
BOA	Basic Ordering Agreement
Board of Directors (for a CRSP)	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
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
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
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. This may include improvements in physical facilities, equipment, furnishings, transportation, organization, but refers primarily to the development and training of a professional cadre.

IPA	Inter-governmental personnel act
JCARD	Joint Committee on Agricultural Research and Development (formerly Joint Research Committee), BIFADEC
JRC	Joint Research Council, USAID
LDC	Lesser Developed Countries
LUPE	Land Use Productivity Enhancement Project
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
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 processes occurring in pond systems; 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. Now known as Dirección General de Pesca y Acuicultura, Honduras
R&D Bureau (R&D/AGR)	(Formerly S&T/AGR Bureau of Science and Technology) 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 agreement by the ME and AID
TC	Technical Committee - a group of scientists participating in the research of the CRSP as PI's, selected to help guide the scientific aspects of the research program of a CRSP
Title XII	the Title XII Amendment to the International Development and Food Assistance Act of 1975 as passed by the United States Congress and subsequently amended
UAPB	University of Arkansas at Pine Bluff
UCD	University of California at Davis
UH	University of Hawaii
UM	University of Michigan
UNR	Universite Nationale du Rwanda
USAID	United State Agency for International Development
USAID Project Officer	an official AID employee designated to oversee a CRSP on behalf of AID