TITLE XII
COLLABORATIVE RESEARCH SUPPORT PROGRAM

POND DYNAMICS/AQUACULTURE

SIXTH ANNUAL ADMINISTRATIVE REPORT

(1 SEPTEMBER 1987 TO 31 AUGUST 1988)

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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 from 1 September 1987 to 31 August 1988. Program activities are funded in part by the United States Agency for International Development Grant Number: DAN-4023-G-SS-7066-00.

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INTRODUCTION

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

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

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

The beginning of this reporting period marked the start of a new phase of research for the CRSP. With the completion of the first three cycles of standardized global experiments, the CRSP began to focus on the statistical interpretation of data that were collected at the six project sites. The research program was modified successfully to reflect the reduction in sites without changing the overall emphasis of the CRSP. The global nature of the program remained intact; experimental protocol conforms to that of the previous three cycles. Field experiments blend program-oriented and project-oriented (site-specific) considerations in response to the results of the earlier experiments. Subsequent experiments also will emphasize calibration and verification of predictive models under field conditions, and field testing of pond management practices.

In January 1988, the second Triennial Review of the Pond Dynamics/Aquaculture CRSP began. The External Evaluation Panel, composed of eminent scientists in aquaculture, and an Internal Management Review team consisting of staff from AID and BIFAD participated in the CRSP Annual Meeting in Hawaii in January 1988. Members of the review teams visited former as well as present CRSP field sites throughout the winter and spring of 1988. The Triennial Review is expected to be completed in June of 1989.

The purpose of this report is to summarize technical accomplishments, program organization and management during the period from September 1, 1987 through August 31, 1988. The CRSP Global Experiment and the attendant analysis of data were the dominant activities during this reporting period. Notable progress also was made in management of the CRSP Central Data Base and in the publication of CRSP research.

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SUMMARY OF ACTIVITIES AND ACCOMPLISHMENTS: 1 SEPTEMBER 1987 TO 31 AUGUST 1988

The consolidation of the CRSP Central Data Base, the development of models, and the interpretation of results from the Global Experiment constituted the major accomplishments during this reporting period.

The CRSP Central Data Base, which is maintained by the Management Entity, is now complete and up-to-date. Nearly 90,000 observations on 96 variables related to pond dynamics were made at each field site, culminating in the compilation of over 1.5 million observations into the CRSP Central Data Base. The Data Base is unique in that it contains the largest standardized collection of measurements in pond dynamics and aquaculture in the world. The CRSP, through its data base, provides a great service to the world aquaculture community by collecting and compiling data on photosynthetically active radiation, rainfall, evaporation, air temperature and wind speed concurrently with biological measurements (e.g., primary productivity, fish growth, and yield). Detailed records such as these are rare in the aquaculture literature.

The Central Data Base was designed to facilitate communication with other large data bases, such as the Tropsoils CRSP data base, thereby creating opportunities for collaboration. CRSP scientists may access the data base via personal computers or mainframe computers. Data also are accessible to the world aquaculture community through electronic communications, computer diskettes, or in print form as it appears in CRSP Data Reports (a series of reports that contain data and results of the Global Experiment).

The outlook for the Central Data Base is healthy. Inefficiencies in the computer programs and reporting procedures have been resolved; consequently, compilation of new observations should be quick and easy. Revisions in the work plans are reflected in new templates for data entry each year, demonstrating the flexibility of the system. For example, the Fourth Work Plan, which was written during this reporting period, modified the sampling protocol so that intensive diel sampling periods are now required. The templates were redesigned to incorporate these changes and to allow for optional measurements that might be collected during site-specific experiments. Future changes to the Data Base might include additional templates for new field sites (as proposed in Rwanda) and adjustment of reporting frequencies to accept data obtained from automated water quality data acquisition systems (data loggers) more easily.

During the past year, major advances were made in analyzing and synthesizing data from the Global Experiment. Statistical analyses of the Central Data Base revealed differential growth rates and productivities between sites. Preliminary results indicate that the CRSP ponds in Thailand were most productive (i.e., experienced the highest yields) and those in Rwanda were least productive. Correspondingly, maximum physiological growth rate of tilapia in Rwanda was the lowest (0.42) of the CRSP sites. Growth rates at the other CRSP sites averaged 0.66, with Thailand being the highest (0.74). Further statistical analysis (principal component analysis) revealed possible reasons for these differences. Strong correlations were found between environmental parameters (e.g., solar radiation and air temperature) and pond productivity. Future analyses will determine whether density dependence contributes to these differences.

The global data also were used to develop three empirical models for examining the flow of oxygen through pond systems. A mechanistic model was designed to provide a detailed view of short-term oxygen dynamics in ponds. Another model provides a more general, ecosystem view of aquaculture systems and allows simulations using fourteen variables (e.g., phytoplankton, fish number and size, dissolved oxygen, ammonia, pH, inorganic carbon). The third model is being used to analyze dissolved oxygen and inorganic carbon data and to obtain indicators of phytoplankton condition.

A final model, an *expert system*, was designed to classify ponds according to fertilization practices that have the highest probability for optimizing fish yield. This model groups ponds into general categories based on climate, soils, and water quality. Refinement of the model (through the addition of functional or mathematical relationships) will allow recommendations to be made on type and amount of fertilizer, cost effectiveness, and optimization of yield. Functional relationships, which are being defined by statistical analysis and mechanistic models described previously, will drive the expert system. Verification of the models through field testing will be used to refine the models. The ultimate output will be a manual of guidelines for the efficient management of aquaculture ponds in the tropics.

The Data Analysis and Synthesis Team, which is responsible for model development, provided suggestions to the field researchers for refining their experiments. New measurements (i.e., suspended solids, total volatile solids, water budget parameters) and intensive diel sampling were added to the experimental protocols as a result of this feedback. Researchers at the field sites cooperated with the modelers in designing new experiments that would enhance the comprehensiveness of the Global Experiment.

Accomplishments at the field sites centered on various aspects of the Global Experiment. Researchers from Michigan State University applied knowledge gained from the CRSP experiments in Indonesia (project terminated in August 1987) to new experiments in Thailand. They developed guidelines for adding fertilizer in quantities that would lead to predictable and reliable fish yields.

Researchers from the Royal Thai Department of Fisheries, the Asian Institute of Technology, and the University of Michigan studied the effects of fish stocking density and biomass on pond dynamics. They found that increased stocking density did not increase yield, that carrying capacity of ponds did not vary much with the stocking densities tested, and that increases in fish abundance did not change ecosystem function.

Researchers from the National University of Rwanda (UNR) and Oregon State University examined the effects of locally available inputs (e.g., composts) on fish production. Preliminary results indicate that in-pond compost (raw materials submerged in bamboo enclosures) was the most effective composting method for increasing fish yield. Further studies on autotrophic and heterotrophic pathways will provide the CRSP with better information for applying scarce fertilizer resources. Researchers from Auburn University also worked with scientists from UNR in determining the effects of stocking density on production. Maximum revenues at the Rwasave Fish Culture Station (a CRSP field site), based on rudimentary estimates of costs, occurred during the third month for ponds stocked at a rate of 1 fish/m^2. After that, the value of additional production did not compensate for the cost of additional inputs. Maximum return for ponds stocked at 1.5 and 2 fish/m^2 occurred in the fourth and fifth months, respectively.

The CRSP field site in Panama was terminated in December 1987, halfway through this reporting period, when CRSP researchers were directed by USAID to relocate. In this short period, however, a brackish water experiment was completed. Researchers from Auburn University and the National Directorate of Aquaculture in Panama found that increasing stocking density had an immediate effect on shrimp growth and that increasing the level of protein in the diet did not significantly influence production, mean weight, feed conversion, or survival at the two stocking densities tested (4 and 8 shrimp/m^2). They also found that shrimp production was greater at the higher density but lower economic returns resulted from the lower price per unit weight paid for the smaller shrimp.

After departing from Panama in December 1987, CRSP researchers were faced with finding a new site for conducting the Global Experiment. While maintenance of diversity in field locations through inclusion of a brackish water site was important to the CRSP, the realities of starting over (e.g., cost and time lost) became evident. The CRSP was fortunate to be able to resume its relationship with the Department of Renewable Natural Resources (RENARE) in Honduras. Experiments began in August 1988 at the former freshwater CRSP site in Comayagua. Auburn University will continue to explore the possibility of establishing a brackish water research site for the CRSP in Honduras.

Ancillary to the Global Experiment, but still important to the overall goals of the CRSP, are activities geared toward country-specific research and educational needs. All U.S. staff overseas contribute some time to extension work such as training students and technicians, teaching short courses on aquaculture, and conducting site-specific experiments: These activities are described in the sections Project Development and Public Service and Host Country Special Topics Research Reports.

During this reporting period, CRSP researchers and staff from the Program Management Office greatly broadened the contact of this CRSP with the world aquaculture community through the dissemination and publication of research results. The rate at which results are being published in the scientific literature continues to climb. The CRSP now has a list of publications (including theses, reports, and presentations) that number over 275 and are distributed to a broad domestic and international audience. Detail on our results and publications is presented in the Sixth Annual Administration Report.

Hillary S. Egna

CRSP RESEARCH PROGRAM BACKGROUND

The CRSP Research Program has three components:

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

The Global Experiment and related data synthesis activities are the major research focus of this CRSP and account for more than 90% of the total research program. Special Topics Projects in the U.S. and in Host Countries complement the Global Experiment. These research activities, their purposes, and their 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 and undertook overseas site visits to determine research needs and availability of local support in less developed countries. The findings from these surveys were then translated into planning guidelines.

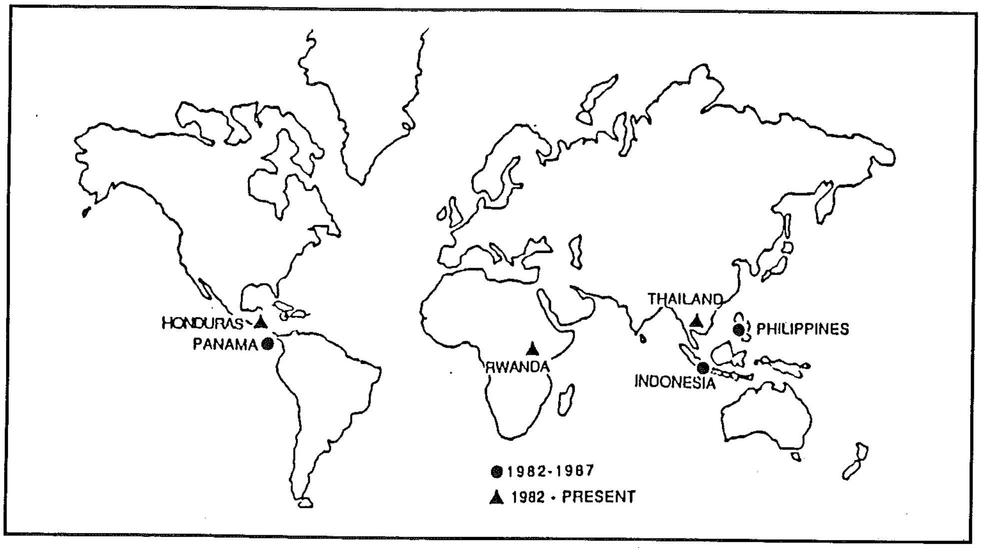
In the course of the planning activities, it became apparent that there are two important aspects of improving the efficiency of pond culture systems. First, there is a need to improve the technological reliability of pond production systems. Second, there is a need for economic optimization consistent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

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

The need for rigorous economic analyses of pond aquaculture systems is typically encountered in attempting to formulate appropriate fisheries and aquaculture development strategies, both in developing countries and in the U.S. In order to determine if contemporary pond management practices are the most efficient approach to fish production, it is necessary to develop quantitative production functions to facilitate analyses of the various strategies or combinations thereof.

These functions can not be developed without first making numerous and often tenuous assumptions because the dynamic mechanisms regulating pond productivity are poorly understood. The common denominator in improving production technologies on the one hand and facilitating economic analyses on the other, therefore, is directly related to understanding pond dynamics.

The Pond Dynamics/Aquaculture CRSP is unique relative to other CRSP's in several ways. The most visible difference is that it is funded at a substantially lower level than most CRSP's. A less obvious difference is that whereas other CRSP's 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 data on pond aquaculture was a major constraint to improving the efficiency of pond culture systems. The abundant technical literature about pond aquaculture can provide general guidelines for the operation of pond culture systems. However, because of the lack of standardization in experimental design, data collection, and analysis, these reports can not be statistically compared to one another and consequently are of limited utility for predicting the performance of pond culture systems. The approach taken by the CRSP to develop quantitative expressions to improve production technologies and facilitate economic analyses has been to develop a standardized data base that can be used to quantitatively evaluate pond performance over a broad range of environments.

The statistical design for the experiment involves monitoring environmental and fish production variables at seven geographical locations. The location of project sites was carefully selected to include a geographical cross-section of the world where advances in pond aquaculture would be most beneficial and apt to succeed. All of the projects 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 and then collectively by the Data Analysis and Synthesis Team. Additionally, data are filed in a centralized CRSP data base. Standard statistical methods are used to test hypotheses about correlations between variables and to evaluate the sources of variance 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 are developed by the CRSP Technical Committee. Each work plan represents a detailed experimental protocol for one experimental cycle. A cycle involves two series of observations of four to five months duration. One set of observations is made during the dry season and the other during the wet season.

Four work plans have been developed to date. The rationale of the first work plan was to manage all ponds in exactly the same way to establish a detailed baseline of data on pond variables. Then in subsequent experiments, the pond environments were manipulated in different ways and the responses observed. The plan specified standardized methods for pond preparation and monitoring. It was developed at a meeting of CRSP participants in Davis, California on March 2-3, 1983.

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

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

The Fourth Work Plan was developed by the CRSP Technical Committee at their meeting in Portland, Oregon on February 25-26, 1987. CRSP participants reviewed the progress of the first three cycles of the Global Experiment. Specific statistical hypotheses were formulated for research in Host Countries and the United States based upon results of previous experiments. New experiments were designed to allow the continued collection of standardized data for the CRSP Central Data Base. This work plan was further refined at the Technical Committee Meeting in Kona, Hawaii on January 10-14, 1988. As recommended by the External Evaluation Panel during the first Triennial Review, the work plan now encompasses two years of experimental protocols rather than one. A biennial work plan was adopted because it avails greater opportunity for results to be analyzed before planning subsequent research.

Data Management

Consistent with its long-term goal, the CRSP is heading toward the development of practical pond management models to improve the efficiency of pond culture systems. The development of quantitative models is dependent upon the efficient management of 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, data tabulations are filed in a centralized CRSP data base maintained by the Management Entity. The centralization of the data base allows the most efficient access to the CRSP data sets by all CRSP participants, but particularly by the Data Synthesis and Analysis Team. The latter body was appointed by the CRSP Board of Directors to accomplish data analysis, synthesis, and model development. The various activities of Team members are supported as part of the U.S. Research Component.

One of the major accomplishments made during this reporting period was that the CRSP Central Data Base was brought up-to-date. This consisted of the translation and verification of *all* data that were manually entered into personal computers at the seven field sites over three cycles of experiments. Each site makes approximately 90,000 observations per year of 96 variables. This amounts to over one-half million observations that have been compiled and translated into standardized formats.

The current status of the Data Base facilitates communication with other large agricultural data bases. More importantly, researchers worldwide now have ready access to data from the Global Experiment.

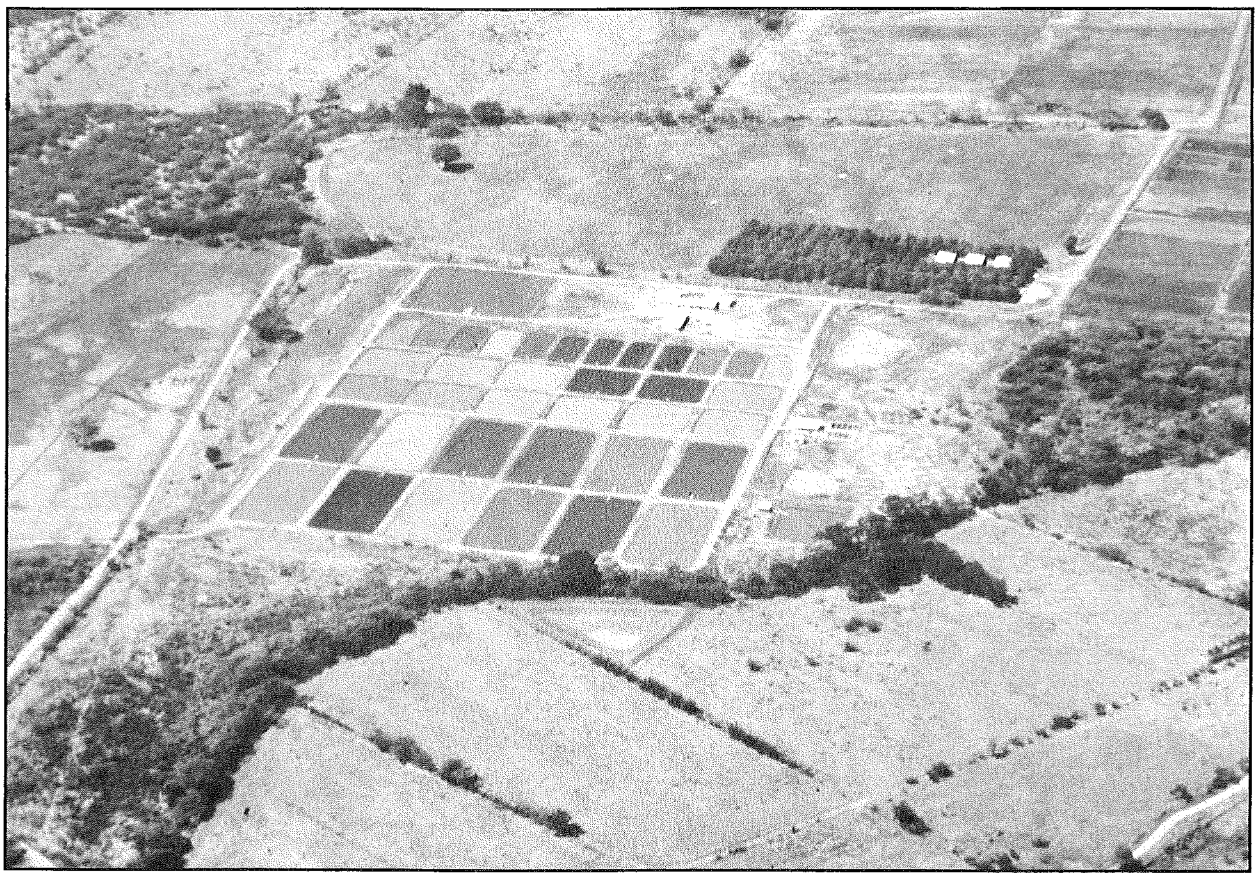
Reorganization- First year in a new phase of the global experiment

During this reporting period, the CRSP executed a new phase of operations. CRSP participants, under the guidance of BIFAD and USAID staff, developed a plan in January 1987 to continue CRSP activities after the original CRSP grant period ended on 31 August 1987. Proposals for reorganization were submitted to two meetings of the joint JCARD Panel on CRSP's and the Agricultural Sector Council Subcommittee. The first plan, submitted in December 1986, was revised and resubmitted in January 1987. With minor modification, the revised plan was accepted as a three-year continuation plan.

The erosion of funding in 1986 and 1987 made it necessary to discontinue four of the seven CRSP projects in order to maintain a high quality research program within budgetary constraints. The three remaining sites are representative of the three USAID geographical areas in which the CRSP has conducted overseas research: Southeast Asia, Latin America, and Africa. The CRSP was able to incorporate these changes without altering the overall emphasis of the research program.

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

The Fourth Work Plan, which represents the new phase of research under the reorganization of the CRSP, was implemented on September 1, 1987. The CRSP Technical Committee refined this work plan twice during the year and expanded it to a biennial work plan. Future work plans will emphasize the calibration and verification of predictive models under field conditions, and field testing of pond management practices.



RESEARCH PROGRAM ACCOMPLISHMENTS

The Global Experiment

Interrelationships

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. 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 seven geographical locations in accordance with standardized work plans.

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

Results of the Global Experiment

The fourth year of the CRSP Global Experiment was successfully completed at two of the three research locations. Experiments at the CRSP site in Panama could not be completed due to political initiatives outside the mandate of this CRSP. In December 1987, AID directed CRSP scientists to terminate experiments and seek another research site. New Memoranda of Understanding were drafted with institutions in Honduras in the Spring of 1988 and experiments began at the former CRSP research site in Comayagua, Honduras in August 1988.

Cycle IV experiments at the freshwater sites in Rwanda and Thailand focused on the chemical, physical, and biological responses of ponds treated with varying rates of fertilizers. *Oreochromis niloticus (Tilapia nilotica)* was stocked at all freshwater sites. At the brackish water site in Aguadulce, Panama, the objectives were to observe differences in physical, chemical, and biological responses of ponds stocked at various densities with shrimp, and to determine the effects of diet protein on shrimp production. Development of another brackish water site is being pursued by the CRSP project in Honduras.

The Fourth Work Plan differs from previous work plans in that hypotheses about pond dynamics are tested in different field experiments at each research location. This procedure allows the CRSP to rapidly proceed 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 Waste Water, American Public Health Assoc., 1980) continued to be used for recommending materials and procedures for collecting data. Additional detail on the Fourth Work Plan is presented in Appendix A.

The experimental protocols for each cycle of the Global Experiment are provided in the corresponding work plan. Technical progress for the fourth cycle is described briefly for each site.

Central America

Panama

Effects of diet protein and stocking density on production of *Penaeus vannamei* in tropical earthen ponds

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Abstract

A randomized experiment in 2 x 2 factorial arrangement was conducted to investigate the effects of diet protein on growth of *Penaeus vannamei* stocked at different densities in earthen ponds. Diets consisting of 29% and 37% protein were offered to juveniles stocked at densities of 4 and 8/m^2. Treatments were replicated 3 to 4 times. At harvest after 99 days of growth, production, survival, and mean weight of shrimp were not significantly different ($P > 0.05$) for the two levels of protein at either stocking rate. Mean production for shrimp receiving low and high protein diets was 564 and 586 kg/ha, respectively, and mean weight was 12.7 and 11.8 g, respectively. Production of shrimp was significantly greater ($P \leq 0.05$) at the high stocking density, while mean weight and survival was significantly less. Mean production for high and low density was 624 and 533 kg/ha, respectively, and mean weight was 9.7 and 14.5 g, respectively. Although production was greater at the high density, significantly lower economic returns resulted from the lower price per unit weight paid for the smaller shrimp.

Introduction

In Panama, little public information exists on the effects of density and diet on the production of Penaeid shrimp. However, shrimp aquaculture accounts for 30% of shrimp exports from Panama, and shrimp exportation is second only to bananas in foreign earnings. Earnings of the producer are directly affected by quantity of production, feed conversion, and size of shrimp at harvest. The price per body weight of shrimp increases with average shrimp size, and together with total harvest weight greatly influences final income at harvest. Mean size and total weight at harvest of shrimp grown for a fixed period of time are directly affected by stocking density. Thus, it is important that effects of density on shrimp survival and growth be well known in order for producers to maximize their income.

The standard shrimp feed in Panama is formulated to contain 25% protein, although feeds of higher and lower protein contents are available. However, there is little information on effects of protein level on production and feed conversion. Especially scant is information on the interaction between stocking density and level of protein in the diet. Since inclusion of higher levels of protein in the diet is potentially more expensive, information on cost-effective formulation of diets is essential.

The objectives of the present experiment were to determine the effects of stocking density and diet protein on production of *Penaeus vannamei* and income to the producer.

Materials and Methods

The experiment was conducted on the Pacific coast of Panama at Estacion Enrique Ensenat, Aguadulce. The brackish water experimental station is operated by the National Directorate of Aquaculture (DINACC) of the Government of Panama.

A randomized experimental design, in 2 x 2 factorial arrangement, was employed to investigate effects of two levels of diet protein on growth of *Penaeus vannamei* stocked as juveniles (0.9 g) at 4 and 8/m^2 in earthen ponds (550 m^2 by 0.6 m deep). Treatments were replicated 3 to 4 times. Diets nominally consisted of 25 and 35% protein, but later analysis of the feed indicated that low and high protein actually contained 29 and 37% crude protein, respectively. Diet formulation is presented in Table 1. The feed was fabricated at a local plant, and the feed pellet was water stable for at least six hours.

The shrimp were fed six days a week based on a feeding table (Table 2). Shrimp in all treatments were fed equally for the first 42 days. Thereafter, because of low weekly gains, the feeding rate of the high density treatments was increased to 1.25 times that of the low density treatments.

Water quality was monitored with weekly secchi disk visibilities and twice a week early morning dissolved oxygen (DO) measurements until low levels were encountered; thereafter, DO was measured daily. Water exchange in the ponds commenced after six weeks of culture. Water was exchanged once per week at 15 and 20% of pond volume for low and high density treatments, respectively. In addition, water was exchanged in individual ponds later in the season when DO became less than 1.5 mg/L. Salinity was measured weekly by densimetry (APHA 1975) of a sample of water collected with a column sampler (Boyd 1979).

A limited economic analysis of the experimental data was accomplished. Gross income was based on real prices received at a local processing plant, and was related to both shrimp size and production weight. Operating costs were calculated only for the three major variable costs incurred during the experiment: feed, larvae, and pumping. Net income was calculated simply as the difference between gross income and variable costs.

The culture period lasted 99 days during June to September of 1987. Data were analyzed by 2-factor analysis of variance (Feldman and Gagnon 1986), and differences were declared significant at alpha level 0.05.

Results and Discussion

The experiment commenced at the beginning of the rainy season, so salinities decreased with time (Figure 1) as the rains increased in frequency and duration; mean seasonal salinity was 27.4 ppt. Both secchi disk visibility (Figure 2) and early morning dissolved oxygen decreased with time (Figure 3), and there were no significant differences among treatment means for either variable. During the last three weeks, DO dropped below 1.5 mg/L in many ponds due to long stretches of cloudy weather and the higher daily feeding rates. Partial mortalities occurred in some ponds during this period, and shrimp growth rates decreased (Figure 4).

It was expected that higher levels of protein would increase production, especially at the higher stocking density where nutrition (protein) would presumably be a growth limiting factor. However, increasing the level of protein in the diet did not significantly influence production, mean weight, feed conversion, or survival of shrimp at either stocking rate (Table 3). Mean production for low- and high-protein treatments was 564 and 586 kg/ha, respectively, and mean weight was 12.7 and 11.8 g, respectively. Since the growth of shrimp that were fed diets at both protein levels was equal throughout the season, we conclude that a higher level of protein in the diet was unnecessary for stocking densities of 4 or 8/m^2. Possibly, higher levels of protein would have been beneficial had higher stocking densities been used.

Stocking density had an immediate effect on shrimp growth. Mean shrimp weight was obviously less in the high density groups by the fourth week of growth (Figure 4). Production of shrimp was significantly greater at the high stocking density, while mean weight and survival was significantly less (Table 3). Mean production for high and low density was 624 and 533 kg/ha, respectively, and mean weight was 9.7 and 14.5 g, respectively. Production and feed conversion were better than average at both densities relative to previous years at the experimental station. But greater production may have been obtained at the high stocking density if a higher feeding rate had been used. An increase in the high density feeding rate at day 42 appeared to stimulate weight gain for the next month, after which gain decreased again (Figure 4). However, low DO was encountered during the last three weeks of the season (Figure 3) and higher feeding rates would have exacerbated the problem.

Although production was greater at the high density, significantly lower economic returns resulted from the lower price per unit weight paid for the smaller shrimp (Table 4). Gross income from either density was not different, but the higher variable costs for the high stocking rate decreased net income significantly. The average tail size of the majority of the high density shrimp fell into the upper range of the 71/90 count which sold at $3.41/kg. Another 7 to 10 days of growth would have increased the average size to the 61/70 range which sells for $4.18/kg, a 23% higher price per unit weight. Likewise, an additional 10 to 14 days of growth could have increased the average shrimp size of the low density group from a 41/50 count ($4.62/kg) to a 36/40 count ($5.50/kg). Thus, a slightly longer growing period could have increased net income, but poor water quality would have greatly increased the risk of shrimp mortality and led to major financial loss. If the capacity for aeration or large exchange of water is not available, it appears more prudent to stock ponds at 4/m^2, and to harvest after 12 to 14 weeks. Such a scheme is in fact already used by many producers in Panama. More research is needed to refine the stocking rate to growth period interaction in order to produce the size shrimp that will earn the most at the time of harvest. Attention also needs to be focused on the role that shrimp nutrition can play in developing an ideal culture scheme.

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Table 1. Feeding table for administration of pelleted feed to *Penaeus vannamei* stocked at 4 and 8/m^2.

TWO-WEEK PERIOD	DENSITY 4/m^2 (kg/ha/d)	DENSITY 8/m^2 (kg/ha/d)
1	3	3.0
2	6	6.0
3	9	9.0
4	12	15.0
5	15	18.8
6	18	22.5
7	21	26.3

Table 2. Formulation of the 25 and 35% protein diets fed *Penaeus vannamei* at Estacion Enrique Ensenat, Aguadulce, Panama.

ITEM	25% PROTEIN (%)	35% PROTEIN (%)
Fish Meal	15.0	22.0
Soybean	10.0	23.0
Meat & Bone Meal	14.0	16.0
Corn	55.5	36.0
Binder (Basfin)	0.7	0.7
Vitamin Premix	0.5	0.5
Fish Oil	4.5	2.0

Table 3. Initial and final numbers and weights of *Penaeus vannamei* grown at two densities (4 and 8/m^2), and receiving diets containing 25 or 35% protein. Included are the totals for each factor and the differences between levels of each factor.

TREAT (Protein/Density)	INIT NUMBER (#/ha)	INIT MEAN WT (g)	REPLICATES	GROSS PROD (kg/ha) Mean	GROSS PROD SE	FINAL MEAN WT (g) Mean	FINAL MEAN WT SE	FEED CONV Mean	FEED CONV SE	SURVIVAL (%) Mean	SURVIVAL SE
25/4	40,000	0.9	4	531.4	11.64	14.9	0.50	1.65	0.05	90	13.3
25/8	80,000	0.9	3	608.0	14.88	9.8	0.24	1.74	0.05	77	1.8
35/4	40,000	0.9	4	535.5	4.24	14.2	0.35	1.66	0.02	95	2.5
35/8	80,000	0.9	4	636.1	38.27	9.5	0.31	1.73	0.13	84	5.2
TOTALS	TOTALS	TOTALS	TOTALS	TOTALS		TOTALS		TOTALS		TOTALS	
25	60,000	0.9	3.5	564.2		12.7		1.69		84	
35	60,000	0.9	4	585.8		11.8		1.69		89	
Difference	0	0	-	21.6		0.9		0		5	
4	40,000	0.9	4	533.4		14.5		1.66		92	
8	80,000	0.9	3.5	624.1		9.7		1.73		81	
Difference	40,000	0	-	90.7**		4.8**		0.07		11*	

* Significant difference ($P \leq 0.05$)
**Highly significant difference ($P \leq 0.01$)

Table 4. Income and major variable costs of *Penaeus vannamei* production at two densities (4 and 8/m^2), and two diets (25 and 35% protein). Included are the totals for each factor and the differences between levels of each factor.

TREAT (Protein/Den)	MEAN SHRIMP TAIL PRICE ($/kg)	GROSS INCOME ($/ha)	MAJOR VARIABLE COSTS PUMPING• ($/ha)	FEED•• ($/ha)	LARVAE••• ($/ha)	TOTAL ($/ha)	NET INCOME ($/ha)
25/4	4.62	1,645	56	285	200	541	1,104
25/8	3.92	1,602	66	324	400	790	812
35/4	4.57	1,638	56	282	200	551	1,087
35/8	3.70	1,581	66	345	400	806	775
TOTALS	TOTALS	TOTALS	TOTALS	TOTALS	TOTALS	TOTALS	TOTALS
25	4.32	1,627	60	302	286	648	979
35	4.13	1,609	61	313	300	679	931
Difference	0.19	18	1	11	14	31	48
4	4.59	1,641	56	283	200	546	1,095
8	3.80	1,590	66	338	400	799	791
Difference	0.79**	51	10**	55**	200**	253 **	304**

* Significant difference ($P \leq 0.05$)
** Highly significant difference ($P \leq 0.01$)
• Calculations based on a 4,000 gal/min pump that used 1.25 gal diesel/hr; diesel cost $1.27/gal.
•• Calculations based on feed that cost $0.35/kg for 25% protein and $0.36/kg for 35% protein.
••• Larval costs based on the hatchery price of $5/1,000.

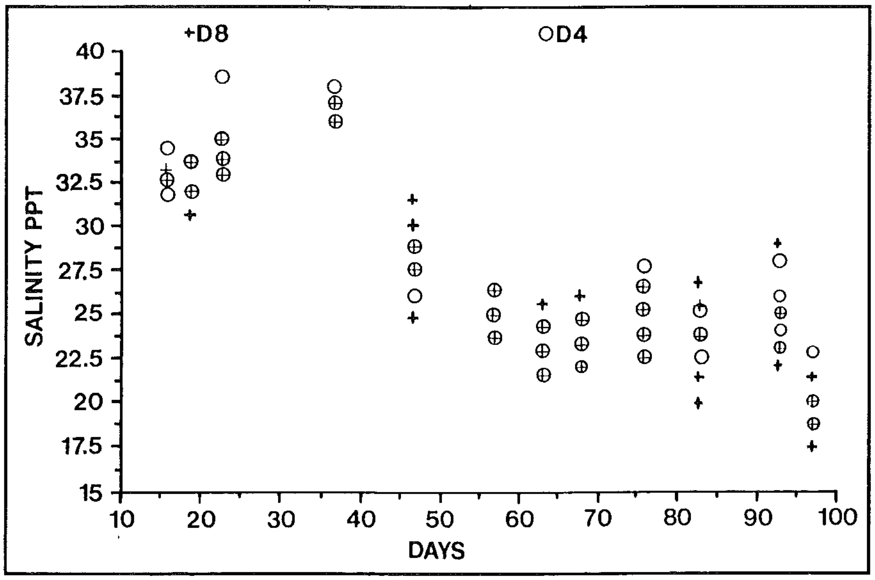

Figure 1. Salinity by time for high and low densities.

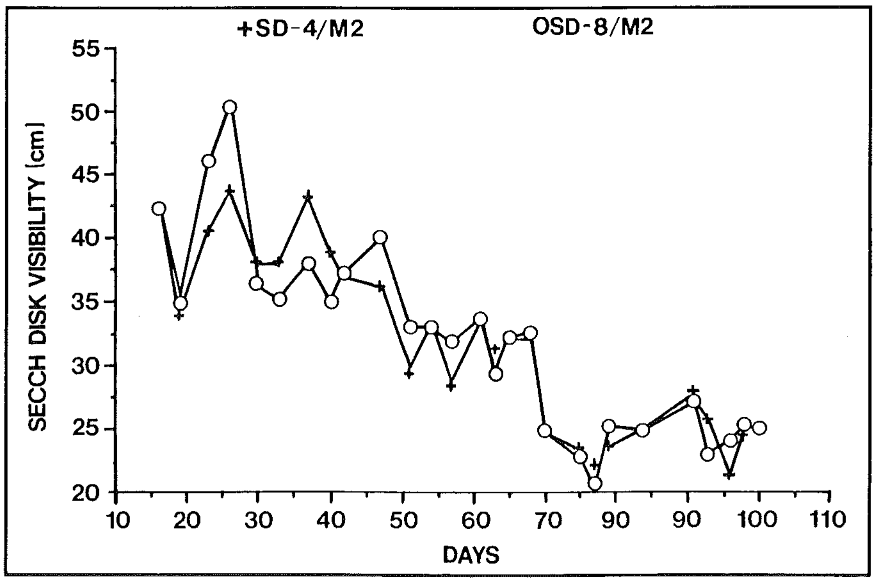

Figure 2. Mean secchi disk visibilities for high (8/m²) and low (4/m²) stocking densities.

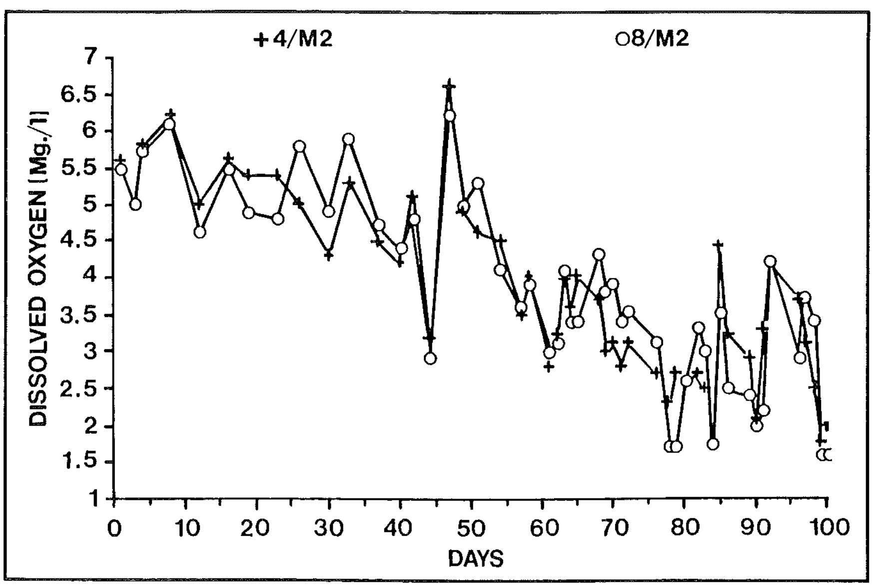

Figure 3. Early morning dissolved oxygen concentrations for high (8/m²) and low (4/m²) stocking densities.

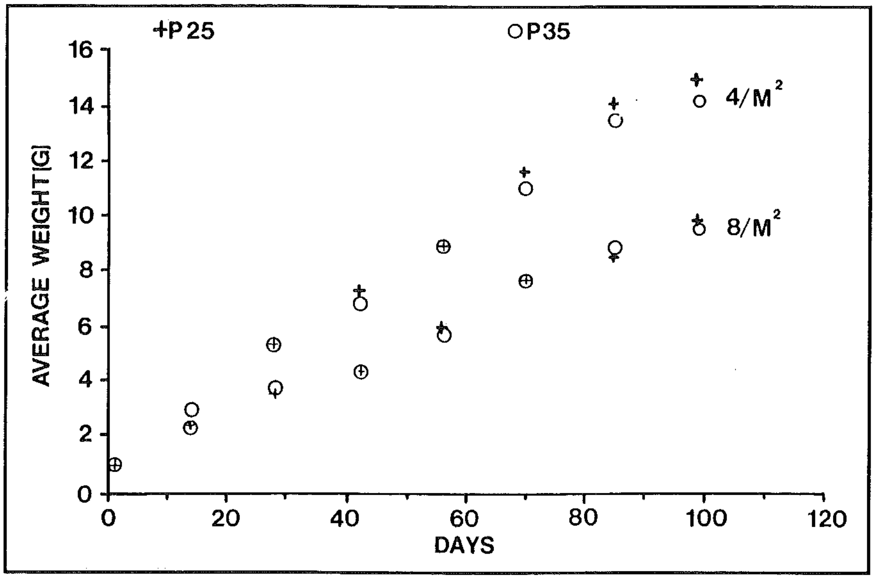

Figure 4. Mean shrimp weights for high (35%) and low (25%) protein, and high (8/m²) and low (4/m²) densities.

Honduras

Status of proposed coastal component in Honduras

Bryan Duncan, Auburn University, Alabama

Upon leaving Panama, Auburn University searched for a coastal site where the CRSP program could be moved, but there were no facilities available in Latin America. Thus, the CRSP Board of Directors recommended that Auburn University return to the former CRSP freshwater research site in Comayagua, Honduras. Auburn University also was charged with developing a brackish water site in Honduras.

Auburn University presented a proposal to AID/Honduras for expanding the CRSP project to include a coastal component in addition to the inland component at El Carao. This expansion was to be funded primarily by a new 50 million dollar AID Land Use and Conservation Program (LUPE) that was to be implemented by September 1988. AID has identified shrimp farming as being of high priority for their funding, and proposals for use of funds were being encouraged. However, in the past months LUPE has undergone drastic changes as the project paper was being finalized, and shrimp farming has been totally eliminated from the program and placed under a different AID program. This program, FEPROEXAAH, was primarily established to provide loans and marketing assistance to local farmers producing exportable crops. Auburn University personnel have met with FEPRO managers in AID offices several times to discuss possibilities for a coastal development and research program with infrastructural costs to be funded by them. However, FEPRO does not want to fund any research in the immediate future. Rather, they plan to contract for aquacultural extension assistance to farmers accepting their loans. After shrimp farmers are established, and if recommended by the farmers themselves through their association (ANDAH) and the technical assistance team, FEPRO may consider funding a research program. However, this research would be practical and aimed at solving specific problems faced by farmers in Honduras.

In addition to several months of negotiations with AID/Honduras, Auburn University did establish a research program with a large Honduran shrimp farm (Granjas Marinas San Bernardo) which is managed by Mr. Ralph Parkman, an Auburn University alumnus. Mr. Parkman approached Auburn University in July 1988 with the idea of using 12 of his smaller ponds for part of the year to test various feeding and management practices. He would provide all of the inputs, and Auburn University would provide technical assistance in formulating and managing the experiments. The data generated from these studies could be published, and extended directly to neighboring farms. Through this arrangement, experimentation was initiated in September 1988. Auburn University personnel in Honduras designed the experiments and are paying monthly visits to the farm to help maintain quality control. At harvest, Auburn University personnel will analyze and help interpret the data collected by farm biologists. These data will consist of input costs, daily oxygen readings, weekly secchi disk visibilities, salinity, and shrimp growth.

Pond dynamics might be difficult to study at the farm because there is no water quality laboratory there, and El Carao is located five hours away. The possibility of collecting water samples to be frozen for later analysis is being considered, but the value of complicated experiments managed from a distance is questionable and the time that farm biologists have for research is limited. In the future, we may be able to get funding for a laboratory from FEPRO if Granjas or another farm would give permission to construct such a building on their property, and if ANDAH would recommend it.

In summary, establishment of a CRSP Pond Dynamics program on the coastal area of Honduras within the next year does not appear feasible, although there is a reasonable probability of establishing one by August 1990. Meanwhile, experimentation in the coastal environment is being conducted as a CRSP Special Topics Project.

Africa

Rwanda

Method of composting influences tilapia production and pond processes in Rwandan ponds receiving compost inputs

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Wayne Seim and Richard Tubb, Department of Fisheries and Wildlife, Oregon State University

Introduction and Objectives

Composted plant and animal wastes can provide a sustainable fertilizing input. In composted ponds, tilapia production and pond processes in general depend on the nature of the raw materials and the composting process. This experiment examines the influence of composts formed by three processes on tilapia production. The primary objective of this experiment is to determine which of the three compost inputs results in the greatest fish production and to understand how the differences occur.

Materials and Methods

Compost produced by three processes was tested in 21 Rwandan ponds of six ares each (one are=100 sq. m). The three processes were aerobic (on land), anaerobic (in pits), and in-pond (submerged). For each process, the ratio of grass:manure used was: 80:20, 90:10, and 100:0 (in percent), respectively. An additional ratio of 50:50 was tested for in-pond compost only. All treatments were triplicated.

Parameters measured are described in the CRSP Fourth Work Plan. Additional parameters include weekly measurements of chlorophyll *a*, pH, and dissolved oxygen. Fish stomach content analysis was performed on at least four fish from each pond.

Results

This experiment terminates on about 20 November 1988. Initial results indicate that the use of in-pond compost will result in greater fish production. Low levels of green and bluegreen algae and increased presence of protozoans and other consumers may indicate that heterotrophy is enhanced by this treatment.

Anticipated Benefits

This experiment is designed to provide a basis for selecting the most advantageous composting process and ratio of plant to animal material. Greater understanding of the processes involved can lead to effective use of scarce organic resources as fertilizing inputs for relatively cool, high altitude equatorial environments.

Characterization of compost processes

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Introduction and Objectives

The response of the pond community to the use of plant and animal wastes as sources of energy and nutrients depends on both the level of input and the quantity and chemical form of the substances used. In less developed countries, composted organic matter can provide a sustainable source of fertilizing inputs. Whether such material is composted in aerobic or anaerobic conditions or added directly to the pond to decompose in a low-oxygen, underwater environment will affect the physico-chemical characteristics of the input materials. This experiment is designed to determine how these characteristics differ through time for organic matter decomposed by the three processes. An additional objective is to characterize these composts for four ratios of manure:plant matter.

Materials and Methods

Three composting techniques were used. These were: aerobic (AB), anaerobic (AN), and in-pond (IN). One cubic meter piles were mixed to achieve four ratios of green grass:manure. The percent composition of grass was 50, 80, 90, and 100 percent by weight, any remainder being chicken manure. For AB compost, the piles were perforated with bamboo pipes and turned every two weeks to facilitate oxygen transfer. A similar amount of material was placed in earthen pits and covered with plastic and soil to limit oxygen for the AN compost. The raw materials for the IN treatment were submerged within a bamboo enclosure and turned daily.

The experiment ran for 12 weeks (14 weeks for AN compost). Treatments were triplicated. Samples were taken at the start of the experiment and at 14-day intervals. Samples were analyzed for kjeldahl-N, organic carbon, potassium, COD, BOD loss on ignition, and phosphorus. Additional measurements at the end of the composting process were made for sodium, magnesium, calcium, and nitrate.

Results

Anaerobic composting in the cool Rwandan environment is like anaerobic storage with only a small amount of fermentation occurring over a 100-day period. Organic carbon remained at about 40% by weight, kjeldahl-N remained at 2.2-2.7%. The carbon:nitrogen ratio was 18:20. Aerobic compost changed characteristics with time but very little with mixture. Carbon dropped from 40 to 22% over this period. The carbon:nitrogen ratio dropped from 16 to 6.6. In-pond compost changed rapidly with time. Carbon dropped from 40 to 24% over 12 weeks. Kjeldahl-N went from 2.6 to 1.2% then up to 1.6%. Phosphorus remained about 0.03-0.06%. The carbon:nitrogen ratio increased from 16:1 to 27:1 and then decreased to 16:1, perhaps due to bacterial colonization.

Anticipated Benefits

Characterization of organic materials composted by different processes provides a basis for understanding the differential response of ponds to different composts. Additionally, knowledge of the time course of chemical changes during composting and the final compost quality, will facilitate development of optimized methods for using scarce resources as fertilizers.

Southeast Asia

Thailand

The effect of stocking density of *Oreochromis niloticus* on the dynamics of aquaculture ponds

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Introduction

Fish may have complex interactions with their ecosystem. This is particularly true in aquaculture ponds, where water volume is low and fish biomass is high. Fish may influence physical factors, such as mixing and stratification; chemical factors, such as nitrogen or phosphorus availability; biological factors, such as species composition of zooplankton; and yield, by competition for food and space. Control of aquatic systems may occur by nutrient availability, by fish predation pressure, or by a combination of these effects. The purpose of this study was to document the effects of fish stocking density and biomass on the physical, chemical, and biological dynamics of aquaculture ponds.

Materials and Methods

Earthen ponds, 220 m^2 in surface area, were stocked with *Oreochromis niloticus* at 0, 1, 2, and 3 fish per m^2. Fry were manually sorted by sex prior to stocking, and only males were used. Three replicate ponds were run at each density. The ponds were fertilized with chicken manure at 500 kg/ha/wk. Physical, chemical, and biological sampling was conducted according to the standard CRSP protocol (CRSP Fourth Work Plan, 1987). Ponds were stocked on 2 February 1987 and harvested on 1 July 1987.

Results

Ponds without fish developed very dense zooplankton populations. However, there were no significant differences in zooplankton abundance among the three fish density (1, 2, or 3 fish/m^2) treatments. There also were no significant differences in primary production or chlorophyll *a* concentration between all four treatments. Secchi disk depth differed significantly with the presence or absence of fish, probably due to increased turbidity caused by fish activity. Total inorganic nitrogen and total phosphorus did not differ significantly among treatments.

Fish growth rate was inversely proportional to stocking density (Figure 1), indicating strong density dependence in growth. Although monosex culture was attempted, substantial reproduction occurred. The biomass of young produced also was inversely proportional to stocking density (Figure 2). Total yield of adults was similar for all three treatments (Figure 3), indicating that adult carrying capacity was reached. However, total yield of young and adult tilapia was inversely correlated to density (Figure 4).

Anticipated Benefits

Knowledge of pond carrying capacity is central to aquaculture production. In this experiment, increased stocking density did not increase yield, due to density dependent growth. Carrying capacity of adults was remarkably consistent among treatments.

The results of this experiment were confounded by differential production of young tilapia between treatments. Since young and adult tilapia may compete for resources, we plan to replicate this experiment using sex reversed fish for stocking. This will remove the interference of differential reproduction among treatments, and will more truly test density dependence of adults.

The trophic cascade hypothesis holds that aquatic communities are regulated by top-down processes, where fish consumption reduces prey abundance, which increases the abundance of the next trophic level, and alternately cascades through the ecosystem (Carpenter et al. 1985). The trophic cascade hypothesis is not supported by our aquaculture data. Presence or absence of fish (not biomass) did correlate with zooplankton abundance, but this effect did not cascade to other trophic levels. Increases in fish abundance did not result in changes in ecosystem function.

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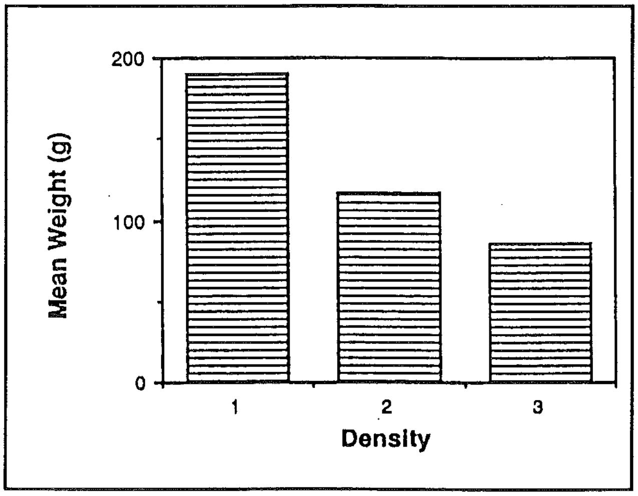

Figure 1. Growth of adult tilapia, as indicated by final mean weight, for each density treatment.

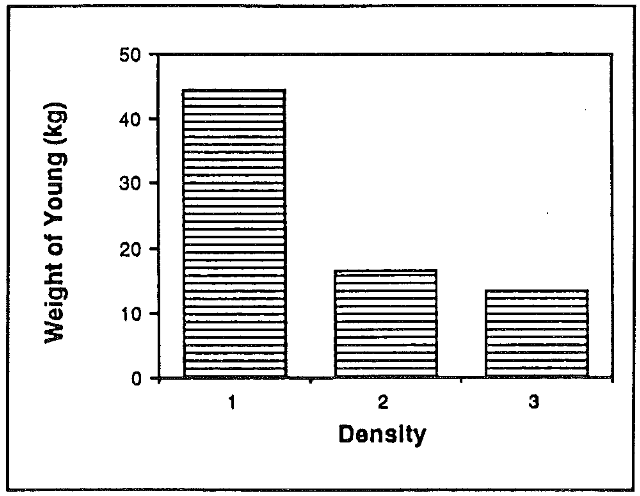

Figure 2. Total weight of young tilapia produced for each density treatment.

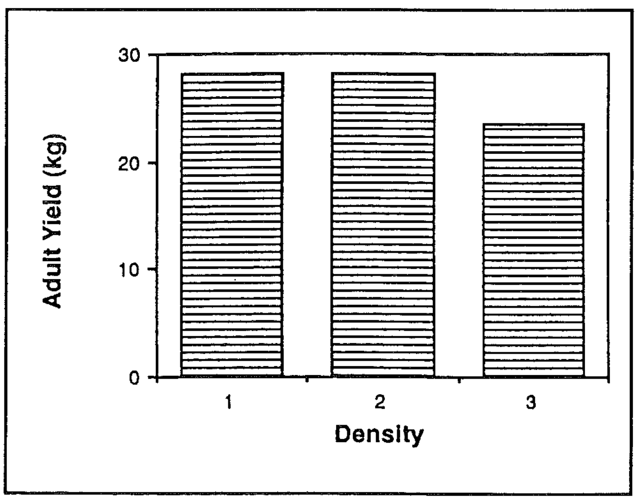

Figure 3. Yield of adult tilapia produced for each density treatment.

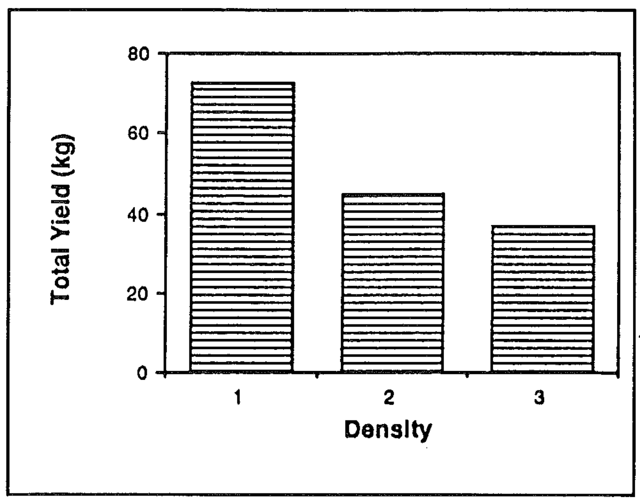

Figure 4. Total yield of adult and young tilapia for each density treatment.

Managing fertilizers for fish yield in tropical ponds in Asia

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Abstract

The purpose of this work was to develop a strategy for fertilizer application to improve predictions of yields. Pond productivity was analyzed relative to supplies of dissolved inorganic carbon (DIC), dissolved inorganic nitrogen, and dissolved reactive phosphorus. Phosphorus did not limit pond production in any of the treatments used. Algal productivity and yield of male Nile tilapia (*Oreochromis niloticus* Trewavas) were limited by DIC when low alkalinity ponds were fertilized with chicken manure or triple superphosphate and urea. In high alkalinity ponds with adequate DIC, nitrogen limited production when chicken manure was added.

Nitrogen limitation with adequate DIC present was demonstrated in the following experiment. In the first treatment, chicken manure was added at 500 kg/ha/wk. In the second treatment, chicken manure and urea were added at 44 kg/ha/wk and 25 kg/ha/wk, respectively. The experimental design provided for the same amount of nitrogen in both treatments. Also, the ratio of phosphorus to nitrogen in fertilizers was made 1:7 by weight in order to avoid phosphorus limitation. Our prediction that mean net algal productivities and fish yields would be the same for these treatments was verified by the data. Fertilizer costs per kg of yield were US$0.07 for the chicken manure treatment, and US$0.06 for the chicken manure + urea treatment. Guidelines for developing fertilizer applications that result in predictable yields of fish can be taken from this work.

Introduction

Modern variations of the ancient practice of fertilizing ponds to increase the yield of fish have been considered by Schroeder (1974), Almazan and Boyd (1978), Stickney (1979), Seymour (1980), and others. A significant portion of increased fish yield following the successful use of fertilizer is generally due to the growth of algae, and the transformation of algae to fish flesh through food webs of ponds. Some 19 elements are known to be required by organisms at the base of aquatic food webs (Wetzel 1983). Among these, phosphorus and nitrogen have received the greatest attention relative to the use of fertilizers to promote fish yields (Boyd 1982). However, there is considerable inconsistency in yields obtained using phosphorus and/or nitrogen fertilizers. McNabb *et al.* (1988) suggest that growth limitation on algae due to shortages of dissolved inorganic carbon may be one cause of inconsistent results obtained from site to site with the same loading rates of these nutrients.

The purpose of this experiment was to improve the predictability of fish yields obtained with fertilizers. We examined the relationships between carbon, phosphorus, nitrogen, and algal, growth in fertilized ponds, and algal growth and yield of *Oreochromis niloticus*. Experiments were conducted at the Babakan Fisheries Station of Institute Pertanian Bogor in Indonesia (6.6°S, 106.1°E) and the Bang Sai Station of the Royal Thai Department of Fisheries near Ayutthaya in Thailand (14.2°N, 100.5°E).

Three sets of data are presented. Treatments in the first two sets were not conducted simultaneously. They were selected from experiments conducted with fertilizers between 1985 and 1988 in the relatively constant year-round environment of the wet tropics (McNabb *et al.* 1988). Treatments in the third set of data were conducted simultaneously as part of the same experiment in 1988. The requirements of algae for carbon, phosphorus, and nitrogen in an approximate ratio of 1:7:40 by weight (Round 1973, Vallentyne 1974, Wetzel 1983) was an underlying principal in our work. Our approach to obtaining predictable fish yields was to manage algal productivity, and presumably, abundance in the overall food web of fish, by using fertilizers to meet the requirements of that ratio.

Materials and Methods

The first set of data was examined for evidence of poor phosphorus and nitrogen utilization in fertilized ponds where inorganic carbon was low and potentially limiting the growth of algae. The work was conducted at the Babakan Fisheries Station. Ponds had a surface area of 0.020 ha and were maintained at depths close to 0.9 m. Makeup water was added as required to compensate for net losses due to rainfall, evaporation, and seepage (McNabb *et al.* 1988). Egna *et al.* (1987) describe physical features of the ponds and general chemical characteristics of water used to fill them.

There were three fertilizer treatments in the first set of data. Three ponds were used in each treatment. Chicken manure was added at a rate of 125 kg/ha/wk in one treatment, and 250 kg/ha/wk in another. In the third treatment, triple superphosphate and urea were added at rates of phosphorus and nitrogen that were equivalent to the addition of 500 kg chicken manure/ha/wk. Chicken manure averaged 2.5% phosphorus and 1.7% nitrogen by dry weight. *Oreochromis niloticus* fingerlings, weighing between 40 and 50g each, were sorted by sex. Males were selected and planted at a density of one fish per m^2 of pond surface. Grow-out periods were between 147 and 149 days.

Measurements of algal productivity and amounts of inorganic carbon, dissolved reactive phosphorus, and dissolved inorganic nitrogen (NH_3-N + NO_2-N + NO_3-N) were made in ponds at the beginning of treatments and every four weeks thereafter. Net algal productivity was obtained from the difference in dissolved inorganic carbon (DIC) present at dawn and at dusk (Vollenweider 1974). Measurements of alkalinity, pH, and temperature were used to calculate DIC after the work of Harvey (1955) and Park (1969). DIC at dawn was used as a measure of carbon that would be available for photosynthesis during the following day. Egna *et al.* (1987) describe procedures that were used to collect water samples and make the chemical analyses. The adequacy of supplies of phosphorus and nitrogen in ponds relative to requirements of growing algae was analyzed by the procedures of Md. Yusoff and McNabb (in press). Ponds were drained at the end of grow-out periods, and fish were collected and weighed to provide data on yields.

The second set of data was examined for potential limitations of carbon, phosphorus, and nitrogen on algal growth where ponds were fertilized at the same rates with phosphorus and nitrogen. DIC at dawn was the independent variable in a total of five treatments. Treatments varied in length from four to five months. Ponds were fertilized with chicken manure at a rate of 500 kg/ha/wk, or an equivalent mass of phosphorus and nitrogen as triple superphosphate + urea. In each case, phosphorus and nitrogen were added to ponds at rates of 12.5 and 8.5 kg/ha/wk, respectively. Three ponds were used in each treatment. Ponds in four treatments with low mean DIC at dawn (5 to 11 g C/m^2 and mean alkalinities ranging from 21 to 54 mg $CaCO_3/L$) were located at the Babakan Fisheries Station in Indonesia. Ponds in the fifth treatment had high mean DIC at dawn (29 g C/m^2 and alkalinity of 124 mg $CaCO_3/L$). These were located at the Bang Sai Fisheries Station in Thailand. Ponds in Thailand had a surface area of 0.022 ha and were maintained at a depth of 0.9 m. Egna *et al.* (1987) describe features of these ponds. Sampling procedures, parameters measured in ponds, and methods used for analyses were the same as those described above.

The third set of data examined the question of fertilizer loading rates needed to obtain predictable fish yields from productivity of algae and food web organisms in ponds where DIC was high and not limiting to algae. The work was done at Bang Sai. Pond size, operating depth, types of measurements, and procedures for obtaining data were as described above. Four ponds were used in each of two treatments. In the first treatment, chicken manure was applied at a rate of 500 kg/ha/wk. The chicken manure consisted of 4.1% phosphorus and 2.5% nitrogen by dry weight. In the second treatment, chicken manure was applied at a rate of 44 kg/ha/wk, and urea was added at 25 kg/ha/wk. Nitrogen in the chicken manure + urea equaled the nitrogen in 500 kg/ha/wk of chicken manure that was applied in the first treatment. Also, the amount of phosphorus in the chicken manure in the second treatment was such that the P:N ratio in fertilizers for that treatment was 1:7 by weight. *Oreochromis niloticus* males were planted at a density of two per m^2. A grow-out period of 124 days was used. A detailed economic assessment of these treatments was made and includes costs of labor and materials as well as value of the fish crops in the local market (Hanson and Chuenpagdee in preparation). In this paper, treatments were compared in terms of fertilizer costs per unit weight of fish harvested.

Results

The first set of data is summarized in Table 1. Each of the three treatments resulted in low algal productivity (0.70-0.86 g $C/m^2/day$) and low fish harvest (780-990 kg/ha in five months). DIC at dawn also was low, ranging from 5 to 6 g C/m^2 (alkalinity 21-28 mg $CaCO_3/L$). The nutrient analysis showed that greater amounts of both phosphorus and nitrogen were present on the average in ponds than were required to meet the daily net production needs of the algae. This result suggests that neither phosphorus nor nitrogen were limiting. The data suggest that inorganic carbon, some other nutrient, or perhaps light was limiting algae and subsequent fish production in these treatments.

A summary of the second set of data is presented in Table 2. Ponds at five different levels of DIC were fertilized at the same rates with phosphorus and nitrogen. For reference, mean alkalinities were 21, 26, 33, 54, and 124 mg $CaCO_3/L$ in treatments I through V, respectively. Net algal productivity increased with increasing DIC. Phosphorus relationships given in the table show that phosphorus was always abundant in ponds relative to algal requirements for growth. Nitrogen was also abundant in treatments I and II, but was present in an amount close to the average daily requirement of algae in treatment III, and was in short supply relative to algae requirements in treatments IV and V. In the latter treatments, daily algal requirements for nitrogen were 2 to 4 times higher than amounts of nitrogen available in ponds.

The relationship between net algal productivity and DIC at dawn in individual ponds used in treatments I through V of Table 2 is shown in Figure 1. It is evident that algal productivity increased linearly as DIC increased at low concentrations between about 5 and 7 g/m^2 (alkalinities between 20 and 33 mg $CaCO_3/L$). Phosphorus and nitrogen abundances in treatments I, II, and III (Table 2), and the steep linear increase in algal productivity with increasing DIC in treatments I, II, and III (Figure 1), suggest that algal productivity was limited by inorganic carbon at low concentrations of DIC. It is also clear that algal productivity tended toward an asymptote at concentrations of DIC above 7 g/m^2. Table 2 shows that nitrogen was in very short supply in treatments in this portion of the curve (treatments IV and V). We concluded that algae in ponds in treatments IV and V were limited by nitrogen.

Table 3 contains data from an experiment designed to test this conclusion. Four ponds with high DIC (25-29 g/m^2, alkalinities of 105 and 124 mg $CaCO_3/L$) were used in each of two treatments. Chicken manure was applied at a rate of 500 kg/ha/wk in the first treatment. The nitrogen in the chicken manure was matched in the second treatment by weekly additions of 44 kg/ha chicken manure plus a urea supplement. This fertilization scheme also resulted in a 1:7 ratio of P:N in the fertilizers added in the second treatment. Given that nitrogen was indeed limiting in these ponds at rates of chicken manure addition of 500 kg/ha/wk as previously suggested, we predicted that algal productivity and subsequent fish yield would be the same in both treatments. Data in Table 3 confirmed that this prediction was true in cases where mean algal productivities and fish harvest were not significantly different between treatments: $p = 0.35$ for productivities and 0.54 for fish harvests. It can also be noted in Table 3 that phosphorus and nitrogen in ponds in the second treatment were closely balanced, on the average, with needs of algae for growth. Fertilizer costs per kg of fish yield were found to be nearly the same for the two treatments: US$0.07 and US$0.06 in the first and second treatments, respectively.

Discussion

Daily requirements of phosphorus and nitrogen for algae were calculated in this paper from daily net primary productivity and a reported 1:7 ratio of these nutrients needed for growth (Round 1973, Vallentyne 1974, Wetzel 1983). Mean concentrations of dissolved reactive phosphorus and dissolved inorganic nitrogen in ponds were then compared to daily algal requirements to discriminate between conditions of abundance and nutrient limitation. This approach used those forms of both nutrients that are most readily taken up by algae from the pool of total phosphorus and total nitrogen present in ponds (Goldman and Horne 1983). Md. Yusoff and McNabb (in press) used algal bioassays in conjunction with this procedure. Algal productivity was not limited in their ponds when required amounts of these nutrients were approximately equal to or greater than amounts present. Algal productivity was limited when concentrations of dissolved reactive phosphorus and dissolved inorganic nitrogen were at least four to six times less than daily requirements. Therefore, we concluded that phosphorus was not limiting in any of our treatments.

A non-limiting supply of nitrogen, as well as phosphorus, was present on the average in ponds that we used for the first set of data (Table 1). However, net algal productivities and fish yields were lower than expected for well-managed ponds. They ranged from 0.70-0.86 g C/m^2/day and 780-990 kg/ha with 148-day grow-out periods, respectively. For comparison, Hepher (1962) reported net algal productivity on the order of 2.9 g C/m^2/day during warm summer months in Israel when pond temperatures were similar to temperatures of ponds used here (30°C). DeMaeseneer (1984) cites production of 2000 kg/ha/yr for tilapia in tropical subsistence ponds. Productivity in ponds in Indonesia used for Table 1 appeared to be limited by some factor other than the phosphorus or nitrogen supplied in fertilizers.

McNabb *et al.* (1988) assessed whether light is a limiting factor under conditions of frequent and dense cloud cover that occurs throughout the year at Babakan Station in Indonesia. Their assessment was based on areal photosynthetic efficiencies (PE = energy photosynthetically stored in primary producers per m^2/ light energy per m^2 at the surface). They concluded that adequate light existed in ponds for net algal productivity to occur at least twice as fast as rates given in Table 1. Their work suggests that some factor other than light limited productivity in those ponds.

There is strong inference in the first data set that inadequate supplies of dissolved inorganic carbon limited pond production. In fact, carbon limitation appears to have occurred in all cases where chicken manure (2.5% phosphorus and 1.7% nitrogen), or equivalent amounts of phosphorus and nitrogen as triple superphosphate and urea, was applied at 500 kg/ha/wk or less to ponds with dissolved inorganic carbon in the range 5 to 7 g/m^2 at dawn (alkalinities 20-33 mg $CaCO_3$/L). Convincing evidence came from treatments I, II, and III in the second set of data. At the same loading rate of chicken manure, and phosphorus and nitrogen contained therein, net algal productivity increased in a rapid, linear fashion as DIC increased from 5 to 7 g/m^2. The work of King (1970, 1972), King and Novak (1974), and Young and King (1980) predicts such a result in low alkalinity ponds where, as we have demonstrated, phosphorus and nitrogen were not limiting.

Manures, chicken manure included, are deficient in nitrogen relative to the phosphorus requirements algae have for these nutrients (Boyd 1982, Wetzel 1983). Our work shows that addition of chicken manure to ponds with adequate dissolved inorganic carbon will promote nitrogen deficiency because of this imbalance (Table 2 and Figure 1). Other manures are expected to cause the same problem. On the other hand, nitrogen in these fertilizers will likely promote carbon limitation in ponds with inadequate DIC. Thus, the quantity of DIC in ponds has the potential to profoundly influence growth responses of algae, food web organisms, and fish when manures are used. Data presented show that the same results are expected from triple superphosphate and urea used in proportions found in manures.

Results of the experiment in our third data set demonstrate the increased biological efficiency obtained by supplying phosphorus and nitrogen in fertilizers in a ratio appropriate for growth of organisms at the base of pond food webs. From our analysis of fertilizer costs, doing so was economical. Mean fish yield in the experiment was 1435 kg/ha using 44 kg/ha/wk chicken manure plus 25 kg/ha/wk urea. The grow-out period was 124 days using fingerlings averaging 20 g each at $2/m^2$. We predict higher yields using the same proportions of these fertilizers at higher loading rates. Clearly, data presented show that assessments of carbon, phosphorus, and nitrogen are all required to improve the level of predictability of results obtained from fertilizer applications. Reduction of inconsistencies associated with fertilizer use will result from this approach.

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Table 1. Productivity and nutrients in fertilized ponds that had low amounts of dissolved inorganic carbon (DIC). Net algal productivity (NP) is for the daylight period.

Treatment	NP (g C/m^2/day)	Fish Harvest[1] (kg/ha)	TIC at Dawn (g C/m^2)	Nutrient Analysis[2]			
				Required (g P/m^2)	Present (g P/m^2)	Required (g N/m^2)	Present (g N/m^2)
Chicken Manure (125 kg/ha/wk)	0.82	780	5	0.02	0.07	0.14	0.19
Chicken Manure (250 kg/ha/wk)	0.86	990	6	0.02	0.11	0.15	0.21
TSP and Urea at Phosphorus and Nitrogen Levels Equal to 500 kg/ha/wk Chicken Manure	0.70	890	5	0.02	0.15	0.12	0.51

[1] 45 g fingerlings stocked at 1/m^2 with growout periods of 147-149 days.

[2] Phosphorus (P) and nitrogen (N) required is based on NP g C/m^2 /day and a P:N:C requirement of 1:7:40 by weight for normal growth. P and N present are mean concentrations of dissolved reactive phosphorus and dissolved inorganic nitrogen in pond water, respectively.

Table 2. Nutrient relationships with increasing dissolved inorganic carbon (DIC) in ponds fertilized at a rate of 500 kg/ha/wk chicken manure. Net algal productivity (NP) is for the daylight period.

Treatment Number	DIC at Dawn (g C/m^2)	NP (g C/m^2/day)	P and N Relationships[1]			
			Required (g P/m^2)	Present (g P/m^2)	Required (g N/m^2)	Present (g N/m^2)
I[2]	5	0.70	0.02	0.15	0.12	0.51
II	6	1.03	0.03	0.15	0.18	0.39
III	7	1.29	0.03	0.33	0.23	0.15
IV	11	1.42	0.04	0.32	0.25	0.09
V	29	1.84	0.05	0.21	0.32	0.13

1 Amounts of phosphorus (P) and nitrogen (N) required and present calculated as in Table 1.
2 Treatments other than this received chicken manure (2.5% P and 1.7% N by dry weight) at 500 kg/ha/wk. Ponds in this treatment received triple superphosphate and urea each week at amounts of P and N equivalent to the chicken manure treatments.

Table 3. Influence of nitrogen on productivity in fertilized ponds that had high amounts of dissolved inorganic carbon (DIC). Net algal productivity (NP) is for the daylight period.

Treatment	DIC at Dawn (g C/m^2)	Nutrient Loading P (kg/ha/wk)	Nutrient Loading N (kg/ha/wk)	NP (g C/m^2/day)	P and N Relationships[2]			
					Required (g P/m^2)	Present (g P/m^2)	Required (g N/m^2)	Present (g N/m^2)
Chicken Manure (500 kg/ha/wk) (P:N at 1:0.6)	29	21	12	1.84	1205	0.19	0.32	0.12
Chicken Manure (44 kg/ha/wk)	25	1.7	1	2.27	1435	0.03	0.40	0.41
+ Urea (25 kg/ha/wk) (P:N at 1:7)			11					

1 20 g fingerlings stocked at 2/m^2 with a growout period of 124 days.
2 Amounts of phosphorus (P) and nitrogen (N) required and present calculated as in Table 1.

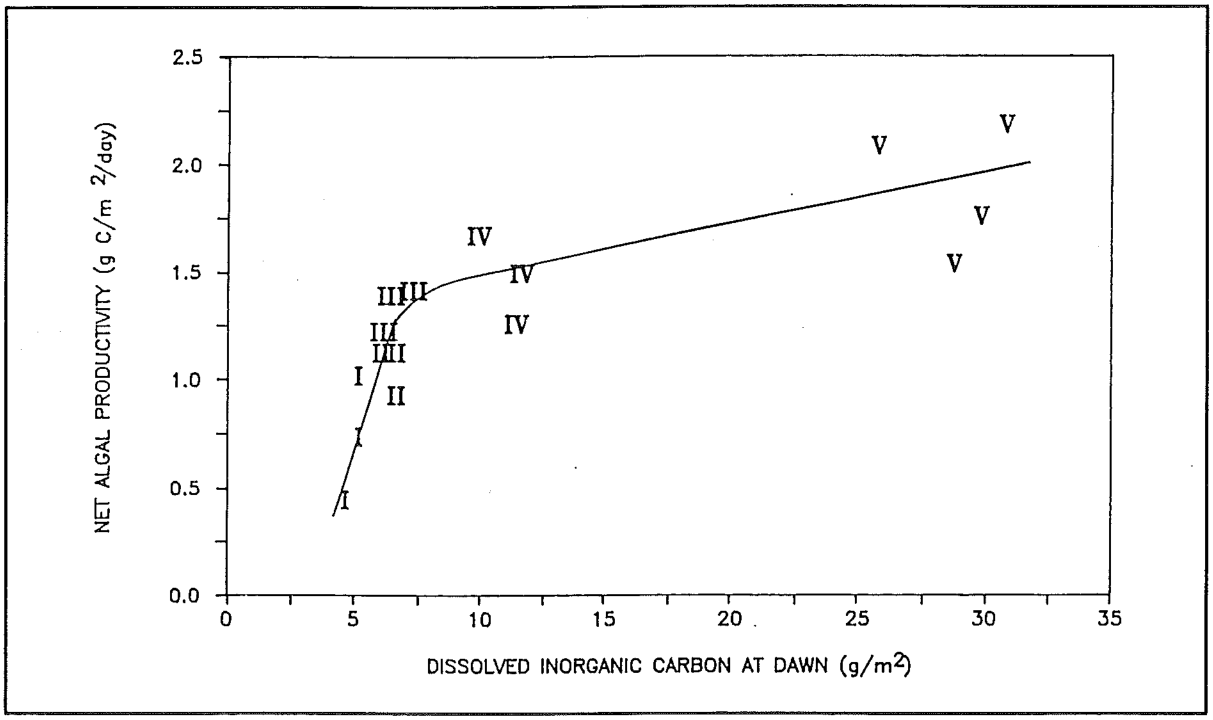

Figure 1. Relationship between inorganic carbon and net algal productivity in ponds loaded at a rate of 500 kg/ha/wk chicken manure. Roman numerals designate means for individual ponds used in treatments listed in Table 1.

UNITED STATES RESEARCH COMPONENT OF THE GLOBAL EXPERIMENT

Introduction

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

A U.S. research component was organized during the third year of the CRSP. Several projects have been funded and were successfully completed in 1987. These projects studied timely research problems that could not be addressed in the overseas component. Consequently, the projects help to strengthen the overall effectiveness of the CRSP.

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

The Special Topics Research Studies described above are only one part of the U.S. Research Component. The overall success of the CRSP depends heavily on the management, analysis, and modeling of data collected from the seven overseas CRSP sites. The comprehensive analysis of the global data base 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.

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 computerized analysis of the data a necessity.

A major focus of the CRSP is on the analysis and synthesis of data collected at seven overseas locations during the Global Experiment. The Data Analysis and Synthesis Team was established in September 1985 to provide comprehensive, global interpretations of the CRSP Central Data Base. The Data Analysis and Synthesis Team's activities are decentralized; members of the Team operate from offices at the University of California at Davis, the University of Michigan, and Oregon State University. Through their involvement on the Technical Committee, members of the Data Analysis and Synthesis Team interact with scientists from the field-based research component of the global experiment. The Data Analysis and Synthesis Team works in concert with the Data Base Manager to translate and verify the large amount of data that have been compiled into the CRSP Central Data Base.

An important accomplishment that occurred during this reporting period was the completion of the Central Data Base. Complete and verified data sets from all sites are available to members of the Data Analysis and Synthesis Team and to other participants.

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.

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 then are 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 that were developed by the Data Base Manager and approved by the Technical Committee.) Verified files are entered in the Central Data Base for use by the Data Analysis and Synthesis Team. Specific data sets may be retrieved from the mainframe 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.

The Data Analysis and Synthesis Team also performed statistical analyses on the data. A few significant relationships were revealed. These relationships were constructed with the partial data base and do not necessarily provide a general relationship for all research sites. The results do, however, show the existence of possible statistical relationships in the data. Significant differences ($P<0.05$) were found between chlorophyll *a*, and total nitrogen, pH, alkalinity, and Secchi disk depth. No statistical difference was found between chlorophyll *a* and phosphorus. These results may indicate that phosphorus is not a limiting nutrient for phytoplankton growth in the ponds for which data were analyzed. Nitrate and total nitrogen, however, may be more important than is generally assumed for algal growth in fish ponds. 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 modes, such as difficulty of use, incompatibility between computers, and oversimplification 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 computer models. The models are designed to utilize the data collected at weekly or biweekly intervals to calculate oxygen production and consumption. One of the models is programmed in FORTRAN and is based on a generalized model of pond ecosystems (Figure 1). Another is designed to be "user friendly." It is programmed with a dynamic modeling language (STELLA™) on a microcomputer and simulates dissolved oxygen. The models are being used to study the factors that affect the dissolved oxygen cycles and how these factors change between sites in response to varying management practices or treatment effects (Figure 2).

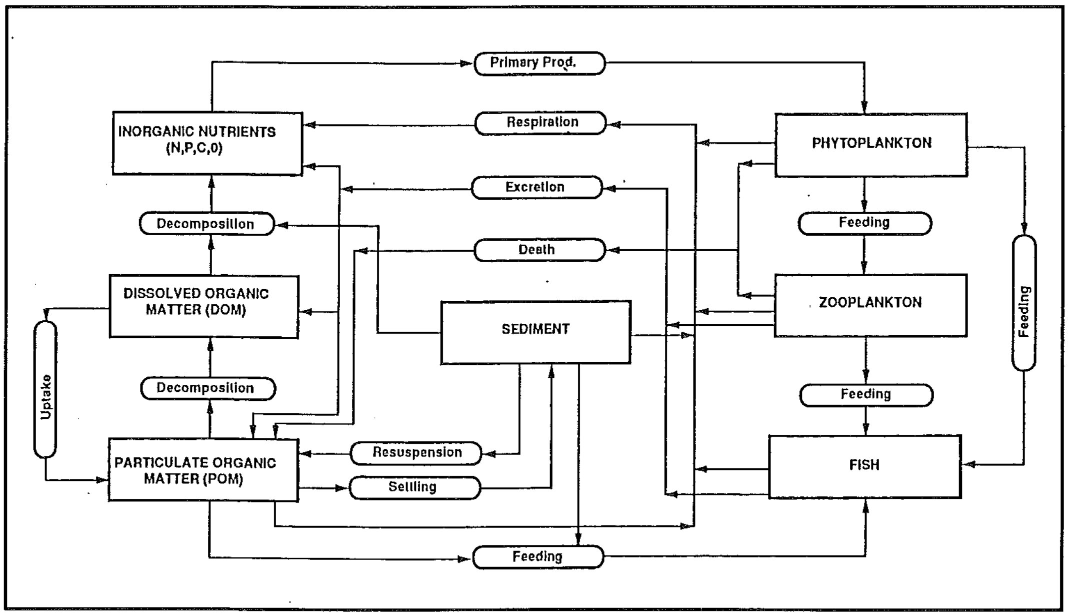

Figure 1. CRSP conceptual model of an aquaculture pond. The arrows connecting the model's components represent the paths for movement of mass in the system. The system includes both biological and non-biological components. The strictly biological components are phytoplankton, zooplankton, and fish,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

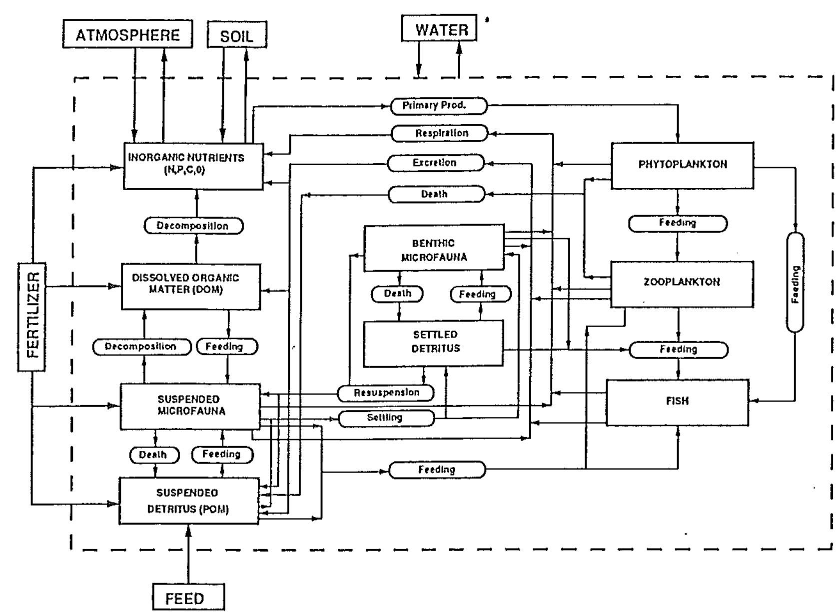

Figure 2. Recent iteration of the earlier CRSP conceptual model.

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

Summary of Activities

Data Analysis and Synthesis Team

William B. Chang (Great Lakes Research Division, The University of Michigan, Ann Arbor)
J. E. Lannan (Hatfield Marine Science Center, Oregon State University, Newport)
Raul H. Piedrahita (Department of Agricultural Engineering/Aquaculture and Fisheries Program, University of California, Davis)

Work by the members of the Data Analysis and Synthesis Team (DAST) is progressing along three complementary lines. Each of the three members of the Team is primarily responsible for one area of activity, providing an integrated approach to the task of processing data and producing useful guidelines for pond aquaculture. The tasks are:

1. Statistical analyses of the data (Chang).
2. Mechanistic modeling of short-term dissolved oxygen cycles (Piedrahita).
3. Pond classification techniques and information dissemination (Lannan).

The goal of carrying out statistical analyses of the global data is to identify significant relationships between fish growth and pond management activities or water quality parameters. Fish growth is the ultimate measure of success in an aquaculture operation. Information obtained from this analysis will be used in the design of management strategies and in obtaining production estimates.

Mechanistic models of short-term dissolved oxygen cycles provide critical information on the nature of the processes controlling the primary limiting factor in pond culture, dissolved oxygen. The model is general in nature, and data from the various CRSP sites are being used to calibrate it. Model results will be used to propose short-term and long-term management strategies to prevent dissolved oxygen depletion in ponds.

Pond classification based on climatic, soil, and water quality characteristics provides a useful mechanism for designing appropriate management guidelines. Distinct pond groupings have been identified that have fundamental characteristics that determine their response to environmental parameters and management actions. This classification will provide the basic structure for disseminating pond management guidelines. Each of the three tasks is reviewed in detail below.

Fish Production: Data Synthesis and Model Development

W B. Chang (Center for Great Lakes and Aquatic Sciences, The University of Michigan)

Introduction

Fish yield from ponds is strongly dependent on the growth rate and the number of fish stocked in a pond. The number of fish stocked is especially important as it affects natural food availability and the efficiency with which food and feed resources are utilized in ponds. In general, production increases as more fish are stocked in a pond. Maximum yield per unit generally is attained at some optimal stocking density in a pond when sufficient natural food production can be provided and when environmental factors are not limiting. If stocking density is too low, food resources are not fully utilized and yield is low. When stocking density is too high, the carrying capacity may be exceeded and yield may be reduced.

In this analysis, we have focused on fish growth. The rate of fish growth is directly related to the availability of an appropriate quality and quantity of food in the water and is influenced by environmental factors such as temperature, wind, solar energy, and dissolved oxygen concentration. When environmental factors are not limiting, the optimal stocking rate for achieving the highest possible growth will depend on the quality and quantity of available food. If no supplementary feed is added to a pond, the relationship between fish growth rate and food availability depends entirely on natural food production. In order to understand and to model the dynamics of pond fish growth, quantitative relationships must be established between growth and environmental parameters. Data available from the CRSP Global Experiment allow examination of the rates and patterns of fish growth for different locations in the tropics, and for different levels of enrichment and environmental conditions. These analyses used data from the first three cycles of the Global Experiment. Maximum growth capacity is an important measurement for estimating potential fish yield from a pond environment. Therefore, both the maximum growth capacity and average growth rates for different sites were determined. These growth rates were then examined to see whether they are affected by levels of enrichment, different geographical locations, and physical conditions. This information is critical for providing baseline ecological relationships and frameworks used in constructing fish production models.

Objectives

The objectives for the research conducted between September 1, 1987 and August 31, 1988 are listed below:

1) To establish a complete CRSP Central Data Base for Cycles I, II, and III;
2) To synthesize the CRSP data using statistical methods;
3) To test the H_0 hypotheses for Cycles I, II, and III of the CRSP experiments; and
4) To develop a statistical model for fish production, based on a conceptual framework that uses the CRSP Central Data Base.

Methods

The methods used in this study can be grouped under the following major steps: data compilation, data base management, numerical data analyses, and statistical analyses. Some data were compiled in 1985, but most of the data compilation began in 1987 and 1988. The complete set of data on the CRSP Global Experiment is available from the CRSP Data Management Office at Oregon State University. The CRSP Central Data Base includes information collected from six countries (Thailand, Philippines, Rwanda, Indonesia, Panama, and Honduras) and covers three cycles. Each cycle contains both dry and wet seasons and usually constitutes a year. The raw data in ASCII form were recompiled into a compatible data base format and were examined for their consistency and completeness. Portions of the data that were invalid or inconsistent are absent from the data base for each site and cycle. In the second cycle, fish data are available only from four sites. Table 1 shows the results of the data inventory analyses which indicate the available fish data from each site of the CRSP Global Experiment.

Before data analyses and modeling began, major efforts were dedicated to data restructuring, error checking, and estimations of missing values. While requirements for data restructuring and error checking are reduced as we progress, this stage still requires a lot of time. In addition, increasing effort has been devoted to the estimation of missing values, from the simplest estimation of non-reported weekly fish weights (which can be determined using the total population weights for a week divided by the number of fish sampled) to complex numerical estimations.

After each template was analyzed, it was checked for errors. Data errors were numerous, some due to the transfer of data using computers, others the result of incorrect tabulation of data or incorrect measurements. Corrections of the errors due to data transferral were made by electronic messages to the CRSP Data Management Office, which corrects the errors within a few days. We decided that the best way to deal with other types of data problems is to exclude the affected data from our data analysis. We found that the data from Cycle III are the most complete and consistent, whereas the data from Cycle I are the least consistent and the data from Cycle II are the least complete.

Microcomputers and mainframe computers were used to analyze the data. An IBM microcomputer with 10 MB of hard disk memory was used for standardizing the data, error checking, evaluation of data consistency, and computation of the daily growth rate from fish weight and length. In order to estimate daily fish growth rate, a separate computer program was needed for each site and cycle as a result of the differences in data reporting formats. Several statistical packages (MIDAS™, SAS™, and BMDP™) were used to examine the patterns of fish growth as affected by levels of enrichment and geographical locations and to analyze the relationship between growth rate and increases in weight.

Daily fish growth rates were estimated for all fish data using the equations listed below:

$$W1 = Wt - Wo / \Delta t \quad (1)$$

$$W2 = Wt2 - Wt1 / \Delta t \quad (2)$$

$$L1 = Lt - Lo / \Delta t \quad (3)$$

$$L2 = Lt2 - Lt1 / \Delta t \quad (4)$$

Where Wt represents the weight of fish sampled on the date t, W1 and W2 indicate the daily growth rate between the date of stocking and sampling and the daily growth rates between time intervals. Lt is the length of fish on the date t. L1 and L2 are the daily growth rates by length between the dates of stocking and sampling and the daily growth rate within a time interval. At the time the analyses were performed, data on fish length were incomplete; consequently, the estimates for daily growth rates based on fish length data represent limited conditions and are not as informative as those rates derived from fish weight. Our major effort, therefore, concentrated on growth rate by fish weight. In order to understand whether fish growth rate changes with age and weight, the relationships between fish growth rate and fish weight were explored using the equation below:

$$dW/dt = K W^{x} \quad (5)$$ or in its linear form

$$\log dw/dt = \log K + X \log W \quad (6)$$

The values of K and X were determined for each site, cycle, and season. Maximum growth capacities were computed for each site using k values estimated from Equation 6 and the closest vertex to the Y-axis of the data cluster.

As enrichment conditions in ponds change, the fish length-weight relationship changes. This relationship also is affected by the age and species of fish. Changes in the length-weight relationship can be examined using Fulton's condition factor, Kw. We determined the condition factor from the CRSP data to understand changes in growth patterns. The equation used for this analysis is shown as Equation 7.

$$Kw = W * 10^2/L^3 \quad (7)$$

Results and Discussion

The patterns and rates of fish growth were examined using the data collected from the CRSP Global Experiment. An average daily upper limit of 2 g in weight gain for tilapia was found at all research sites. The daily rates of growth were lowest in the ponds in Rwanda (averaging 0.3 g, while the fastest daily gains were from Thailand -- about 1.1 g). Daily gain in fish weight from four other research sites was found to be between 0.5 and 1 g per day. Table 2 shows average daily gain in fish weight, and mean fish weight and length for each CRSP site. Fish were larger on average in the ponds in Thailand than at other CRSP sites. The smallest average sizes were from Rwanda (Table 2). Relationships between daily gain in fish weight and size for all CRSP research sites for Cycles I, II, and III are shown in Figures 1, 2, and 3, respectively. The rate and variability of fish growth increased with fish size. Growth patterns were similar for all three cycles, except that Cycle I had the largest number of fish with a daily gain of less than 0.5 g and Cycle III had cases in which the daily gain exceeded 2 g.

Little information is available for evaluating the effects of seasonality on fish growth. The CRSP Central Data Base was used to examine these effects. Significant differences were found between fish growth during dry and wet seasons. The sites that showed significant differences in growth rates between seasons were Thailand, the Philippines, and Rwanda. Some inconsistencies were found in the Cycle III data from the Philippines; consequently, it was difficult to determine whether artificial factors caused the significant differences that were found. Daily fish growth rates were substantially higher during the dry period than the wet period in Thailand and Rwanda.

Earlier analyses performed by the CRSP indicated major differences in fish growth rates between the research sites. Further analyses were undertaken to examine whether there were major growth pattern differences for different cycles in each site and set of enrichment conditions. Statistical analyses revealed significant differences in growth rates between cycles for each site. The rate of growth was generally slowest in Cycle I and increased in the later cycles, but major increases in growth rate among the cycles were not constant. For example, growth rates from Cycle I were significantly different than those in Cycles II and III in Panama, Thailand, Honduras, and Rwanda. In Indonesia, however, growth rates from both Cycles I and II were significantly different from those in Cycle III (Table 3). The only site with a lower growth rate in the third cycle was the Philippines; however, the cause of this anomaly may be due to sampling errors.

In aquaculture environments, fish weight gain is found to be related to the availability of food, which in turn is strongly affected by enrichment conditions, such as supplemental food and fertilizer. Fertilization is commonly used to increase natural food availability and to provide additional organic matter for fish food. Rates of fish growth were found to be directly related to the amount of enrichment when ponds were low in nutrients. The effects of fertilization on fish growth were less noticeable in pond environments that were hypereutrophic.

Fertilization experiments were carried out in all three cycles of the CRSP Global Experiment. Analyses were conducted to examine the effects of enrichment on pond environments and fish production. Differences in the focus of each cycle's experiments were reflected in how the hypotheses from each cycle were tested. The first cycle examined the effects of the addition of inorganic fertilizers (PO_4). Since there were no control ponds (ponds without additions of nutrients) established in this cycle, a comparison of fertilization effects can not be made. Cycle II studied the relative effectiveness of adding organic and inorganic fertilizers, and Cycle III focused on the effects of different levels of inputs of organic fertilizers. In Cycle II, daily fish growth rates in ponds receiving organic fertilizers were significantly greater than in ponds receiving inorganic fertilizers, but the responses were not consistent from all sites. Some sites showed no significant difference between these treatments. In Cycle III, the addition of increased levels of organic fertilizers resulted in a corresponding increase in daily fish growth rate as shown in Table 4, where levels 1, 2, 3, and 4 correspond with 125, 250, 500, and 1000 kg/ha/wk of organic fertilizer, respectively. The average rates of fish growth increased from about 0.46 to 1.29 mg per day when the weekly additions of fertilizer were raised from 125 kg/ha to 1000 kg/ha. As the enrichment conditions in ponds change, fish length and weight relationships can also change. Fulton's condition factor was examined for fish from different treatments, but no significant differences were found among them. Changes in fish length-weight relationships as indicated by this factor were noted among fish cultured in different geographical areas.

Maximum physiological growth rate (Equation 6) is an optimal growth rate that is dependent on fish size. Values derived from the CRSP experimental sites were similar for all sites and were in a range from 0.58-0.74, except those from Rwanda, which were much lower (0.42) (Figures 4 to 9). Parker and Larkin (1959) indicated that most rates derived from Equation 6 for steelhead trout (*Oncorhynchus mykiss*) and chinook salmon (*Oncorhynchus kisutch*) were under 0.80 and generally between 0.50 and 0.83. Hepher (1978) suggested that when food is not a limiting factor, the maximum physiological growth rate as indicated by the regression coefficient of the growth-weight ratio is about 0.66 and is determined by an intrinsic physiological character, whereas the specific growth rate (Y intercept) is determined by the genetic characteristics of the fish and by the environment. Since, in theory, the same tilapia species were stocked in all CRSP research sites, the much lower values in growth rate for the Rwanda site could be due to limitations on food supply.

Research Plan for the Coming Year

(1) To continue statistical analyses based on the "top-down" model and to test the relationships that affect pond fish production.

(2) To develop a global, pond-fish production model based on the relationships derived from the CRSP data.

(3) To verify the fish production model and to expand this model for use in the examination of the relationships between the fish component and other parameters in pond ecosystems.

References Cited

Hepher, B. 1978. Ecological aspects of warm-water fishpond management. *In: Ecology of Freshwater Fish Production*, pp.447-468. Blackwell Scientific Publications.

Parker, R. R. and P. A. Larkin. 1959. A concept of growth in fishes. *J. Fish. Res. Bd.* Canada 16:721-745.

Table 1. Availability of Fish Data from CRSP Sites
XX indicates a complete data set
X shows an incomplete data set

Sites	Cycle I	Cycle II	Cycle III
Panama (Gualaca)	XX	No Data	XX
Thailand (Ayutthaya)	X	XX	XX
Indonesia	XX	XX	XX
Honduras	XX	XX	XX
Philippines	XX	XX	X
Rwanda	XX	No Data	XX

Table 2. The Average Fish Weight, Length, and Daily Gain for CRSP Sites

Sites	Average Wt	Average Length	Daily Gain (gm/day)
Panama	62.378 (45.600) n=212	15.807 (4.022) n=30	0.596 (0.594) n=157
Thailand	109.05 (75.817) n=216	17.009 (4.239) n=216	1.101 (0.689) n=180
Indonesia	80.831 (45.933) n=384	15.319 (2.424) n=116	0.482 (0.773) n=314
Honduras	88.876 (61.065) n=466	16.086 (3.988) n=463	0.854 (0.495) n=396
Philippines	91.888 (62.775) n=430	14.075 (0.956) n=24	0.865 (0.413) n=358
Rwanda	61.048 (28.232) n=197	14.301 (2.015) n=248	0.293 (0.221) n=208

Table 3. Comparisons Between Daily Growth Rates Between Cycles and Seasons for Different Sites (** = problem with the data),
/ indicates a statistical significance at 0.05 level
*** indicates a statistical significance at 0.01 level

Sites	Cycles	Seasons
Panama	1/3 (No cycle 2)	
Thailand	1/2,3	*** (Dry > Wet)
Indonesia	1,2/3	
Honduras	1/2,3	
Philippines	1,2/3**	
Rwanda	1/3 (No cycle 2)	*** (Dry > Wet)

Table 4. The Levels of Enrichment and the Corresponding Daily Gains in Fish Weights

Enrichment Levels (kg/wk/ha)	Average Daily Gains (gm/day)
125	0.469
250	0.705
500	0.817
1000	1.293

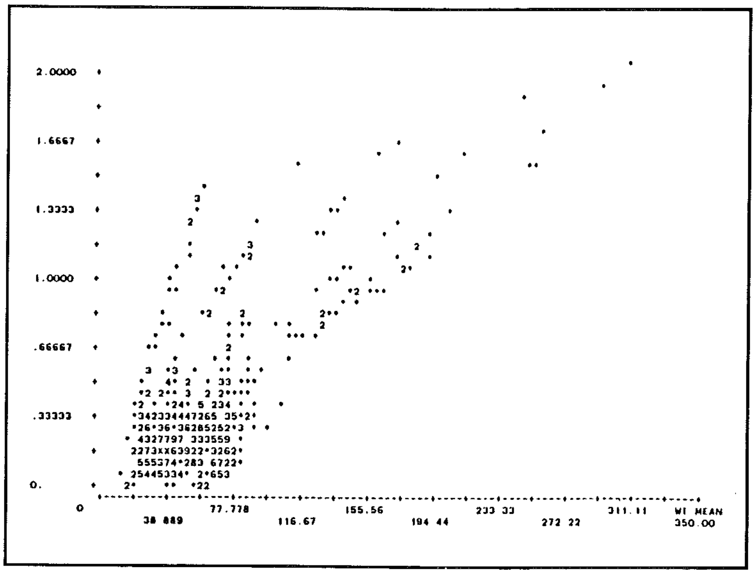

Figure 1. The relationship between daily growth (g) and mean fish weight (g) for Cycle 1, where G is the daily growth and Wt Mean represents the mean weight of fish.

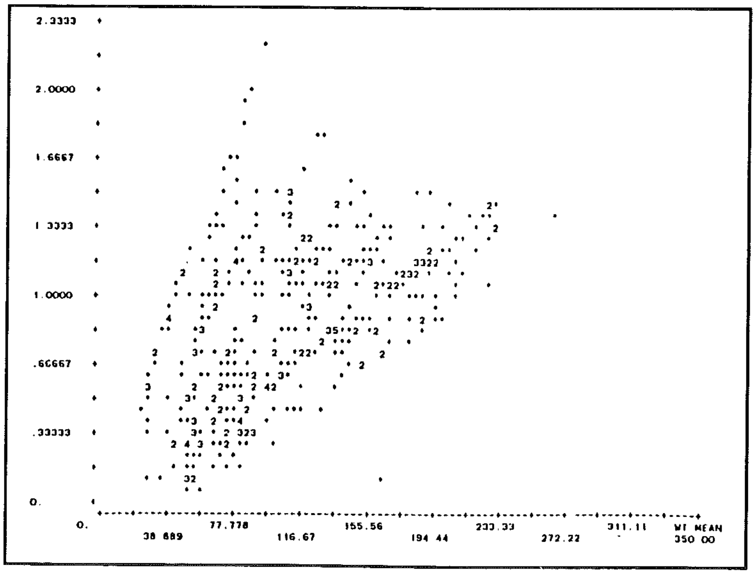

Figure 2. The relationship between daily growth (g) and mean fish weight (g) for Cycle 2, where G is the daily growth and Wt Mean represents the mean weight of fish.

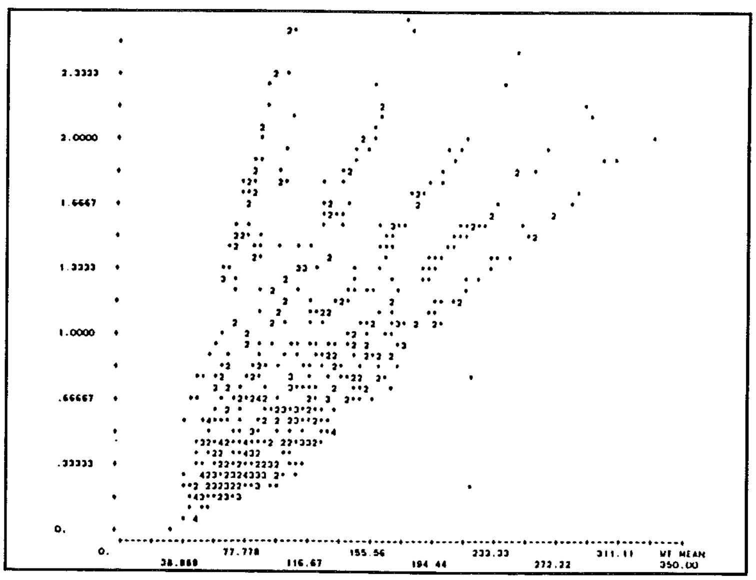

Figure 3. The relationship between daily growth (g) and mean fish weight (g) for Cycle 3, where G is the daily growth and Wt Mean represents the mean weight of fish.

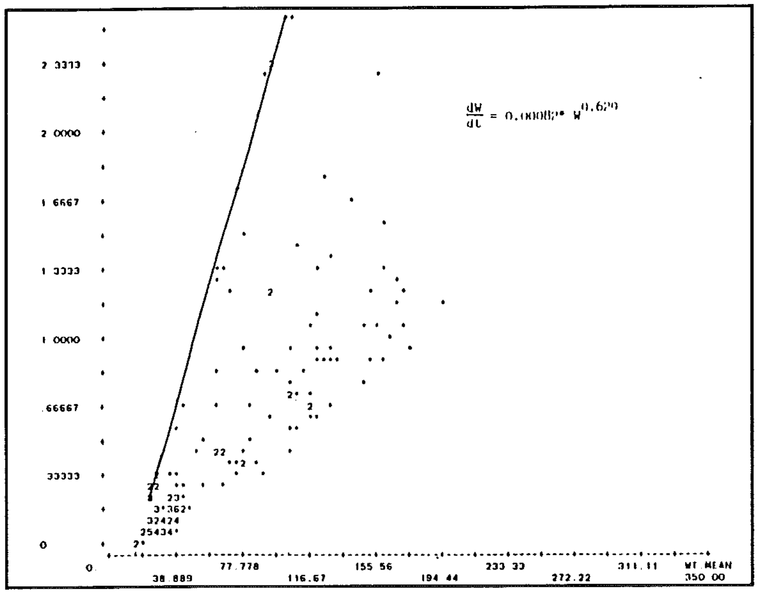

Figure 4. The relationship between daily growth (g) and mean fish weight (g) for Panama. The maximum growth capacities for ponds at this site are shown by the equation. The slope indicates the maximum physiological growth rate, which for this site is 0.629.

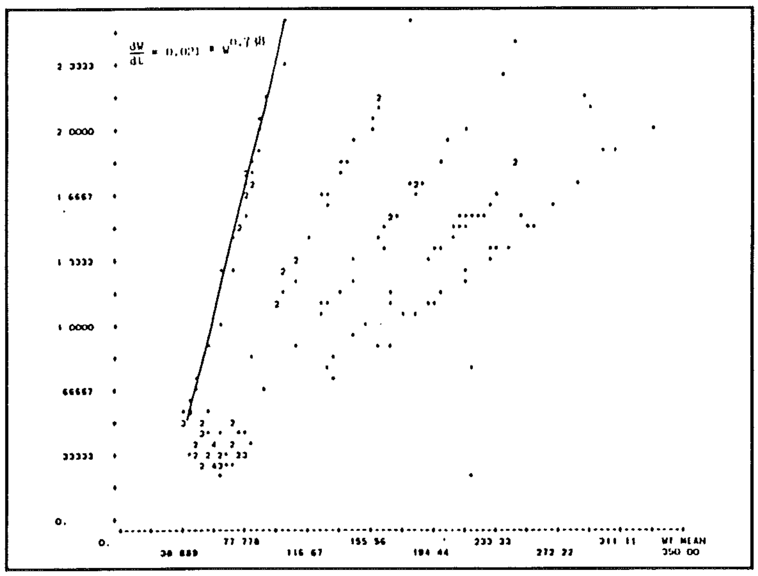

Figure 5. The relationship between daily growth (g) and mean fish weight (g) for Thailand. The maximum growth capacities for ponds at this site are shown by the equation. The slope indicates the maximum physiological growth rate, which for this site is 0.738.

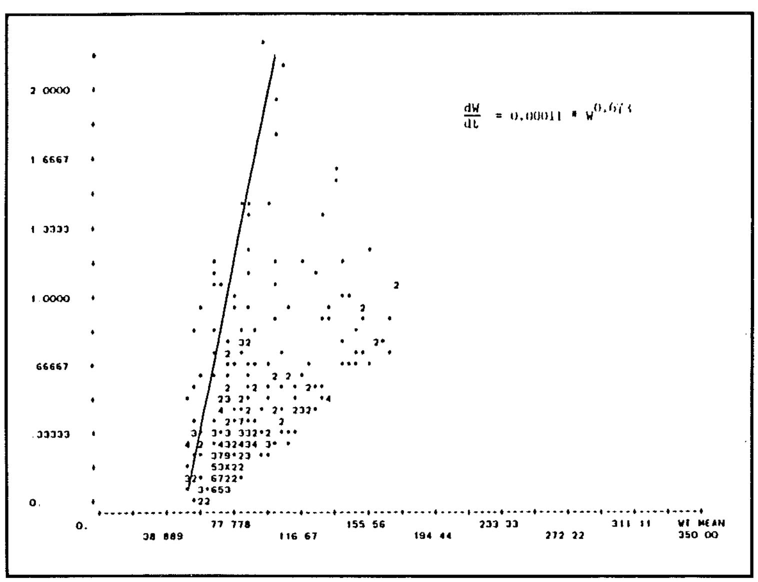

Figure 6. The relationship between daily growth (g) and mean fish weight (g) for Indonesia. The maximum growth capacities for ponds at this site are shown by the equation. The slope indicates the maximum physiological growth rate, which for this site is 0.673.

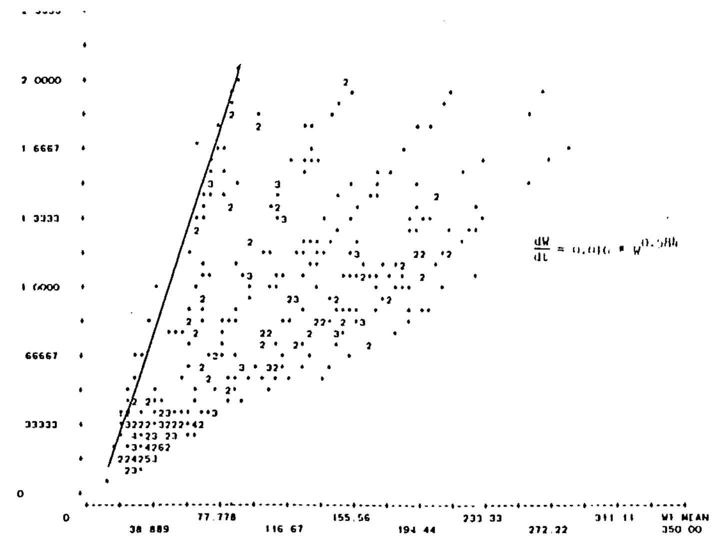

Figure 7. The relationship between daily growth (g) and mean fish weight (g) for Honduras. The maximum growth capacities for ponds at this site are shown by the equation. The slope indicates the maximum physiological growth rate, which for this site is 0.584.

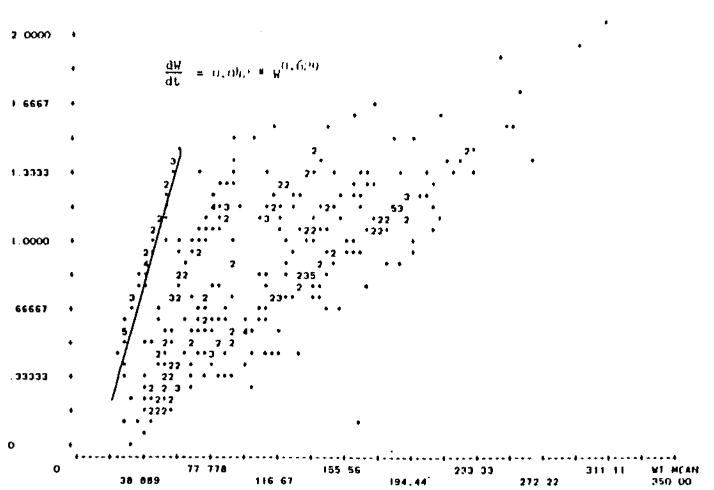

Figure 8. The relationship between daily growth (g) and mean fish weight (g) for Philippines. The maximum growth capacities for ponds at this site are shown by the equation. The slope indicates the maximum physiological growth rate, which for this site is 0.629.

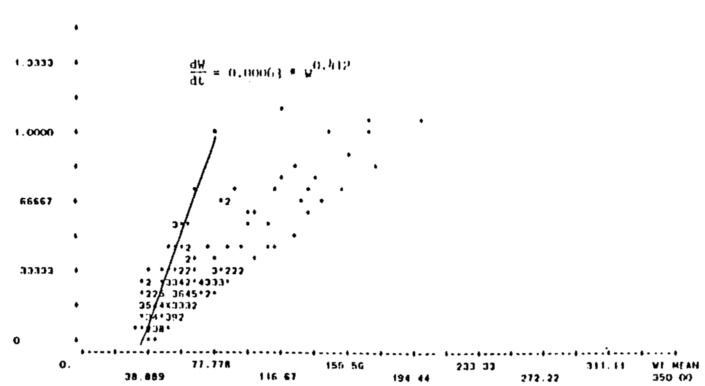

Figure 9. The relationship between daily growth (g) and mean fish weight (g) for Rwanda. The maximum growth capacities for ponds at this site are shown by the equation. The slope indicates the maximum physiological growth rate, which for this site is 0.412.

Modeling of Dissolved Oxygen Concentration

Raul H. Piedrahita (Department of Agricultural Engineering/ Aquaculture and Fisheries Program, University of California, Davis)

Introduction

Dissolved oxygen concentration is the primary factor that limits fish production in ponds. Feeding and fertilization rates, fish growth, and stocking rates are all affected by the concentration of dissolved oxygen. Dissolved oxygen concentration in ponds is affected by production (photosynthesis and reaeration) and consumption (respiration, degassing) processes. Three computer models that simulate different aspects of the dissolved oxygen cycle have been developed and are being calibrated. The models are designed to run 24-hour simulations. Accurate simulations in these short-term cycles would indicate that the processes of oxygen production and consumption are adequately quantified in the models. The models are being developed with a general structure and are made site-specific by the use of coefficients (latitude, longitude, initial conditions, climatic conditions). The three models are based on an assumption of uniform conditions (i.e., ponds are completely mixed).

The models under development are:

- a mechanistic, ecosystem model to simulate 14 variables (PondEco);
- a mechanistic model to simulate dissolved oxygen concentration (PondDO); and
- a mechanistic model to analyze diurnal measurements of dissolved oxygen, pH, temperature, and alkalinity (WholePond).

The models are described in some detail, and simulation results are presented below.

Objectives

The objectives of activities undertaken during the 1987-88 year were:

(1) To develop mechanistic mathematical models of pond processes based on conceptual frameworks;
2) To calibrate the mechanistic models (adjust parameter values by running the models and comparing the results with the values in the data base); and
3) To develop pond operating strategies consistent with each model.

Materials and Methods

The three models are based on the conceptual model proposed in the Fifth Annual Administrative Report of the Pond Dynamics/Aquaculture CRSP (Anon. 1988). The computer models have been implemented on Apple Macintosh computers. The PondEco model was formulated in FORTRAN, whereas the other two models were developed using STELLA™, a dynamic simulation language. FORTRAN is being used because of its flexibility in program size and complexity, and because of its speed of execution. STELLA™, on the other hand, is being used for its ease of model formulation and output analysis.

PondEco

PondEco is based on a model first proposed by Piedrahita (1984), and a listing of the current version of the model is included as Appendix C-1. The model is being used to simulate 14 state variables, including phytoplankton, fish number and size, dissolved oxygen, ammonia, inorganic carbon, and pH. The simulations are run for 24-hour periods. The data used to run the models are extracted from the data base, and include measurements of water quality and climatic conditions. To determine the quality of the simulations, results are compared to the values obtained during the diurnal sampling sessions (CRSP "E" template data). Intensive sampling of water quality measurements (Table 1) reduces the diel cycles required for model calibration to a very small number (one to three) for each of the sites. Hourly values of water temperature, wind speed, and cloud cover are inputs to the model and are obtained from the data base. Water temperature is obtained by interpolating between the measured values obtained at approximately four-hour intervals during the diurnal cycles. Wind speed is obtained by assuming that the wind velocity is uniform during the day, and using the value from template "A". Similarly, an "average cloud" factor is obtained by comparing the solar radiation from template "A" to the theoretical solar radiation for the site and date. This factor is then used to compute the hourly solar radiation values.

The model is formulated as a set of differential equations for the rates of change of the concentration of the state variables. These equations are supported by relationships that quantify the magnitude of the rate coefficients, and their dependence on environmental conditions and water quality.

PondDO

PondDO is designed to simulate the dissolved oxygen concentration in the ponds over a diel cycle. It is based on the same DO production and consumption equations included in PondEco. PondDO was developed to simplify the analysis of dissolved oxygen production and consumption terms. It is implemented in STELLA™ and a listing and flow diagram for the model is included in Appendix C-2. Simulations are run for 24 hours. The data used to run the simulations include the climatic and site characteristics data used in PondEco, as well as hourly values of some state variables obtained from execution of PondEco.

WholePond

This model was developed to analyze dissolved oxygen and inorganic carbon information in the data base, and to obtain indicators of phytoplankton condition (Appendix C-3). The model uses diurnal measurements of dissolved oxygen concentration, estimates of minor respiration terms, and calculated values of reaeration to estimate oxygen production and respiration by phytoplankton. These results are compared to estimates obtained from analysis of the inorganic carbon (carbon dioxide, carbonic acid, bicarbonate ion, and carbonate ion) in the water. Inorganic carbon concentration in the water is obtained from alkalinity, pH, and temperature values (Snoeyink and Jenkins 1980). The method is based on the assumption that oxygen and carbon dioxide are on opposite sides of the photosynthetic and respiratory processes. That is, in photosynthesis, one mole of carbon dioxide fixed (and removed from solution) results in the production of one mole of oxygen. A similar relationship exists for respiration. In the simplest case, the stoichiometric relationship between carbon dioxide and oxygen is one, and that ratio is assumed in WholePond.

Comparison of photosynthesis and respiration rates obtained from inorganic carbon and dissolved oxygen measurements can be made to determine the adequacy of the assumptions (especially the stoichiometric ratio), and the quality of the measurements. Inorganic carbon estimates are very sensitive to pH values, and minor errors in measurements can result in substantial differences in calculated inorganic carbon.

Photosynthesis rates obtained from WholePond can be related back to theoretical models of phytoplankton growth, and specific parameters for the theoretical models can be obtained. These parameters can then be used in PondEco and PondDO.

Results

The models were run with data from all freshwater sites. Brackish water data have not yet been used because available data lack alkalinity measurements. Alkalinity is a critical parameter for all three models. Sample simulation results for Pond 2 at the Ayutthaya, Thailand site are included in this report. The simulations correspond to May 14-15, 1985 (Julian Date 134-135).

PondEco

Results of the simulations were compared to the measured values of dissolved oxygen and pH, the two parameters monitored during the diel cycle (Figures 1 and 2). Dissolved oxygen simulations agreed closely with the measured values, while pH simulations followed the same trend as in the measurements, but did not show as close agreement. Execution of the model with different data sets gave simulations of varying quality of fit. The problems observed in some simulations indicate the need for continued improvement and refinement in the models.

PondDO

Simulation results from PondDO were used to analyze the different components of the dissolved oxygen cycle to determine their relative magnitudes. An example of this is shown in Figure 3 of the same data used in the PondEco simulations shown in Figures 1 and 2. The main processes determining the magnitude of dissolved oxygen fluctuations are those associated with phytoplankton: photosynthesis and respiration. Respiration from particulate organic matter is the second most important process that involves oxygen consumption. Fish respiration represents a minor contribution to the oxygen cycle, although fish may have an indirect effect on the cycle by their eating habits (phytoplankton grazing).

WholePond

Results from this model are still incomplete, as the model is undergoing revision and development. One example of the type of output that can be obtained from the model is dissolved oxygen production and consumption rates from dissolved oxygen and pH-alkalinity measurements (Figure 4). In the case illustrated, there was considerable discrepancy between the rate estimates obtained from the two methods. These discrepancies may be due to experimental error in measurements, or to errors in the oxygen-inorganic carbon stoichiometric ratios.

Anticipated Benefits

Once the accuracy of the simulations obtained with a model is established, the model can be used to predict the possible response of the pond ecosystem to changes in environmental conditions or management actions. These predictions can then be compared with new measurements obtained in the field to determine if the model is describing pond conditions accurately. Examples of the effect of environmental and management changes on pond dissolved oxygen are shown in Figures 5 to 9. The approach in these simulations was to estimate the dissolved oxygen concentration in the event of a cloudy day, with other data as in Figure 1. Light intensity was reduced to the lowest value recorded at Ayutthaya for the experimental cycle under consideration, and an estimate of dissolved oxygen for these conditions was obtained (Figure 5). The next step was to test possible actions that a pond manager could take to alleviate the expected dissolved oxygen problems caused by a reduction in light. Management actions included lowering the pH to increase the availability of inorganic carbon (Figure 6), flushing 20% of the pond volume over the 24-hour period (Figure 7), removing 20% of the pond water with continuous flow over 24 hours (Figure 8), and removing 20% of the pond water suddenly at the beginning of the day (Figure 9). The increase in dissolved oxygen by lowering the pH is an indication that phytoplankton growth is carbon limited, but this limitation is difficult to remedy in low technology systems. Flushing had a very limited effect due to the relative magnitude of the dissolved oxygen flow compared with other processes (see Figure 3). Lowering the water level in the pond had the effect of reducing the proportion of the phytoplankton that is not actively producing oxygen, and also had a noticeable effect on the dissolved oxygen concentration in the pond. The Secchi disk depth for the pond was 32 cm, with a resulting compensating depth of approximately 64 cm. Phytoplankton beyond this depth would be respiring and consuming oxygen, but not producing oxygen, and would constitute a net oxygen drain on the pond. By reducing the pond depth to 77 cm from the original 97 cm, the net oxygen demand in the pond is reduced, while the production is not affected. The results obtained so far indicate that the models can be used to study the possible effect of management actions, and to propose guidelines for pond culture.

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Piedrahita, Raul H. 1984. Development of a computer model of the aquaculture pond ecosystem. Unpublished Ph.D. dissertation. University of California, Davis. 162 pp.

Snoeyink, V.L. and D. Jenkins. 1980. Water Chemistry. John Wiley and Sons, Inc. New York. 463 pp.

Table 1. Site, weather and water quality data required to execute PondEco.

Parameter	Units	Frequency	Template
Latitude	°	once (1)	NA
Longitude	°	once	NA
Elevation	m	once	NA
Pond Depth	m	day (2)	B
Pond Area	m^2	day	J
Solar Radiation	$E.m^{-2}.h^{-1}$	hourly (3)	A
Wind Velocity	$m.s^{-1}$	hourly	A
Water Temperature	°C	hourly	E
Secchi Disk Depth	m	day	D
Chlorophyll-a	$\mu g.L^{-1}$	day	D
Total Ammonia Nitrogen	$mg.L^{-1}$	day	D
Dissolved Inorganic Phosphorus	$mg.L^{-1}$	day	D
Alkalinity	$meq.L^{-1}$	day	D
pH	pH units	hourly	E
Fish Number	$number.m^{-2}$	day	F, B
Fish Size	g	day	F

(1) Site parameters, not functions of time
(2) Measurements required on the simulated day
(3) Hourly values extrapolated from diurnal cycles

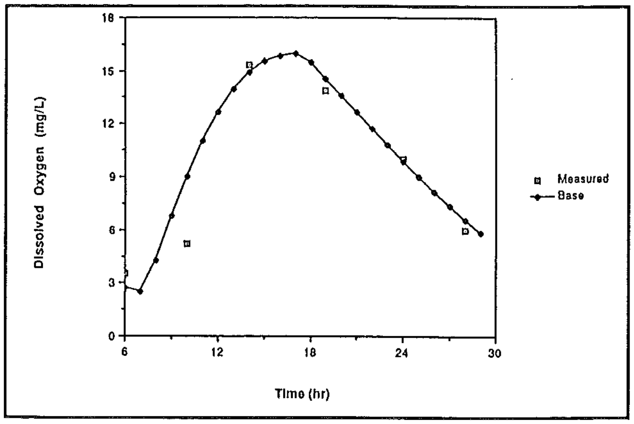

Figure 1. Measured and simulated dissolved oxygen for Pond 2, Ayutthaya, May 14-15, 1985.

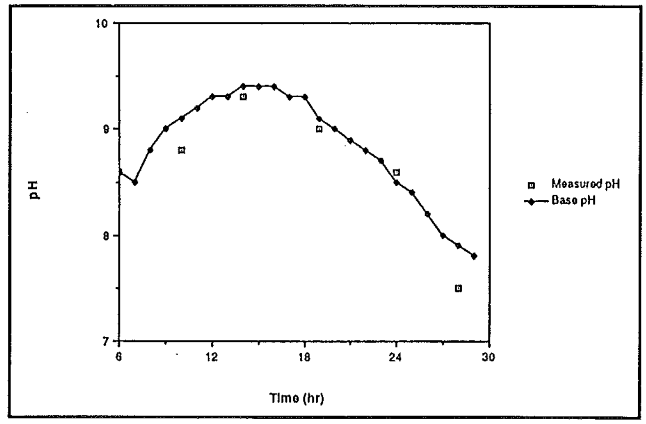

Figure 2. Measured and simulated pH for Pond 2, Ayutthaya, May 14-15, 1985.

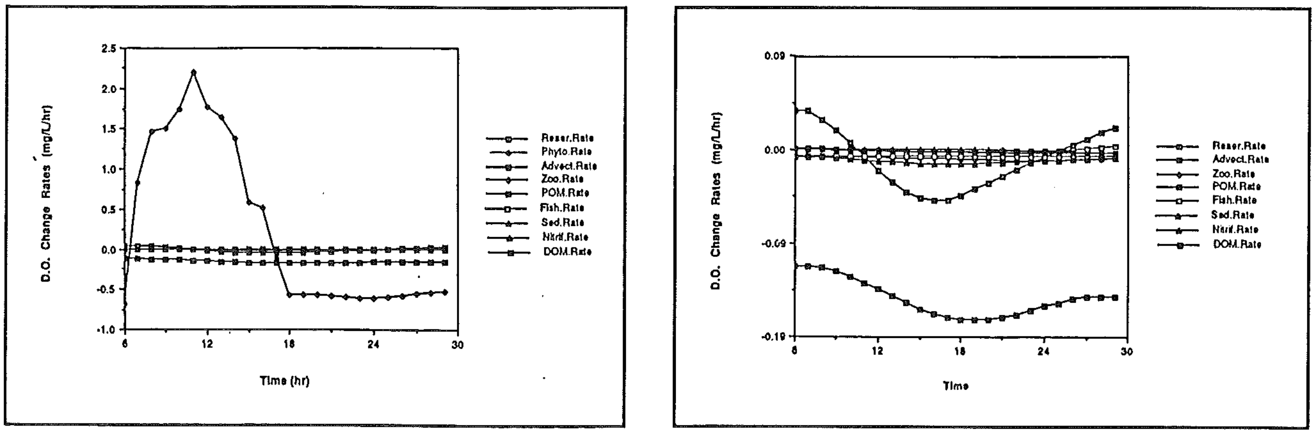

Figure 3. Dissolved oxygen production and consumption rates for the various processes identified in the pond model (Pond 2, Ayutthaya, May 14-15, 1985).

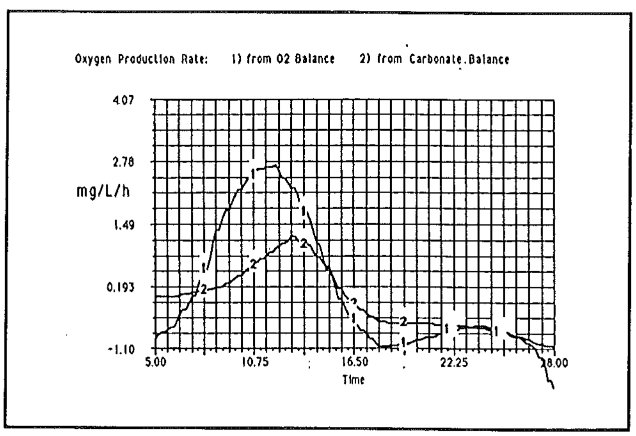

Figure 4. Overall dissolved oxygen and production rates obtained from measurements of dissolved oxygen and pH-alkalinity (Pond 2, Ayutthaya, May 14-15, 1985).

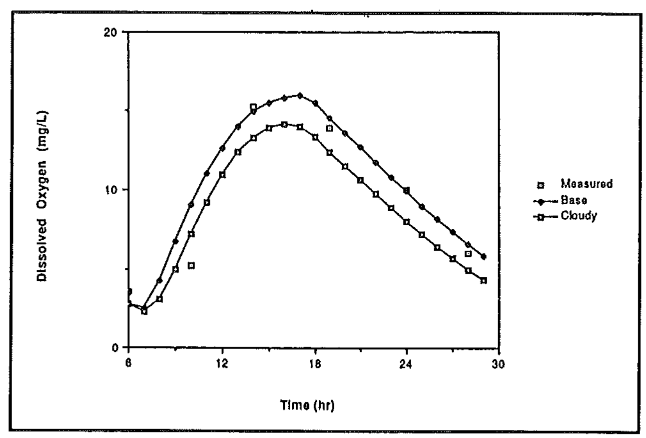

Figure 5. Simulated dissolved oxygen concentration obtained with light intensity reduced by 43% from the measured value for May 14, 1985.

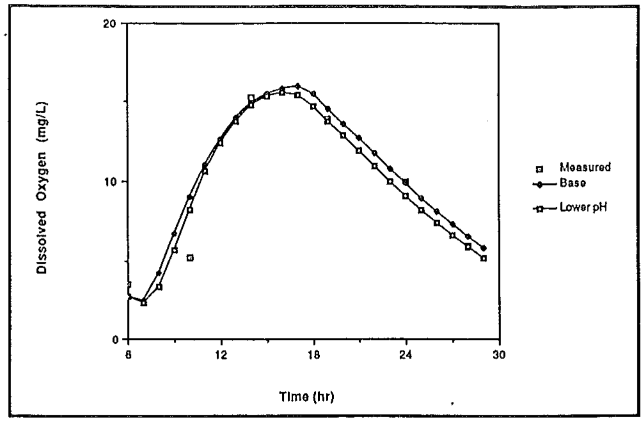

Figure 6. Simulated dissolved oxygen concentration obtained with the reduced light intensity and an initial pH lower than the measured value by 0.2 units.

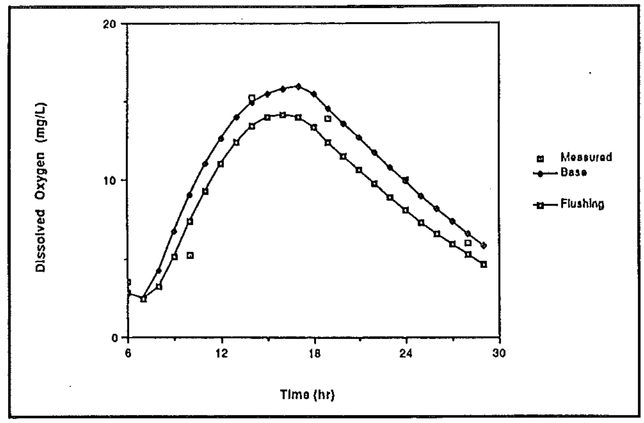

Figure 7. Simulated dissolved oxygen concentration obtained with the reduced light intensity and a flushing rate equivalent to 20% of the pond volume per day.

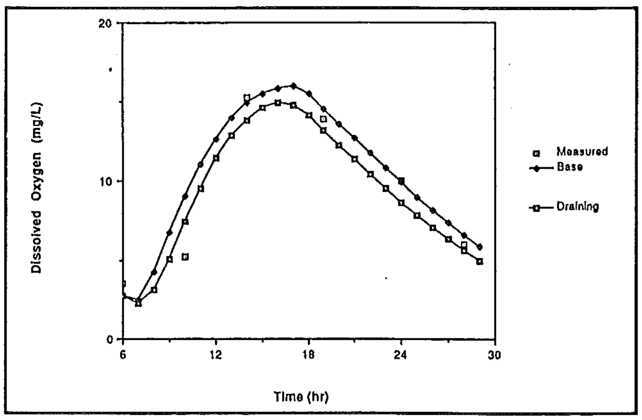

Figure 8. Simulated dissolved oxygen concentration obtained with the reduced light intensity and a continued outflow equivalent to 20% of the pond volume per day, and no make-up water.

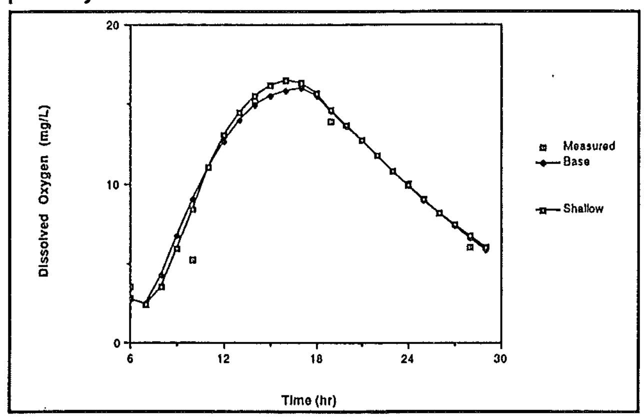

Figure 9. Simulated dissolved oxygen concentration obtained with the reduced light intensity and a water depth equal to 80% of the original pond depth.

Development of a Manual of Pond Management Guidelines

J. E. Lannan (Oregon State University)

One of the purposes of the CRSP Data Analysis and Synthesis Team is to translate the results of pond dynamics research into operational procedures or guidelines for pond management. This report summarizes progress directed toward this purpose during the period 1 September 1987 to 31 August 1988.

Objectives

The activities described in this report address two of the objectives of the present CRSP grant:

- to develop pond operating strategies consistent with each model (as described in the grant); and
- to compile a manual of pond operating strategies for optimizing yields, increasing the reliability and improving the efficiency of pond culture systems.

Approach

The approach taken for translating the results of pond dynamics research into a manual of operational procedures or guidelines for pond management is:

(1) to identify target audiences for the research information;

(2) to develop methods for organizing the research information in a form that identifies the correspondences between pond ecology and appropriate management practices; and

(3) to compile the organized information in a manner that facilitates dissemination to interested audiences.

Target Audiences for CRSP Research Information

Pond management guidelines are of potential interest to aquacultural producers, development planners, and aquaculture scientists. Producers want to maximize the efficiency of pond aquaculture systems. They need dependable guidelines on the fish cultural practices that are appropriate given certain technical and economic constraints. Development planners want to assess the economic feasibility of proposed or existing pond aquaculture activities. They need dependable methods of evaluating the suitability of proposed pond sites and production functions that describe probable yields given various inputs. Scientists want to understand the dynamic processes occurring in aquaculture ponds. They need reliable information about the functional relationships between components of aquaculture ponds.

Organization of CRSP Research Information

The approach taken for organizing the research information is to develop a functional classification of pond ecosystems according to the fertilization practices that have the highest probability for optimizing fish yield, and developing quantitative functional relationships that describe the appropriate levels and frequencies of application of the various practices for each classification. The rationale for pond classification is that the productivity of fertilized farm ponds is related to chemical, physical, and biological factors. Research findings indicate that critical reactions occur in the water column, in the pond soils, and at the soil-water interface. The rates of the critical reactions are related to climatic factors. Therefore, ponds with similar environments require similar practices, and pond environments may thus be ordered into a hierarchical classification according to the appropriate practices corresponding to each combination of source water, soil, and climate. The hierarchical classification may be simplified by specifying that pond classes differ from one another only if they require different practices.

Functional relationships are quantitative expressions of the relationships between two or more pond variables. They are mathematical functions; if the value of one variable is given, the corresponding values of the other variables can be determined. It is anticipated that most or all of the functional relationships required for the classification model will ultimately come from the empirical and mechanistic models being developed by other members of the DAST.

Compilation and Dissemination of Information

An "expert system" is being developed to compile information for dissemination to interested audiences. The expert system is a computer program that organizes information (i.e., "facts") about a specific pond according to a set of specified rules. In the present application, the rules are the pond classification system and the fertilization practices corresponding to the several classes. To use the expert system, one enters information about a pond of interest. The program then classifies the pond, specifies the appropriate practices, and calculates the levels and frequencies of the practices.

Accomplishments

During the period of this report, effort has focused on further development of the pond classification model and on development of the "expert system."

Pond Classification Model

Development of a preliminary hierarchical classification of tropical farm ponds is completed. Ponds are classified according to source water chemistry (five categories), soil properties (four categories), and climatic factors (eleven categories), for a total of 220 pond classes with a unique set of corresponding practices for each class. Pending analysis of additional research data, it may be possible to further simplify the classification system in cases where two or more classes require similar management practices. A manuscript describing the classification model is in preparation.

Development of an Expert System

A computer program named PONDCLASS has been written and tested. PONDCLASS is a "shell" of the expert system to be used with the pond classification model, and is designed to be run on personal computers. The version of PONDCLASS for the IBM-PC and compatible hardware is operational. A second version for the Apple Macintosh is in preparation. A schematic diagram of the current iteration of PONDCLASS is shown in Fig. 1.

PONDCLASS is designed to serve as a farm management tool. The program uses the classification hierarchy described above to organize information about a specific pond environment of interest, and provides recommended fertilization practices that have a high probability of optimizing fish yield in that pond. To utilize PONDCLASS, one enters information about water, soil, and climatic variables. The information criteria are provided in "Help Screens" for each level of the classification hierarchy. PONDCLASS determines the pond classification, provides the user an opportunity to verify the classification, and then prints the recommended fertilization practices for the pond.

The user may provide PONDCLASS with numerical data about the specific pond environment if such information is available. However, numerical data may not be available in many instances; for example, for small farms in less developed countries or for use in planning aquaculture development. In these cases, descriptive information may be utilized.

In order to provide recommended fertilization practices for a given pond, PONDCLASS must verify certain assumptions about the fish species in the pond, stocking levels, availability of feeds and fertilizers, and other management actions applied to the pond. An "assumptions" screen is provided (under "Information about PONDCLASS" in Fig. 1) to enable the user to instruct PONDCLASS about which assumptions to use in determining recommended fertilization practices.

Summary of Tasks for the Next Year

The following tasks will be addressed during the period 1 September 1988 to 31 August 1989:

(1) Complete the Macintosh version of the PONDCLASS program;

(2) Continue the compilation into PONDCLASS of fertilization guidelines based on research information; and
(3) Continue the development of the functional relationships required for the classification model.

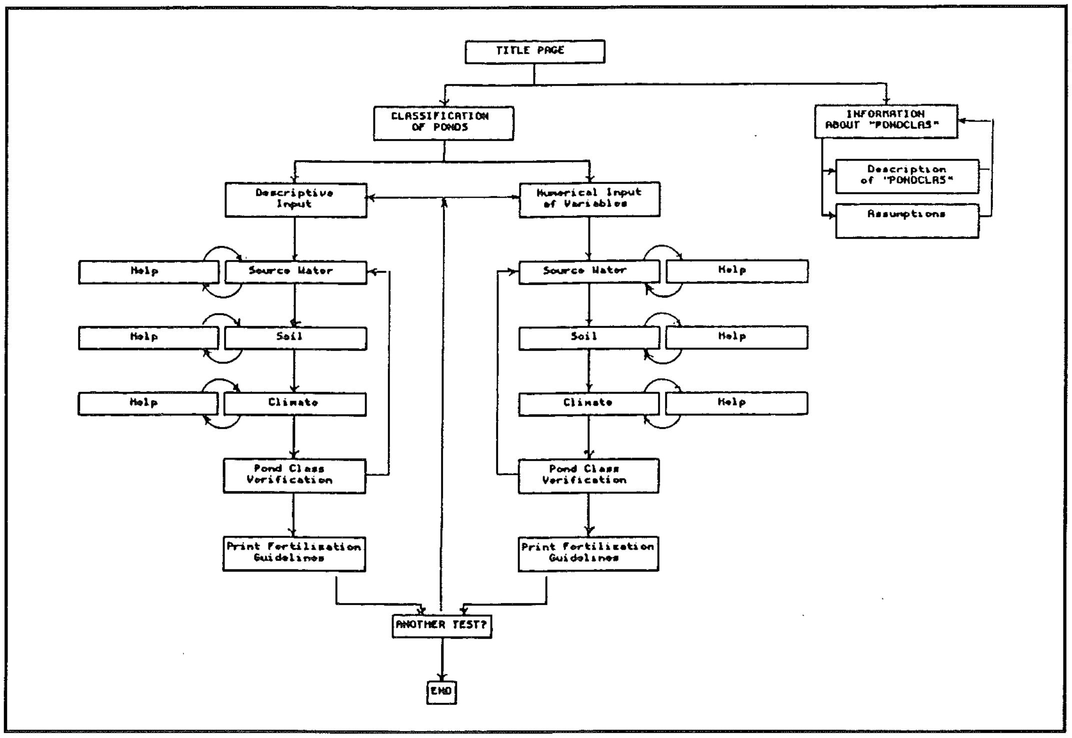

Figure 1. Schematic diagram of the PONDCLASS program.

US SPECIAL TOPICS RESEARCH REPORTS

Evaluation of sex steroids and inhibition of UDP-glucuronyltransferase are out of phase during gonadal maturation in the common carp

Francis D. Sikoki, Richard A. Tubb, and Lawrence R. Curtis
Oregon State University

Plasma sex steroid concentrations, onset of gonadal maturation, and hepatic microsomal UDP-glucuronyltransferase (UDPGT) activities were followed under natural temperature and photoperiod in outdoor tanks, and under controlled laboratory temperature and photoperiod regimens in common carp (*Cyprinus carpio*). Decreased activity of UDPGT was out of phase with elevations in plasma testosterone and 17β–estradiol during gonadal maturation. Injection of pituitary extract induced final gonadal maturation and transient elevations (within 24 hrs) of both plasma sex steroid concentrations and UDPGT activities. There were no simple relationships between plasma sex steroid concentrations and activity of hepatic microsomal UDPGT in common carp.

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Automated water quality data acquisition in aquaculture systems

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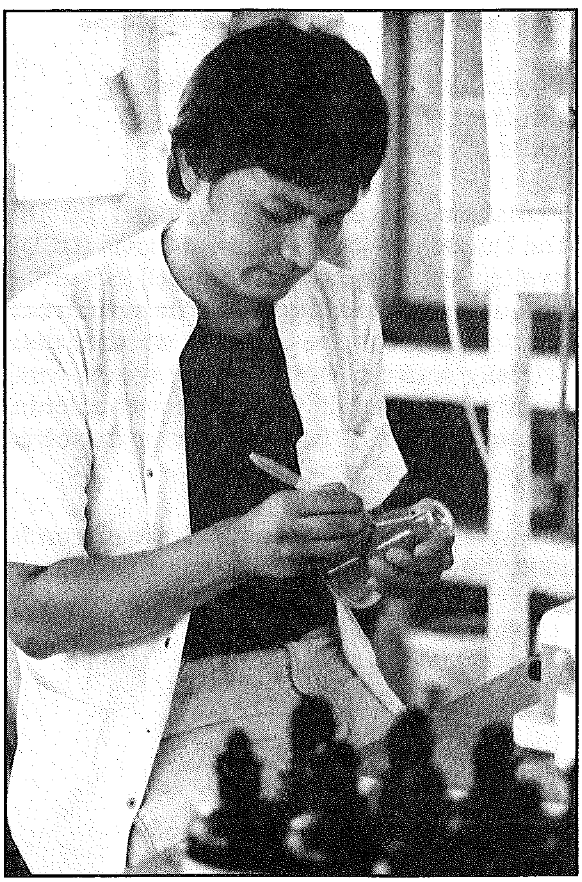
An automated water quality data acquisition system was developed by the Aquacultural Engineering program at the University of California at Davis (UCD). The self-contained computer based system consists of a Campbell Scientific "micrologger," a weather station and a unique water sampling raft. The system can monitor and record the following information on a routine basis; a) weather data including solar irradiance, photosynthetically active radiation, wind speed, wind direction, air temperature, relative humidity and rainfall; b) pond environmental data taken at 20 cm intervals (to a maximum depth of 175 cm) including dissolved oxygen, temperature, pH and photosynthetically active radiation.

This poster describes the data acquisition system, its uses in aquaculture research, and possible modifications for use in monitoring commercial aquaculture systems.

Chinese integrated agriculture and aquaculture: An economically and ecologically efficient system

William B. Chang
Great Lakes Research Division, The University of Michigan, Ann Arbor, Michigan

Aquaculture practice in China dates back more than 3,000 years, with the first document on the culture of common carp (*Cyprinus carpio*) assembled in 500 B.C. by Fan Li, who described widely used culture methods of the time. This document showed that even this early in human history Chinese fish culture had been integrated with agricultural production,. Since then, many improvements have been made; the Chinese have perfected culture practice and led the world in per unit pond fish production (exceeding 10,000 kg/ha in 1985). Two main types of integrated agriculture/aquaculture practices are found in china today. Integrated pond aquaculture, which turns the wastes from animal husbandry and the by-products from fields into food and feed and uses a high fish stocking density and rotation in harvesting to achieve high rates of fish growth and production, is the principal method used. This is an efficient ecological system since the agricultural wastes are used to produce fish while the aquacultural wastes such as pond soil are used for crop production. Integrated lake farming systems have further improved this operational efficiency by reducing the problem of low dissolved oxygen and increasing the production of aquatic plants which have a higher growth rate and are more efficient as fish feed than phytoplankton.



HOST COUNTRY SPECIAL TOPICS RESEACH

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 the host country. The intent was 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 short-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 CRSP Global Experiment. 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 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.

Host Country Special Topics Research Reports

A comparative study of the effects of four organic inputs on tilapia pond production at Rwasave Fish Culture Station

Felicien Rwangano (Oregon State University)

Introduction and Objectives

In higher elevation areas of East Central Africa, available fertilizers for fish ponds are largely locally-produced, organic waste materials. The type and nature of these materials determines their effectiveness as fertilizing inputs. The objective of this study was to analyze the differential impacts of four organic input materials on pond productivity for male *Oreochromis niloticus*. The materials used were: green grass, composted green grass, compost mixed with cow manure, and compost enriched with vinasse (a by-product of the distillation of molasses).

Materials and Methods

Fingerlings averaging 37 grams were sorted by sex twice and stocked at 1 fish/m^2 in twelve 600 m^2 earthen ponds. The four treatments were triplicated. Organic materials were loaded into ponds at about 250 kg/week as dry matter, with 45% added one week before the experiment started and 55% allocated over the remaining period. Fish weights were monitored monthly. Both water and pond soils were sampled. Monthly assays were made for organic carbon, total N, P, Ca, Mg, and percent dry matter.

Results

Tilapia in ponds receiving the green grass treatment grew more quickly than tilapia receiving other treatments. Chemical and biological data are being analyzed to determine the basis for the differences in pond productivity.

Anticipated Benefits

This is a country marked by limited availability of commercially prepared feeds and inorganic fertilizers. Efficient use of scarce resources can be optimized by using waste organic materials that produce the most favorable results in pond culture. This experiment will identify promising sources for farm pond inputs.

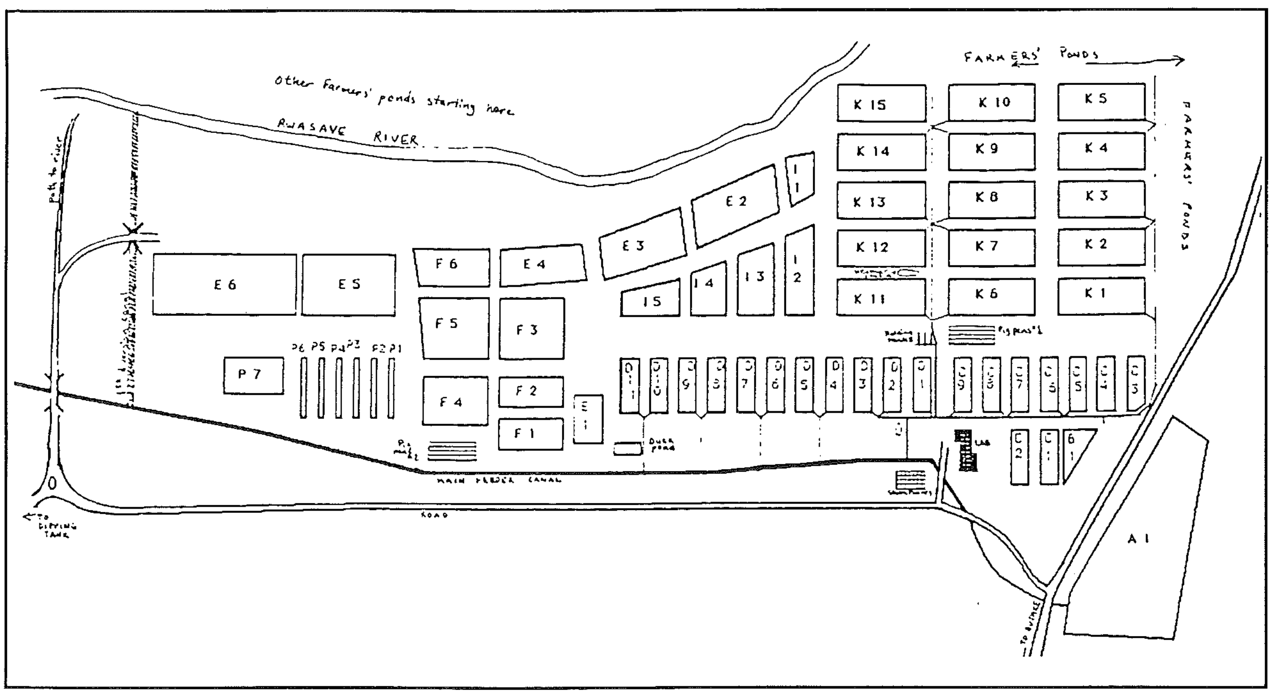


Figure 1. Total area: 8 ha water surface. CRSP ponds are B,C,D series; other experiments are conducted in the K series ponds.

Examination of the production variability for tilapia in unfertilized ponds

Karen Veverica (Auburn University)
Lieven Verheust and Eugene Rurangwa (National University of Rwanda)

Introduction

During pond experiments at Rwasave Fish Culture Station, some ponds have consistently performed better than others receiving the same treatment. These "good" ponds were sometimes grouped in the same treatment, causing researchers concern about the viability of relying on random methods of assigning treatments to ponds. This experiment was designed to investigate this variability.

Objectives

The objectives of this study were to "restandardize" the CRSP experimental ponds and to utilize some of the residual material remaining in pond sediments from previous experiments. This experiment will investigate productivity of tilapia in individual ponds not receiving inputs.

Materials and Methods

Twenty-one ponds were filled two weeks prior to the start of this experiment, then drained and refilled. Before refilling, and again at the end of the experiment, 2 cm and 5 cm-deep soil samples were taken and analyzed for pH, organic carbon, Kjeldahl nitrogen, and phosphorus. The ponds were measured and found to be 700 m^2 in area at 10 cm below full (120 cm depth at the monk). Ponds were stocked at 2.2 fish/m^2; mixed-sex fish averaged 9 grams at stocking. Fish were sampled monthly and at three months when the experiment ended. No other water quality parameters were measured, but the ponds were observed for plankton blooms.

Results

Mortalities of about 20% occurred early in the test, probably because the fingerlings were about six months old and in poor condition. Net production ranged from 0.78 to 11.6 kg/ha/yr. The best pond contained a dense bloom of *Anabaena sp.* during the last month, increasing fish growth in this pond. Weight of fry produced was greater for ponds showing the fastest growth of stocked fish.

Pond soils increased in average percent carbon and in average percent organic nitrogen from before stocking to after draining at three months. However, there was no clear correlation between pond productivity and pond soil characteristics.

Anticipated Benefits

This information is useful in classifying ponds at the Rwasave Station. Additionally, a more rational distribution of treatments and assessment of effects can be made in future experiments.

Comparison of tilapia production at three different stocking densities

Rurangwa, E., F. Rwangano, and M. Van Speybroeck
(National University of Rwanda)
Karen Veverica (Auburn University)

Introduction and Objectives

This experiment examined the influence of fish stocking density on production rate. Theoretically, production should increase with stocking density to some point, then decline as individual growth rate is reduced by limited food availability. For ponds receiving supplemental feeding, this relationship is not clearly applicable. In this experiment, production was tested both for ponds receiving a density-adjusted ration and for unfed and unfertilized ponds.

Materials and Methods

Replicate 600 m^2 ponds were stocked with male *Oreochromis niloticus* of about 35 grams each. Stocking rates were 1, 1.5, and 2 fish/m^2 (treatments SR1, SR2, SR3, respectively). Two ponds at each stocking level received a rice bran feed at a rate of 10% of body weight per day, split between morning and afternoon feedings. Ration was adjusted monthly based on a sample weight of at least 25 fish. An additional pond at each stocking level was not fed or fertilized (treatment NF). Ponds were drained after 153 days.

Results

Net fish productivity for the SR2 ponds was highest, averaging 44.7 kg/are/yr. Production rates for SR1 and SR2 were not significantly different, averaging 34.6 and 31.8 kg/are/yr, respectively. During the first month, food conversion ratios ranged from 7:1 to 8:1, which are typical rates for rice bran feeding in Rwanda. In following months, food conversion rose to 10-15:1 for all SR treatments, indicating that the 10% ration was too high for the larger fish.

Fish production in non-fed ponds was 1.8, 5.7, and 0.66 kg/ha/yr for ponds NF1, 2, and 3, respectively. Variability was attributed to previous pond history.

A rudimentary estimate of revenues per year was determined by subtracting the cost of feed from the value of the fish produced in the feeding trials. Maximum return for SR1 ponds occurred at approximately the third month of growth. After that, the value of additional production did not compensate for the cost of the additional feed. Maximum return for SR2 and SR3 ponds was reached at the fourth and fifth month, respectively.

Anticipated Benefits

This information can be used to plan stocking rates and harvest intervals based on the market size desired. This experiment also raises questions concerning mixed-sex culture and the role of intermediate harvesting practices. The stocking density data will be useful for designing future experiments.

Fingerling production of *Oreochromis niloticus* at the Rwasave Fish Culture Station at the National University of Rwanda

Felicien Rwangano, Marijke Van Speybroek, and Eugene Rurangwa
Faculte d'Agronomie, Universite Nationale du Rwanda, Rwanda
Karen L. Veverica, Department of Fisheries and Allied Aquacultures, Auburn University, Alabama
Boyd J. Hansen, OSU/UNR Pond Dynamics CRSP, Department of Fisheries and Wildlife, Oregon State University

Rwanda's climate is cooler than its latitude would indicate (2°S), because elevation of most of the country lies between 1500 and 2500 meters. For this reason, the suitability of tilapia culture has been questioned. However, in light of local management constraints, *Oreochromis niloticus* have proven satisfactory when fingerlings were made available.

Production of fingerlings in ponds stocked with *Oreochromis niloticus* brooders has been monitored at the National University of Rwanda's aquaculture research station since 1984, when this species was re-introduced to Rwanda. Fingerling production is generally very low (usually 10-30 fingerlings per female per month). Age of females at first reproduction was about nine months. Reproduction occurs in every month but is lowest during the dry season (June-August), when minimum air temperatures fall to 4°C to 10 °C. Reproductive success has also been attributed to pond design. Brooders stocked in ponds with vertical levees and minimum depths greater than 80 cm did not reproduce. Nesting typically occurs at depths of 20 to 50 cm on gently-sloped sandy substrates.

The low reproductive rate of tilapia in Rwanda may be advantageous and simplify management practices for the rural fish farmers.

Breeding and rearing of sand goby (*Oxyeleotris marmoratus, blk.)* fry

Panu Tavarutmaneegul, Pathum, Thani Fisheries Station, Nong-Sua, Pathum Thani, Department of Fisheries, Thailand
C. Kwei Lin, Great Lakes Research Division, The University of Michigan, and The Asian Institute of Technology, Thailand

Large-scale production of sand goby fry was conducted at the Nong-Sua Hatchery Station, Thailand, for one year. Approximately 1,000 egg nests containing 25 million eggs were collected from January through October under semi-natural breeding conditions. The hatching rate of fertilized eggs reached 80%. Fry were reared in two stages. In stage 1, the newly developed fry, with average total body length of 4 mm and mouth clutch opening of about 0.1 mm, were first fed with a combination of chicken-egg slurry and live rotifers. The survival rate at this stage ranged from 7 to 55%. with an average of 20% among batches of egg nests collected during the year. Stage 2 involved raising older fry that were fed with live *Moina sp.*, chironomid larvae, and ground trash fish from days 30 to 60, during which the survival rate ranged from 60 to 90% and length increased from 2.4 to 3.8 cm. Growth rate was inversely related to stocking density at this stage. A total of 147,300 juvenile fish was produced in the one-year effort.

Published in *Aquaculture*, 69 (1988) 299-305.

An analysis of biological characteristics of *Macrobrachium rosenbergii* (de Man) in relation to pond production and marketing in Thailand

C. Kwei Lin, Agricultural and Food Engineering Division, Asian Institute of Technology, and The University of Michigan, Ann Arbor, Michigan
Mali Boonyaratpalin, National Inland Fisheries Institute, Thailand

Data on production and marketing of the giant freshwater prawn were collected over a seven-month, grow-out period through collaboration with a medium-sized commercial prawn farm in central Thailand. Juvenile prawns with an average weight of 4.2 g were stocked at a density of 6 prawns/m^2 in three 0.5-ha earthen ponds. Average growth rate determined during the first three months of the grow-out period was 0.4 g/prawn per day; prawns of marketable size were harvested selectively during the remaining four months of the rearing period, resulting in a total accumulated yield of 1.3 tons/ha with an average prawn weight of 32 g and 60% survival. As different sexes and sizes of prawns were sold at different prices, the harvests were customarily sorted into several categories: large, medium, and small males, long-clawed males, soft shells, females with eggs, females without eggs, and terminal males. The total weight and number of prawns recorded for each of these categories showed that the female to male ratios were 1.6:1 and 4:1 by weight and number, respectively, while the ratio of short-to long-clawed males was 3:1 by weight and 4:1 by number. Four percent of the marketable population was termed "soft shells" and 64% of the females bore eggs. The ratio of head weight to tail weight of marketable prawns varied substantially among the different categories: 1.0:1 for females, 2.5:1 for long-clawed males, and 1.6:1 for short clawed males. Females predominated in the first and second 1.5-month harvest periods while males predominated in the final 1.5 months of the harvest. The economic yield of prawn culture was not only determined by the biomass, but also by the population structure of the various biological categories and the harvest season.

Published in *Aquaculture*, 74 (1988): 205-215.

Effects of water depth and artificial mixing on dynamics of Philippines brackish water shrimp ponds

Arlo W. Fast and Kent E. Carpenter, Hawaii Institute of Marine Biology, University of Hawaii at Manoa
Victor J. Estilo and Hernane J. Gonzales, Brackishwater Aquaculture Center, University of the Philippines in the Visayas

The effects of pond water depth (0.5, 1.0, and 1.5 m) and artificial circulation on certain pond dynamic processes were evaluated in a factorial design. Deep ponds had more uniform temperatures, with less rapid temperature changes, greater whole pond respiration, and greater temperature and oxygen stratification. Artificial circulation reduced thermal and oxygen stratification. Sediment respiration, which was estimated using a new technique, was more than three times greater than plankton and shrimp respiration combined, regardless of treatment combination. Shrimp yields were not significantly different for any of the six treatment combinations.

Published in *Aquacultural Engineering* 7 (1988): 349-361.

Nitrate and ammonia depletion in Indonesian aquaculture ponds fertilized with chicken manure

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I.S. Harahat, Institute Pertanian Bogor, Indonesia

Twelve 0.2 ha aquaculture ponds for Nile Tilapia production in West Java were fertilized weekly with 4 levels of chicken manure: 12.5 , 25, 50, and 100 g/m^2. During a 150-day grow-out period, weekly ammonia-N and nitrate-N concentrations often exceeded 0.05 mg/L in ponds fertilized with 12.5 and 25 $g/m^2/wk$, but were usually less than 0.05 mg/L ponds fertilized with 50 and 100 $g/m^2/wk$. These differences between treatment in dissolved inorganic nitrogen (DIN), and apparent nitrogen limitation of algal productivity at higher loading rates, were examined through daily and diurnal measurements of ammonia-N and nitrate-N. Data suggest that algal production was limited by a shortage of CO_2 at lower fertilization rates and by a shortage of DIN at higher fertilization rates. At higher fertilization rates, CO_2 for algae was additionally supplied through microbial respiration of organic carbon in chicken manure. Laboratory experiments measuring the release of ammonia-N and nitrate-N from chicken manure and urea were conducted to evaluate nitrogen transfer rates from these materials. An economic analysis is presented which relates appropriate application rates to fish yields and the cost of fertilizers in West Java.

Hydrology of fish culture ponds in Gualaca, Panama

David Teichert-Coddington, Nathan Stone, and Ronald Phelps, Auburn University, Alabama

During 1985, rainfall, evaporation, and seepage were measured in 12 experimental fish culture ponds at the Gualaca Freshwater Aquaculture Research Station, Gualaca, Panama, to provide baseline pond hydrology data for the area and a water budget for the station. Mean monthly rainfall ranged from 0 to 27 mm/day, while pond evaporation ranged from 1.4 to 8.4 mm/day. An equation was developed to predict pond evaporation from solar radiation measured by photometry. Among the 12 ponds, mean seepage ranged from 19 to 58 mm/day and averaged 31 mm/day. Seepage accounted for 87% of water lost from the ponds. A regression equation was developed to predict the quantity of water gained by runoff into ponds during rainfall. Monthly water balances for the station ranged from -399 to 14 mm/day and averaged -13 mm/day. Water deficits occurred during 9 of 12 months. The annual water deficit could be reduced to zero should seepage be reduced by 66%. Particular attention needs to be given to pond construction on kaolinitic soils, which although high in clay, may be very porous.

Published in *Aquacultural Engineering* 7 (1988): 309-320.

Comparative production of *Colossoma macropomum* and *Oreochromis niloticus* in Panama

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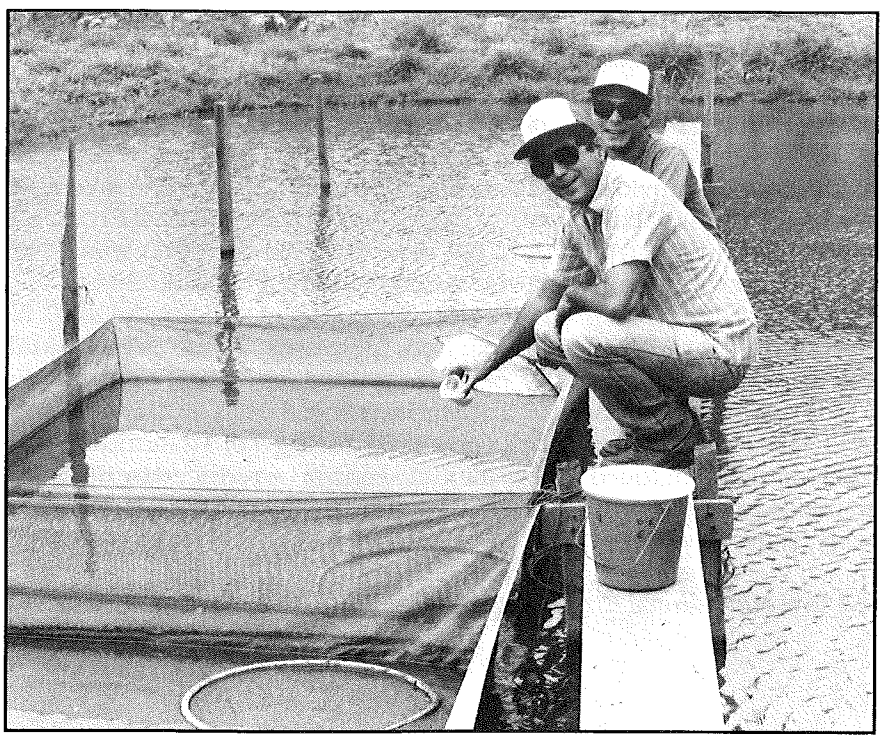
David R. Teichert-Coddington, Department of Fisheries and Allied Aquacultures, Auburn University, Alabama

The production of *Colossoma macropomum*, a relatively little studied fish, was compared with that of *Oreochromis niloticus*, a fish well known for its good production characteristics. Both species were grown simultaneously in a randomized design that was arranged in 2 X 2 factorial with each species being tested at a density of 1 and 0.25 fish/m^2; treatments were replicated three times. Fingerlings were stocked into earthen ponds (870 m^2), fed a commercial diet (25% protein), and harvested after 126 days of growth. Mean net production (kg/ha) for tilapia at high and low density was 3,361 and 917, respectively, and for colossoma was 3,682 and 977, respectively. The production difference between species was not significant ($P > 0.05$) while the difference between densities was highly significant ($P < 0.01$). Although net production was not different for the species, *Colossoma* gained significantly more weight per fish than tilapia; at the low density, low density of tilapia and *Colossoma* gained 379 and 471 g, respectively. While increasing the stocking density four-fold resulted in an almost four-fold increase in net production for both species, mean weight gains were not significantly affected by density. All other variables being equal, we concluded that the production of a 400 g fish with prepared diets could be achieved equally as efficiently with *O. niloticus* or *C. macropomum*. Also, both species should be stocked at a rate of at least 1/m^2 for high production without a significant loss of mean fish weight.



PROJECT DEVELOPMENT AND PUBLIC SERVICE

Public Service

As Pond Dynamics/Aquaculture CRSP projects in developing countries become integrated into USAID's "country strategy," opportunities for providing scientific research support to research institutions and people of these countries have arisen. In each country project of the CRSP, researchers have recognized these opportunities and have assisted their counterparts in initiating activities. Although ancillary to the Global Experiment, these activities contribute to institution building and as such, further 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 in every developing country in which the CRSP has been active. Some of these important contributions are described below.

Although training is not a formal component of this CRSP, the involvement of students from host countries constitutes an important part of the CRSP's international outreach. Enthusiasm for our projects and for learning new skills has led some of these students to graduate school at our participating U.S. universities. The involvement of these universities also has served to extend the domestic outreach of the CRSP.

Number of host country student theses in preparation or completed during this reporting period:

Africa- 12
SE Asia- 18
Central America- 15

In Rwanda, building the facilities at the Universite Nationale de Rwanda (UNR) was only one of the steps undertaken by the CRSP in developing adequate support for aquaculture research. Ms. Karen Veverica, a US field scientist in Rwanda, taught a fish culture course at the National University of Rwanda (UNR) and guided students on their field research projects. The CRSP experimental facility continues to be of interest as a destination for student field trips. Twelve students from the Department of Agricultural Economics at the University of Burundi and 92 students from the Veterinary School, Rubiliz, Rwanda visited the site this past year.

The CRSP built a laboratory at Rwasave Fish Culture Station, which in the past year has become the premier water quality laboratory in Rwanda and one of the best in East Central Africa. The CRSP provides a valuable service to the country by training Rwandan technicians to operate laboratory equipment and to collect measurements on pond dynamics.

The Panama CRSP was an effective complement to existing aquaculture activities in Panama. Under the leadership of Dr. Richard Pretto, aquaculture developed rapidly in Panama with emphasis placed on production, demonstration, and extension. The CRSP's focus on research added another dimension to Panama's aquaculture program.

The CRSP project site in Aguadulce was one of the few brackish water aquaculture research stations in Latin America. Brackish water aquaculture is widely practiced in the region; over 110,000 hectares are devoted to the cultivation of marine shrimp. This CRSP project assisted both DINAAC and private industry with its research on penaeid shrimp. CRSP researchers also have assisted USAID consultants and have given training courses to host country scientists and shrimp farmers. The quality of the staff and facilities developed as part of the CRSP has enabled DINAAC to attract funding from both private and public sources for additional research activities. Unfortunately, collaborative research in Panama ended abruptly in December 1987, at the request of USAID. It is hoped that the sufficient infrastructure was left behind so that research in pond dynamics will continue in the CRSP's absence.

In Thailand, the CRSP has developed professional linkages with the Asian Institute of Technology, an international post-graduate technological institute. Dr. Kwei Lin, the U.S. field scientist, engages in cooperative research activities with scientists from the Asian Institute of Technology and has been appointed to a faculty position. The CRSP project in Thailand continues to enjoy strong cooperation from the USAID Mission.

In Honduras, the CRSP greatly contributed to the renewal of interest in aquaculture. The CRSP built on existing infrastructure and assisted the Hondurans in developing an effective aquaculture program. Mr. Bart Green, the U.S. field scientist, was instrumental in the development of an extension program in aquaculture. The CRSP established an excellent water quality laboratory capable of meeting the CRSP's needs as well as those of RENARE (Honduras' Department of Natural Resources). Under the CRSP's guidance, production at the El Carao facility increased nearly three-fold. The station now also produces Chinese carp fingerlings. These improvements were achieved even though pond area for production was decreased to provide more area for research.

The Honduras CRSP also has served as a catalyst in linking together various groups involved in aquaculture. A Honduran national advisory committee has been formed, which represents government agencies, private and state universities, the Peace Corps, and the CRSP. Through the committee's efforts, the first national aquaculture seminar was held and a second is planned. The ability of the CRSP to work with other programs led the USAID mission in Honduras to fund this outreach for an additional year after the termination of this CRSP project in September 1987. Largely because of this continued relationship, the CRSP was able to relocate the Central American project to its former freshwater station in Comayagua.

Project Development

A new phase for the CRSP in Thailand

The second phase of research that began with the new CRSP grant has been accompanied by changes in the organization of the CRSP in Thailand. The University of Michigan (UM), Michigan State University (MSU), and the University of Hawaii (UH) now cooperate on a single collaborative project in Thailand. The latter two universities previously worked in Indonesia and the Philippines, respectively. Although the Royal Thai Department of Fisheries (DOF), which served as the original Host Country institution to The University of Michigan, welcomed the consolidation, they felt that facilities at the Ayutthaya Freshwater Fisheries Station were limited. Consequently, the Asian Institute of Technology (AIT) was added as a Host Country institution.

AIT, located 40 km north of Bangkok and 30 km south of Ayutthaya station, is an international graduate university that draws 650 students from 25 countries. The CRSP project collaborates with the aquaculture faculty of the Agricultural and Food Engineering Division at AIT. The aquaculture program at AIT focuses its research on integrated animal-fish pond culture, uses of aquatic weeds, and composts for fish production and rice-fish culture. Tilapia, walking catfish, and Chinese and Indian carp are common species used in various aquaculture systems on the AIT campus and its rural fish ponds. The current aquaculture program involves 30 graduate students, five faculty members, and ten technicians. The program has access to 50 earthen ponds (200-1800 m^2), a hatchery with more than 100 cement ponds with a water reuse system, and a well-equipped analytical laboratory. A set of twenty 400-m^2 ponds are assigned for the CRSP experiment. A water reservoir (5 ha surface area and 12 m depth) provides source water for pond and cage culture.

The new managerial arrangement among U.S. and Host Country institutions was established in September 1988. UM serves as lead U.S. institution and represents UM, MSU, and UH in Thailand. This arrangement has facilitated the negotiation and signing of bilateral agreements with DOF and AIT. Dr. James Diana of UM is responsible for project coordination among the three U.S. institutions and Dr. Kwei Lin is the Host Country resident coordinator. He oversees the collaborative efforts between the U.S. and Host Country institutions, as well as logistics for project experiments.

Economics Research Opportunities in Thailand

Results from the CRSP experiments in Thailand may provide aquacultural producers with information on how to increase their biological output, but will not give them any guidance as to which alternative fertilizer regime has the greatest economic efficiency. Economic efficiency relates fish yield to the costs of production and consumer response to changes in the market supply of fish. Efficient application rates will be those that are most cost-effective. Any recommendation on what rates to use in commercial aquaculture operations, therefore, should include information on the cost effectiveness of each alternative and any anticipated commercial market reaction.

A research proposal to conduct an economic study of the CRSP experiment in Thailand was submitted to the CRSP Program Management Office in November 1987. Travel to Thailand to initiate the study was funded by the Institute of International Agriculture at Michigan State University (MSU). Principal researchers involved in the economic study are: Jeffrey Hanson, a resource economist in the Department of Fisheries and Wildlife at MSU, and Ratana Chuenpagdee, Faculty of Fisheries, University of Kasetsart, Bangkok. Dr. Hanson, Ms. Chuenpagdee and others initiated the economic studies in Thailand in concert with the CRSP Cycle

IV experiment, which started in January 1988. Contacts were made with staff economists from the Royal Thai Department of Fisheries, the Faculty of Fisheries at the University of Kasetsart, the Ministry of Agriculture, and with Dr. Thiraphan Bhukaswan and Dr. C. Kwei Lin.

Participation in International Scientific Meetings and Conferences

CRSP researchers from the U.S. and Host Countries participated in a number of international aquaculture conferences and meetings.

- The Pond Dynamics/Aquaculture CRSP was well represented at the January 1988 World Aquaculture Society meeting in Honolulu, Hawaii. The meeting was uniquely geared toward the interests of the CRSP with two special sessions: marketing strategies in aquaculture and aquaculture in developing countries. Twenty-five CRSP researchers attended the meeting and over 15 papers were presented on CRSP-related research. Please refer to the Appendix B (List of Publications) for titles of papers; abstracts for several papers are presented under the section, Special Topics Projects.

- Dr. Raul Piedrahita, member of the Data Analysis and Synthesis Team from the University of California at Davis, presented a paper, "Modeling vertical water quality profiles in aquaculture ponds: Review and evaluation" at the Institute of Chemical Engineers Meeting in Stirling, Scotland. His graduate student, who also works with the CRSP data base, presented a paper at the Summer Meeting of the American Society of Agricultural Engineers in Rapid City, South Dakota entitled, "Analysis and modeling of dissolved oxygen in warm water aquaculture ponds."

- Two invited seminars on CRSP work in Southeast Asia were presented in Japan by Dr. Cal McNabb in conjunction with his site visit to Thailand in 1988. "Management of pond fertilizers for high fish yield" was presented to the faculty and students of the Agricultural University of Tokyo (NODAI) in May 1988 and "Conditions for pond aquaculture in Java" was presented to the faculty of Shiga University in June 1988. These seminars were both well attended and well received. The relationship of CRSP work to projects of the Japanese government in Southeast Asia was a topic of discussion following both presentations.

PROGRAM MANAGEMENT AND TECHNICAL GUIDANCE

The basic organizational structure of the Pond Dynamics/Aquaculture CRSP remained the same as in previous years although there were some notable changes in membership of the various governing bodies. New membership reflects the consolidation of the CRSP into three countries. New appointments were made to the Management Entity, the Board of Directors, 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. The new location, which is next to the Oregon State University Administration Building, facilitates the streamlining of many administrative details essential in properly servicing the CRSP Grant. The CRSP also is part of OSU International Fisheries at OIRD, which is comprised of the Consortium for International Fisheries and Aquaculture Development (CIFAD), the Foreign Fisheries Observer Program, and the International Institute of Fisheries Economics and Trade. The new arrangement with OIRD affords the Management Entity increased support in accounting, purchasing, and other services. The Management Entity is now fully integrated into the larger framework of international agricultural programs at Oregon State University and derives benefits from interacting with these programs. The CRSP, formerly part of the Department of Fisheries and Wildlife in the College of Agriculture, now reports directly to the Vice President for Research, Graduate Studies, and International Programs through the Director of OIRD. Ties to the Department of Fisheries and Wildlife, however, are maintained through faculty appointments and academic interests.

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

- Dr. Howard H. Horton, Director (0.55 FTE)
- Ms. Hillary S. Egna, Assistant Director (1.0 FTE)
- Dr. Kevin Hopkins, Data Base Manager (0.5 FTE) to June 1988
- Ms. Hilary Berkman, Data Base Manager (0.4 FTE) from May 1988
- Mrs. Lydia Perry, Secretary (0.5 FTE)

The Management Entity is responsible for:

- Receiving funds committed by USAID to the CRSP and assuming accountability for their use;
- Providing funds to the participating institutions, and ensuring compliance with terms of the Grant;
- Providing a focal point for the interaction of the Technical Committee,

Board of Directors, External Evaluation Panel, USAID Staff, and BIFAD/JCARD;
- Executing the decisions of the governing and advisory bodies;
- Implementing the program; and
- Maintaining liaisons with overseas and domestic participants.

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

Specific accomplishments include:

- Preparation of a three-year continuation plan, which was approved as the new CRSP Grant, and of new subcontracts with participatory U.S. universities;
- Preparation of CRSP budgets and subcontractual modifications for extending funding and performance periods;
- 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 -- abstracts and tables of contents of current journals are sent to each U.S. Research Associate as requested;
- Publication of research results in two new technical report series and in the program newsletter;
- Organization of the sixth annual CRSP meeting in Kona, Hawaii on January 10-14, 1988 and participation in attendant Board Meetings and Technical Committee meetings;
- Development of a new program brochure;
- Nomination to the Board of Directors of a new External Evaluation Panel Member, Dr. Herminio Rabanal;
- Coordination of the development of the Fourth 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;
- Development of questionnaires to evaluate the Annual and Technical Committee meetings, and to coordinate meeting logistics to better enable host country participants to attend;
- Creation of a new directory which lists CRSP participants' electronic mail codes (e.g., FAX, BITNET, TELEX, MCI);
- Initiation of dialogue with Mr. Floyd O'Quinn (USAID/Washington) regarding CRSP and University of Arkansas at Pine Bluff (UAPB) participation in the grants program for historical black colleges and universities;
- Participation in the "CRSP University Financial Management Workshop," sponsored by AID in Washington, D.C. on 19 November 1987;
- Coordination of activities (meetings and travel) for the External Evaluation Panel and USAID staff as part of the Triennial Review;
- Participation in Board Meetings and Technical Committee meetings;
- Assistance to S&T/AGR through participation on several CRSP Council Conference calls; and
- Coordination of new administrative and contractual details for the collaborative research project in Thailand and Honduras.

Technical Committee

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

Board of Directors

As the primary policy-making body for the CRSP, the Board of Directors has taken 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. Donovan Moss, Auburn University, Chairman;
- Dr. Robert Fridley, University of California at Davis, Member;
- Dr. Philip Helfrich, University of Hawaii (CIFAD institution), Member;
- Dr. Richard Neal, USAID S&T/AGR, Ex-Officio Member;
- Dr. Howard Horton, Oregon State University, CRSP Director, Ex-Officio Member.

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

October 9, 1987	Telephone Conference Call
October 28, 1987	Telephone Conference Call
January 12, 1988	Kona, Hawaii
January 14, 1988	Kona, Hawaii
February 29, 1988	Telephone Conference Call

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;
- Advising 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 Management and the Data Synthesis Team;
- Approval of management and research budgets;
- Appointment of a new member to the External Evaluation Panel;
- Collaboration and coordination of the research program in Thailand;

- Specific recommendations for relocating the CRSP project in Central America;
- Decision to change the role of the at-large Technical Committee to ad hoc participation on the Technical Committee;
- Annual meeting agenda input and approval;
- Advice on international travel procedures;
- Guidance on efforts to strengthen the program in the face of funding constraints; and
- Participation in the sixth annual program meeting in January 1988.

External Evaluation Panel

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

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

The External Evaluation Panel reviewed the technical plan for continuation of the Global Experiment from 1987 to 1990. They provided input on policy matters, the agenda, and discussion topics for the 1988 CRSP Annual Meeting. At the Annual Meeting, the External Evaluation Panel initiated their second major review of the program by interviewing CRSP researchers and staff from the Program Management Office. They followed up these interviews with visits to the three current CRSP sites and to two former CRSP sites (the two sites in Panama were not visited). Their review, with the USAID Administrative Management Review, will provide guidance for the Triennial Review, which is conducted by the JCARD CRSP panel and USAID's Agriculture Sector Council Subcommittee.

CRSP PUBLICATIONS

The CRSP has facilitated technology dissemination through the establishment of 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 275 reports and theses have resulted from CRSP research worldwide.

The two publication series that were launched last year have attracted many new readers. Nearly 300 people 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 six years. *Aquanews*, the program's newsletter, contains informative articles on field projects, summaries of training courses and meetings about aquaculture, and brief notes on the program and its participants. *Aquanews* provides a forum for host country and U.S. participants to share ideas and preliminary research findings.

The Program Management Office also contributes articles to international newsletters, such as AID's *Star* and *Frontlines* and newsletters from other CRSP's and international programs. 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.

List of Reports and Documents

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.

Annual Administrative Report

Pond Dynamics/Aquaculture CRSP, Program Management Office. March 1988. Fifth Annual Administrative Report. Office of International Research and Development, Oregon State University, Corvallis, Oregon. 71 pp.

CRSP Work Plan

Pond Dynamics/Aquaculture CRSP, Program Management Office. November 1988. September 1, 1987 - August 31, 1989. Fourth Experimental Cycle. Office of International Research and Development, Oregon State University, Corvallis, Oregon. 71 pp.

Brochure

Brochure. June 1988. Program Management Office. Office of International Research and Development, Oregon State University, Corvallis, Oregon.

The new brochure contains updated information on the research projects, the participating institutions and scientists, and the CRSP Global Experiment.

Directory

Pond Dynamics/Aquaculture CRSP, Program Management Office. 1988 CRSP Directory. Office of International Research and Development, Oregon State University, Corvallis, Oregon.

The CRSP Directory was updated twice in 1988, in May and October, to account for changes in program personnel. The directory contains an organizational flowchart 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.

Newsletter

With the emergence of the new CRSP technical publications, the relative need for a program newsletter has declined. *Aquanews* will continue as an occasional publication. It will serve to inform CRSP participants and others of program activities that are not of a technical nature. *Aquanews* will contain information on meetings, travel of CRSP participants, and site visits. 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 communication among Collaborative Research Support Programs during the past year has resulted in exchanges between newsletters. An article about the Pond Dynamics/Aquaculture CRSP was submitted to the Stock Assessment CRSP's newsletter. *Aquanews* also will carry articles about other CRSP's and international fisheries and aquaculture projects.

Technical Reports

CRSP Research Reports

Batterson, T.E., C.D. McNabb, C.F. Knud-Hansen, H.M. Eidman and K. Sumantadinata. 1988. Effect of Chicken Manure Additions on Fish Production in Ponds in West Java, Indonesia. CRSP Research Reports 88-8, Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon. 6 pp.

Carpenter, K.E., A.W. Fast, V.L. Corre, J.W. Woessner and R.L. Janeo. 1988. The Effects of Water Depth and Circulation on the Water Quality and Production of Penaeus monodon in Earthen Ponds. CRSP Research Reports 88-6, Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon. 4 pp.

Fortes, R.D., V.L. Corre and E. Pudadera. 1988. Effects of Fertilizers and Feeds as Nutrient Sources on *Oreochromis niloticus* Production in Philippine Brackishwater Ponds. CRSP Research Reports 88-12, Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon. 6 pp.

Lin, C. Kwei. 1988. Acidification and Reclamation of Acid Sulfate Soil Fishponds in Thailand. CRSP Research Reports 88-4, Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon. 4 pp.

Minsalan, C.L.O. and Y.N. Chiu. 1988. Effects of Teaseed Cake on Selective Elimination of Finfish in Shrimp Ponds. CRSP Research Reports 88-11, Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon. 4 pp.

Sanares, R.C., S.A. Katase, A.W. Fast and K.E. Carpenter. 1988. Water Quality Dynamics in Brackishwater Shrimp Ponds with Artificial Aeration and Circulation. CRSP Research Reports 88-7, Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon. 4 pp.

Sikoki, F.D., R.A. Tubb and L.R. Curtis. 1988. Elevation of Sex Steroids and Inhibition of UDP-glucuronyltransferase are Out of Phase During Gonadal Maturation in the Common Carp. CRSP Research Reports 88-10, Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon. 1 pp.

Teichert-Coddington, D.R., N. Stone and R.P. Phelps. 1988. Hydrology of Fish Culture Ponds in Gualaca, Panama. CRSP Research Reports 88-9, Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon. 1 pp.

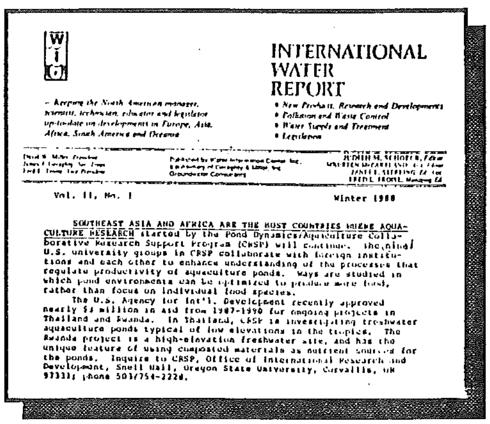
Ver, L.M.B. and Y.N. Chiu. 1988. The Effect of Paddlewheel Aerators on Ammonia and Carbon Dioxide Removal in Intensive Pond Culture. CRSP Research Reports 88-5, Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon. 4 pp.

CRSP Research Reports 88-9 and 88-10 were issued as Notices of Publication, which provide the abstract of the paper and information on where copies may be obtained. *CRSP Research Reports* and Notices of Publication provide a means for the CRSP to comprehensively document all of the research activities conducted by CRSP personnel.

Research Reports is widely distributed and reaches a diverse audience, such as USAID and BIFAD personnel, the world scientific community, USAID Missions, farmers in less developed countries, students, Pond Dynamics/Aquaculture CRSP participants, other CRSP's, and USAID projects.

Collaborative Research Data Reports

McNabb, C.D., T.R. Batterson, B.J. Premo, H.M. Eidman and K. Sumatadinata. 1988. Indonesia: Cycle I of the Global Experiment. Collaborative Research Data Reports, Volume 3. Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon. 67 pp.

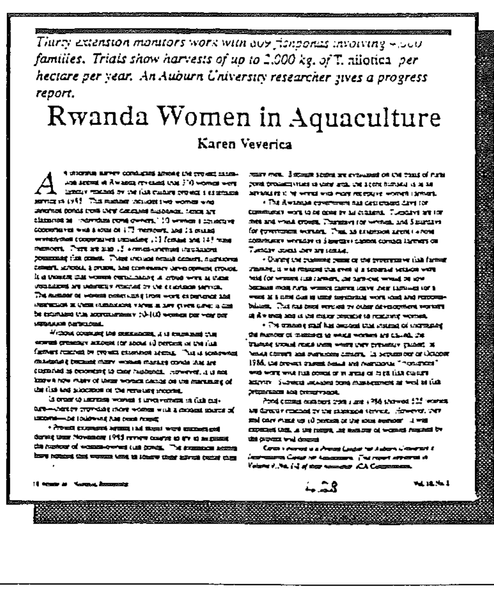


INTERNATIONAL WATER REPORT

Vol. II, No. 1 — Winter 1988

SOUTHEAST ASIA AND AFRICA ARE THE HOST COUNTRIES WHERE AQUACULTURE RESEARCH started by the Pond Dynamics/Aquaculture Collaborative Research Support Program (CRSP) will continue. The nine U.S. university groups in CRSP collaborate with foreign institutions and each other to enhance understanding of the processes that regulate productivity of aquaculture ponds. Ways are studied in which pond environments can be optimized to produce more food, rather than focus on individual food species.

The U.S. Agency for Int'l. Development recently approved nearly $4 million in aid from 1987-1990 for ongoing projects in Thailand and Rwanda. In Thailand, CRSP is investigating freshwater aquaculture ponds typical of low elevations in the tropics. The Rwanda project is a high-elevation freshwater site, and has the unique feature of using composted materials as nutrient sources for the ponds. Inquire to CRSP, Office of International Research and Development, Snell Hall, Oregon State University, Corvallis, OR 97331; phone 503/754-2228.



Thirty extension monitors work with 809 fishponds involving 4,000 families. Trials show harvests of up to 2,000 kg. of T. nilotica per hectare per year. An Auburn University researcher gives a progress report.

Rwanda Women in Aquaculture

Karen Veverica

ENLACE

IMPULSA PISCICULTURA NACIONAL

PROBLEMAS DE LA ESTACION EL CARAO

ACTIVIDADES DE EXTENSION Y PROMOCION

ACTIVIDADES DE INVESTIGACION

STAFF SUMMARY

The Pond Dynamics/Aquaculture CRSP represents the joint efforts of more than 50 professionals and a number of support personnel from U.S. universities. It also represents the collaborative efforts of over 40 scientists, technicians, and graduate students from three project sites in three developing countries. The expertise of host country and U.S. personnel is broad-based and encompasses the major fields of specialization included in this CRSP: Limnology and Water Quality; Fisheries and Aquaculture; Data Management, Analysis, and Modeling; and Research Administration. Agricultural Economics, a new area of expertise for this CRSP, was added during this reporting period.

In addition to staff with formal CRSP assignments, many individuals have participated in the development of host country projects. The CRSP team in Thailand reported that over 20 professors and researchers from the Royal Thai Department of Fisheries and the Asian Institute of Technology play an active role in the program. Growing interest in the CRSP in Honduras and Rwanda also has resulted in an increase in the number of host country scientists involved in CRSP work.

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

STAFF SUMMARY: COLLABORATIVE RESEARCH PROJECTS

(1 Sep 87 - 31 Aug 88)

Individual	CRSP Function	Field(s) of Specialization				Location of Work (1)
		Research Admin.	Limnology/ Water Quality	Fisheries/ Aquaculture	Data Management	
BOARD OF DIRECTORS						
Dr. Donovan D. Moss	Chairman	x		x		Auburn, Alabama
Dr. Philip Helfrich	Member	x		x		Kaneohe, Hawaii
Dr. Robert Fridley	Member	x	x	x		Davis, California
AT-LARGE TECHNICAL COMMITTEE						
Dr. Donald Garling	Member			x		East Lansing, Michigan
Dr. R. Oneal Smitherman	Member			x		Auburn, Alabama
Dr. G. Tchobanoglous	Member			x		Davis, California
MANAGEMENT ENTITY						
Dr. Howard Horton	Director	x		x		Corvallis, Oregon
Ms. Hillary Egna	Assistant Director	x	x	x		Corvallis, Oregon
Dr. Kevin Hopkins	Associate Director of Data Mgmt. (to 5/88)	x		x	x	Corvallis, Oregon
Ms. Hilary Berkman	Data Base Mgr. (from 5/88) Graduate Research Assistant (to 5/88)		x	x	x	Corvallis, Oregon
Mrs. Lydia Perry	Secretary	x				Corvallis, Oregon
Mr. Bruce Sorte	Fiscal Officer	x				Corvallis, Oregon

STAFF SUMMARY: COLLABORATIVE RESEARCH PROJECTS

Individual	CRSP Function	Field(s) of Specialization: Research Admin.	Limnology/ Water Quality	Fisheries/ Aquaculture	Data Management	Location of Work (1)
HONDURAS/PANAMA						
HONDURAS (from 2/88)/PANAMA (to 12/87)-AUBURN UNIVERSITY						
Dr. Ronald P. Phelps	U.S. Principal Investigator	x		x		Auburn, Alabama
Dr. David Hughes	U.S. Research Associate (to 2/88)			x		Auburn, Alabama
Dr. David Teichert-Coddington	U.S. Research Associate		x	x		Auburn, Alabama
Mr. Donald Large	Fiscal Officer	x				Auburn, Alabama
HONDURAS (from 2/88)/PANAMA (to 12/87)-UNIVERSITY OF HAWAII						
Dr. Arlo Fast	U.S. Principal Investigator (to 1/88)	x		x		Univ. of Hawaii
Dr. Robert Brick	U.S. Principal Investigator (from 1/88)	x		x		Univ. of Hawaii
Mr. William Coops	Fiscal Officer	x				Univ. of Hawaii
PANAMA (to 12/87)-HOST COUNTRY PERSONNEL						
Dr. Richard Pretto Malca	H.C. Principal Investigator	x		x		Santiago de Veraguas, Panama
Mr. Jorge Garcia	H.C. Station Chief			x	x	Aguadulce, Panama
Ms. Graciela de Gomez	H.C. Chemistry Lab Director		x			Aguadulce, Panama
Mr. Ernesto Lasso de la Vega	H.C. Field Biologist			x		Aguadulce, Panama
Ms. Cenobia Quintero	H.C. Field Biologist			x		Aguadulce, Panama
Mrs. Marquisela Arrue de Friedman	H.C. Field Biologist			x		Aguadulce, Panama
Mr. Modaldo Bonilla	H.C. Technician			x		Aguadulce, Panama
Mr. Rugierro del Valle	H.C. Data Processor			x	x	Aguadulce, Panama
Mr. Lenin Santamaria	H.C. Field Biologist		x	x		Aguadulce, Panama
Mrs. Dora Hernandez de Santamaria	H.C. Field Biologist			x	x	Aguadulce, Panama
Mr. Hipolito Chavez	H.C. Field Biologist			x		Aguadulce, Panama
Mr. Miguel de Leon	H.C. Field Biologist			x		Aguadulce, Panama

STAFF SUMMARY: COLLABORATIVE RESEARCH PROJECTS

Individual	CRSP Function	Field(s) of Specialization: Research Admin.	Limnology/ Water Quality	Fisheries/ Aquaculture	Data Management	Location of Work (1)
PANAMA HOST COUNTRY PERSONNEL (CONT.)						
Mr. Hamed Tunon	H.C. Field Biologist			x		Aguadulce, Panama
Ms. Aida de Urriola	Administrative Assistant	x				Aguadulce, Panama
Ms. Eva Yaniselli	H.C. Chemist		x			Aguadulce, Panama
Ms. Luz Divina	H.C. Computer Technician	x			x	Aguadulce, Panama
Ms. Blanca Canto	H.C. Librarian	x				Aguadulce, Panama
Ms. Illeana de Zapata	H.C. Technician			x		Aguadulce, Panama
Mr. Medardo Peralta	H.C. Research Associate			x		Gualaca, Panama
Mr. Nelly Serano	H.C. Technician		x			Gualaca, Panama
Mr. Ricardo Rios	H.C. Technician			x		Gualaca, Panama
Ms. Itozela Davis	H.C. Technician			x		Gualaca, Panama
HONDURAS (from 2/88)-HOST COUNTRY PERSONNEL						
Mr. Adan Benavides	H.C. Principal Investigator	x				Tegucigalpa, Honduras
Ing. Hermes Alvarenga	H.C. Research Associate			x		Comayagua, Honduras
Mr. Nelson Hernandez	H.C. Chemist		x			Comayagua, Honduras
Mr. Sagrario Calix	H.C. Secretary	x				Comayagua, Honduras
Mr. Ivan Rodriguez	H.C. Station Manager			x		Comayagua, Honduras
Mr. Miguel Zelanya	H.C. Lab Technician			x		Comayagua, Honduras

STAFF SUMMARY: COLLABORATIVE RESEARCH PROJECTS

Individual	CRSP Function	Field(s) of Specialization: Research Admin.	Limnology/ Water Quality	Fisheries/ Aquaculture	Data Management	Location of Work (1)
		RWANDA				
RWANDA - OREGON STATE UNIVERSITY						
Mr. Wayne Seim	U.S. Principal Investigator	x	x			Corvallis, Oregon
Dr. Richard Tubb	U.S. Co-Principal Investigator	x		x		Corvallis, Oregon
Mr. Bruce Sorte	Fiscal Officer	x				Corvallis, Oregon
Mr. Felicien Rwangano	Oregon State University Graduate Student			x		Corvallis, Oregon
RWANDA - AUBURN UNIVERSITY						
Dr. Ron Phelps	U.S. Principal Investigator	x	x			Auburn, Alabama
Ms. Karen Veverica	U.S. Research Associate		x	x	x	Auburn, Alabama
Mr. Donald Large	Fiscal Officer	x				Auburn, Alabama
RWANDA - HOST COUNTRY PERSONNEL						
Dr. Innocent Butare	H.C. Principal Investigator	x	x			Rwanda
Mr. Eugene Rurangwa	H.C. Research Associate			x		Rwanda
Dr. Venant Ntabomvura	H.C. Participant	x		x		
Dr. Runyinya Barabwiliza	H.C. Participant	x		x		Rwanda
Dr. Valens Ndoreyaho	H.C. Participant	x		x		Rwanda
Mr. Lieven Verheust	H.C. Participant			x		Rwanda
Mr. Ngoy Kasongo	H.C. Technician		x			Rwanda
Mr. Alfonsine Murekeyisoni	H.C. Technician		x			Rwanda
Mr. Joseph Murangwa	H.C. Computer Technician				x	Rwanda

STAFF SUMMARY: COLLABORATIVE RESEARCH PROJECTS

Individual	CRSP Function	Field(s) of Specialization: Research Admin.	Limnology/ Water Quality	Fisheries/ Aquaculture	Data Management	Location of Work (1)
			THAILAND			
THAILAND - UNIVERSITY OF MICHIGAN						
Dr. James Diana	U.S. Principal Investigator			x		Ann Arbor, Michigan
Dr. C. Kwei Lin	U.S. Co-Principal Investigator			x		AIT, Thailand
Mr. Daniel Dettweiler	U.S. Research Assistant			x		Ann Arbor, Michigan
Ms. Barbara Murphy	Fiscal Officer	x				Ann Arbor, Michigan
THAILAND - MICHIGAN STATE UNIVERSITY						
Dr. Clarence McNabb	U.S. Co-Principal Investigator		x	x		East Lansing, Michigan
Dr. Ted Batterson	U.S. Co-Principal Investigator	x	x		x	East Lansing, Michigan
Dr. Chris Knud-Hansen	U.S. Research Associate		x	x		AIT, Thailand
Mr. Gerald Jacobs	Fiscal Officer	x				East Lansing, Michigan
THAILAND - UNIVERSITY OF HAWAII						
Dr. Arlo Fast	U.S. Co-Principal Investigator (to 1/88)	x		x		Honolulu, Hawaii
Dr. Robert Brick	U.S. Co-Principal Investigator (from 1/88)			x		Honolulu, Hawaii
Mr. William Coops	Associate Fiscal Officer	x				Honolulu, Hawaii
THAILAND - HOST COUNTRY PERSONNEL						
Dr. Kitjar Jaiyen	H.C. Principal Investigator (from 2/87)		x	x		NIFI, Thailand
Dr. Sompong Hiranyawat	H.C. Research Associate			x		NIFI, Thailand
Dr. Sompotte Ukatawewat	H.C. Research Associate			x		Ayuthaya, Thailand
Mr. Kiengkai	H.C. Research Assistant		x			NIFI, Thailand
Mr. Sanga	H.C. Research Assistant		x			NIFI, Thailand
Mr. Agaluck Saloaw	H.C. Research Assistant			x		Chacheongsao, Thailand
Mr. Tongsuk Saelee	H.C. Research Assistant			x		Chacheongsao, Thailand
Mr. Supranee Chinabut	H.C. Scientific Collaborator			x		NIFI, Thailand
Mr. Chalor Limsuwan	H.C. Scientific Collaborator			x		Kasetsart Univ., Thailand

STAFF SUMMARY: COLLABORATIVE RESEARCH PROJECTS

Individual	CRSP Function	Field(s) of Specialization				Location of Work (1)
		Research Admin.	Limnology/ Water Quality	Fisheries/ Aquaculture	Data Management	
DATA ANALYSIS AND SYNTHESIS						
DATA ANALYSIS AND SYNTHESIS - OREGON STATE UNIVERSITY						
Dr. James Lannan	Data Synthesis Team Member	x		x	x	Newport, Oregon
Mr. Jim Bowman	Graduate Student		x	x		Corvallis, Oregon
Mr. Andy Snow	Graduate Student		x	x		Corvallis, Oregon
Mr. Bruce Sorte	Fiscal Officer	x				Corvallis, Oregon
DATA ANALYSIS AND SYNTHESIS - UNIVERSITY OF MICHIGAN						
Dr. William Chang	Data Synthesis Team Member		x	x	x	Ann Arbor, Michigan
Ms. Barbara Murphy	Fiscal Officer	x				Ann Arbor, Michigan
DATA ANALYSIS AND SYNTHESIS - UNIVERSITY OF CALIFORNIA AT DAVIS						
Dr. Raul Piedrahita	Data Synthesis Team Leader		x	x	x	Davis, California
Mr. Steven Francis	Data Synthesis Assistant				x	Davis, California
Mr. Gary Grace	Data Synthesis Assistant				x	Davis, California
Mr. Philip Giovannini	Data Synthesis Assistant				x	Davis, California
Mr. George Max	Fiscal Officer	x				Davis, California

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

FINANCIAL STATUS REPORT

This section summarizes the expenditure of USAID, non-federal, and host country funds for CRSP research activities and program management. This unaudited summary is intended to provide an overview of CRSP progress relative to program budgets and matching support.

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 September 1, 1987 to August 31, 1988. Because this is the first year of a three-year grant, 1988 expenditures and cumulative expenditures are the same. The data for the Collaborative Research Projects includes all expenditures made to support research efforts at four project sites from September 1, 1987 to August 31, 1988. Our Continuation Plan called for research projects at three sites, namely Panama, Rwanda, and Thailand. In mid-December, 1987, we were required to leave Panama by USAID directive. We received approval to re-establish the Panama CRSP in Honduras in June 1988. Accordingly, Auburn University expended USAID funds for research activities in both Panama and Honduras. No expenditures were reported by the University of Hawaii for research efforts in Honduras, and by the University of Arkansas at Pine Bluff for activities in Rwanda. In both instances, turnover in project personnel delayed the start of their planned research efforts. These positions have subsequently been filled, and funds have been obligated. The data for Special Topics includes expenditures to support the Data Analysis and Synthesis Teams at Oregon State University, University of California, Davis, and The University of Michigan.

The information on Program Management expenditures includes expenses to support the Program Management Office, the Board of Directors, the External Evaluation Panel, and the Data Base Management function. Because this is a Triennial Review year, expenses for the External Evaluation Panel were substantial.

Cost sharing contributions from the U.S. institutions are presented in Table 1. The amounts reported give a cost sharing of 34 percent, considerably in excess of the 25 percent requirement. These data reflect a strong and continuing commitment by program entities to participation in the CRSP. However, confirmation of these data requires further accounting because the amounts to be excluded in calculating cost sharing requirements in accordance with BIFAD guidelines must be determined after the fact.

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

Table 1. Financial Summary of the Pond Dynamics/Aquaculture CRSP Funds, Cost Sharing, and Host Country Contributions for the Period September 1, 1987 to August 31, 1988.

Collaborative Research Projects	USAID Funds		Cost Sharing		Total		Host Country	
	1988	Cumulative	1988	Cumulative	1988	Cumulative	1988	Cumulative
Honduras-Auburn U.	26,469	26,469	6,797	6,797	33,266	33,266	14,850	14,850
-U. Hawaii	0	0	0	0				
Panama-Auburn U.	87,282	87,282	25,743	25,743	113,025	113,025	30,150	30,150
Rwanda-Auburn U.	56,316	56,316	20,104	20,104	76,420	76,420		
-Oregon State U.	57,011	57,011	18,696	18,696	75,707	75,707	46,980	46,980
-U. Arkansas P.B.	0	0	0	0				
Thailand-Michigan S. U.	30,402	30,402	40,094	40,094	70,496	70,496		
-U. Hawaii	5,308	5,308	7,642	7,642	12,950	12,950		
-U. Michigan	111,201	111,201	13,255	13,255	124,456	124,456	43,000	43,000
Subtotal	373,989	373,989	132,331	132,331	506,320	506,320	134,980	134,980
Special Topics								
Oregon State U.	23,410	23,410	7,725	7,725	31,135	31,135		
U. California, Davis	42,600	42,600	10,650	10,650	53,250	53,250		
U. Michigan	57,405	57,405	17,221	17,221	74,626	74,626		
Subtotal	123,415	123,415	35,596	35,596	159,011	159,011		
Program Mgmt.								
Mgmt. Office, OSU	174,587	174,587			174,587	174,587		
Boards, Comm., Pnls	22,207	22,207			22,207	22,207		
Subtotal	196,794	196,794			196,794	196,794		
TOTAL	694,198	694,198	167,927	167,927	862,125	862,125	134,980	134,980

APPENDIXES

Appendix A. Excerpts from the CRSP Fourth Work Plan.

Appendix B. List of Publications by CRSP Participants.

Appendix C. Dissolved Oxygen Models.

Appendix D. List of Acronyms.

Appendix A. Excerpts from the CRSP Fourth Work Plan.

This work plan differs from earlier work plans in which the same experiment was conducted at each location. Hypotheses about pond dynamics will be tested in different field experiments at each research location. It is anticipated that this procedure will allow the CRSP to proceed rapidly through the testing process. Otherwise, many years of work would be required to thoroughly evaluate each hypothesis at all sites.

In addition to the division of experiments between the sites, the CRSP global experiment will continue intensive sampling of pond variables during the course of each field experiment. A standard sampling protocol will be used at all locations, and the standardized data will be added to the CRSP Data Base to make the existing information even more comprehensive. Sampling protocol, descriptions of field experiments, and data synthesis activities are presented below.

The CRSP Global Experiment

CRSP researchers should read this section carefully because there have been significant changes from previous work plans. In particular, section headings have been changed to reflect alterations in the sampling protocol, some parameters are no longer required, and the frequency of sampling for the "diurnal" studies (now more appropriately named "diel" studies) has been changed from every six hours to the following: pre-dawn, 1000, 1400, 1600, 1800, 2300, and pre-dawn of the next day. Unless otherwise indicated, the fish cultural and analytical methods are as presented in appropriate appendixes to the third CRSP work plan. Please refer to Standard Methods for the Examination of Water and Wastewater for methods not included in the third work plan. Some methods for new procedures are included in the appendix for easy reference. All research locations will follow the same protocol for daily measurements, intensive sampling measurements, fish measurements, optional measurements, and occasional measurements.

Daily Measurements

The following meteorological and physical pond parameters will be recorded daily:

- Solar Radiation
- Wind Speed (*Note*: Anemometers are to be set at a height of 2 m above the level of the pond banks)
- Air Temperature (maximum and minimum)
- Rainfall
- Evaporation
- Pond Depth
- Pond Inflow

Intensive Sampling Measurements

There will be three intensive sampling periods for each experiment: (1) during the second week; (2) midway through the experiment; and (3) during the final week. A number of parameters will be determined on a whole water column sample for each pond in addition to the studies. Primary productivity will be determined by calculation from data collected during the diel studies (i.e., whole pond determinations). The variables to be observed are:

- Total Kjeldahl Nitrogen
- Ammonia Nitrogen
- Total Phosphorus
- Secchi Disk
- Chlorophyll *a*
- Dark Bottle Respiration
- Total Suspended Solids
- Total Volatile Solids
- Diel Studies (Sampling times: pre-dawn, 1000, 1400 1600, 1800, 2300, and pre-dawn the next day. Sample at three depths (top, middle, bottom) for each pond): Dissolved Oxygen
  - Temperature
  - pH
  - Alkalinity
  - Wind (cumulative between sampling times)
  - Solar Radiation (cumulative between sampling times)

Fish Measurements

Sex-reversed *Oreochromis niloticus* of an average weight of 25 grams will be stocked at a rate of two fish/m^2 (20,000 fish/hectare). In addition to the specific measurements listed below, a record will be kept of any reproduction that may occur during the experiment.

- Initial Stocking
  - Total Number
  - Group Weight
  - Mean Weight per Individual
  - Mean Length per Individual
- Monthly Sampling
  - Sample Number
  - Group Weight
  - Mean Weight per Individual
  - Mean Length per Individual
- Harvest
  - Total Number
  - Group Weight
  - Mean Weight per Individual
  - Mean Length per Individual
  - Survival (% of initial stocked)

Optional Monthly Measurements

- Phytoplankton Composition
- Zooplankton Composition
- Benthos Composition

Occasional Measurements

- Pond Soil Characteristics at the beginning and end of each experiment
- Liming Requirements
- Pond Morphometric Characteristics
- Seepage (to complete hydrological characteristics, most of which are included under "Daily Measurements" above)
- Chemical Oxygen Demand (COD) of Inputs
- Nutrient Analysis of Inputs

APPENDIX B. LIST OF PUBLICATIONS

Pond Dynamics/Aquaculture
Collaborative Research Support Program
As of 12/88

AUBURN/HONDURAS

Theses

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

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

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

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

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

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

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

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

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

Reports

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

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

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

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

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

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

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

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

Green, B.W., H.R. Alvarenga, R.P. Phelps and J. Espinoza. 1988. Technical Report: Honduras Aquaculture C.R.S.P. Cycle 3 Rainy and Dry Season Phases. C.R.S.P. Technical Report, unpublished. Auburn University, Alabama.

Green, B.W., H.R. Alvarenga, R.P. Phelps and J. Espinoza. 1987. Technical Report: Honduras Aquaculture C.R.S.P. Cycle 2 Rainy Season Phase. C.R.S.P. Technical Report, unpublished. Auburn University, Alabama.

Green, B.W., H.R. Alvarenga, R.P. Phelps and J. Espinoza. 1986. Technical Report: Honduras Aquaculture C.R.S.P. Cycle 1 Rainy Season Phase. C.R.S.P. Technical Report, unpublished. Auburn University, Alabama. 77 pp.

Green, B.W., H.R. Alvarenga, R.P. Phelps and J. Espinoza. 1986. Technical Report: Honduras Aquaculture C.R.S.P. Cycle 2 Dry Season Phase. C.R.S.P. Technical Report, unpublished. Auburn University, Alabama.

Green, B.W., H.R. Alvarenga, R.P. Phelps and J. Espinoza. 1985. Technical Report: Honduras Aquaculture C.R.S.P. Cycle 1 Dry Season Phase. C.R.S.P. Technical Report, unpublished. Auburn University, Alabama. 51 pp.

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

Presentations

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

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

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

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

Manuscripts

Green, B.W., R.P. Phelps, and H.R. Alvarenga. 1989. The effect of manures and chemical fertilizers on the production of *Oreochromis niloticus* in earthen ponds. Accepted for publication in Aquaculture.

AUBURN/PANAMA-AGUADULCE

Theses

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

Avila, M. In preparation. El efecto del policultivo del pez, _Mugil curema_, a varios densidades de siembra con la produccion de _Penaeus vannamei_ y en la calidad de agua en estanques de tierra. Licenciatura Thesis in Biology, Catholic University of Chile, Santiago, Chile.

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

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

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

Lore, D., H.T. y R. Visuetti. 1984. Efecto de la aplicacion de abonos organicos, concentrados y pescado fresco (_Dormitator latifrons_) en la produccion de _Penaeus stylirostris_ y _Penaeus vannamei_. Licenciatura Thesis in Biology, Univ. Panama.

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

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

Reports

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

Scientific Papers Presented

Chavez, H. December, 1984. Estudio trofodinamico de _Penaeus vannamei_ cultivado en estanques experimentales de aguas salobres. Presented to the First National Scientific Congress, Univ. Panama, Panama.

De Leon, A. November, 1985. El efecto de aplicar fertilizantes inorganicos en la produccion de _Penaeus vannamei_ en estanques. Presented to the Second National Scientific Congress, Univ. Panama, Panama.

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

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

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

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

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

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

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

Lasso de la Vega, E. and M. Villareal. November, 1985. Variacion del zooplancton en estanques de cria de camarones blanco durante la estacion seca. Presented to the Second National Scientific Congress, Univ. Panama.

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

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

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

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

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

Manuscripts

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

MSU/INDONESIA

Theses

Beebe, R.S. In preparation. Fate of fertilizer nitrogen in fish ponds. Michigan State University, East Lansing, Michigan.

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

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

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

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

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

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

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

Strahle, S.L. 1986. The use of resin cartridges for the storage and preservation of aqueous samples for pesticide residue analysis. M.S. thesis, Department of Fisheries and Wildlife, Michigan State University, East Lansing, Michigan. 45 pp.

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

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

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

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

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

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

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

Reports

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

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Appendix C-1
PondEco Model Listing
(first 4 pages of a 15-page program)

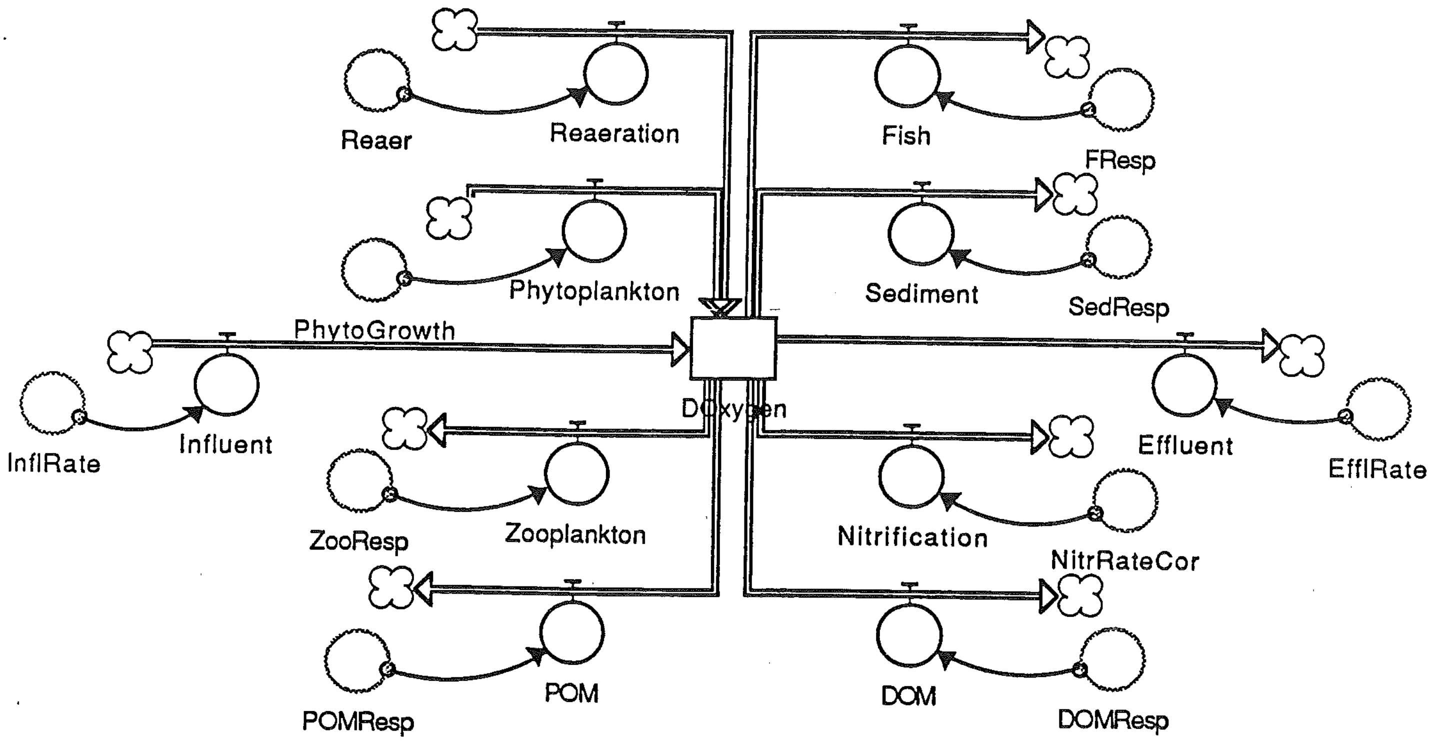
```
C23456789112345678921234567893123456789412345678951234567896123456789772
C
C OLD    MAIN PROGRAM  FOR  THE  POND  MODEL.
C     Modified  by:  Raul  H.  Piedrahita,   88/02.  88/08  (Version  5.4)
C      VERSION  5.4.6    880930:  Revise  Rate  equations  to include  volume  changes.
C      Using  Common  block  instead  of  arguments  to  transfer  additional  inf.
C      Changes  in  light  dependency,  adjustment  of  light  ext.  coeff.  as  a
C      function  of  angle  of  incidence  of  light.
C      This  version  incorporates  changes  in  the  Phytoplankton  subruotines.
C      The  changes  include  the  use  of  a  single  light  dependence  equation.
C      This  version  is  set  up  to  run  for  initial  conditions  at  any  time
C      of  the  day,  and  will  run  in  24  hour  blocks.
C     Modified  by:  Raul  H.  Piedrahita,   87/04
C     DATE  83/11/01.  MODIFIED  85/03/26  by  Loren  Gautz
C       compiled  on  Macintosh  86/01/17  by  Loren  Gautz
C     DEVELOPED  BY:   RAUL  H.  PIEDRAHITA
C     DEPARTMENT  OF  AGRICULTURAL  ENGINEERING,  U.  OF  CALIF.  DAVIS.
C
        PROGRAM  VIEJO
      Integer*2  ary(10)
      REAL  VWIND(24),TEM(24),RADIA(24),CLOUD(24)
      DIMENSION  T(10),CMIN(10),SV(22),SVI(22),R(100),RK(100),D(18),TSV
     X(22),FDAT(3,7),P(3,10)
      CHARACTER*25   FNAME
      CHARACTER*25   DNAME
      COMMON/SHARE1/RC,EA,ER,EM,AEC,T,CMIN/SHARE2/SV/SHARE3/SVI,VOL,FI
     XN,FOUT,FHARA,FHARB,FHARC/SHARE4/R/SHARE5/RK,THETA/SHARE6/DEPTH/S
     XHARE7/D/SHARE8/TSV/SHARE9/FDAT/SHAR10/P/SHARD/ary/SHAR11/DTSL,ET
     X,TIMET,FI,DECL
C POND  LOCATION  AND  SIZE  AND  INTIALIZE  MACHINE
C  also  read  in  initial  values  for  various  parameters
       CALL  LEA(FI,DTSL,AREA,ELEV)
C READ  IN  DATES  FOR  SIMULATION
      READ(5,760)DATEIN,DATEND
      WRITE(6,760)DATEIN,DATEND
  760 FORMAT((2F5.0))
C  READ  IN  TIME  (HOUR)  TO  START  SIMULATION
      READ(5,7600)   TIMEO
 7600 FORMAT  (F5.0)
C     SET  STATE  VARIABLE  INITIAL  VALUES.
      READ(5,711)(SV(I),I=1,22)
  711 FORMAT((5F9.5))
      DATET=DATEIN
C     POND  VOLUME.  M3.
      VOL=AREA*DEPTH
      TIMET=TIMEO
      AMM=SV(10)
      CTCO3=SV(11)
      DIP=SV(12)
      ALK=SV(13)
      PH=SV(22)
      TW=20.0
      CALL  SALK(TIMET,ALK,PH,CTCO3,AMM,DIP,TW,UAMM,CO2)
 4000 CONTINUE
C     READ  THE  DATA  THAT  CHANGES  DAILY
C       WATER  INFLOW  STATE  VARIABLES
      READ(5,711)(SVI(I),I=1,22)
      WRITE(6,711)(SVI(I),I=1,22)
C       WIND  SPEED  HOURLY
      READ(5,800)(VWIND(I),I=1,24)
      WRITE(6,801)(VWIND(I),I=1,24)
C       WATER  TEMPERATURE  HOURLY
      READ(5,800)(TEM(I),I=1,24)
      WRITE(6,801)(TEM(I),I=1,24)
  800 FORMAT((12F5.1))
  801 FORMAT((12F5.1))
```

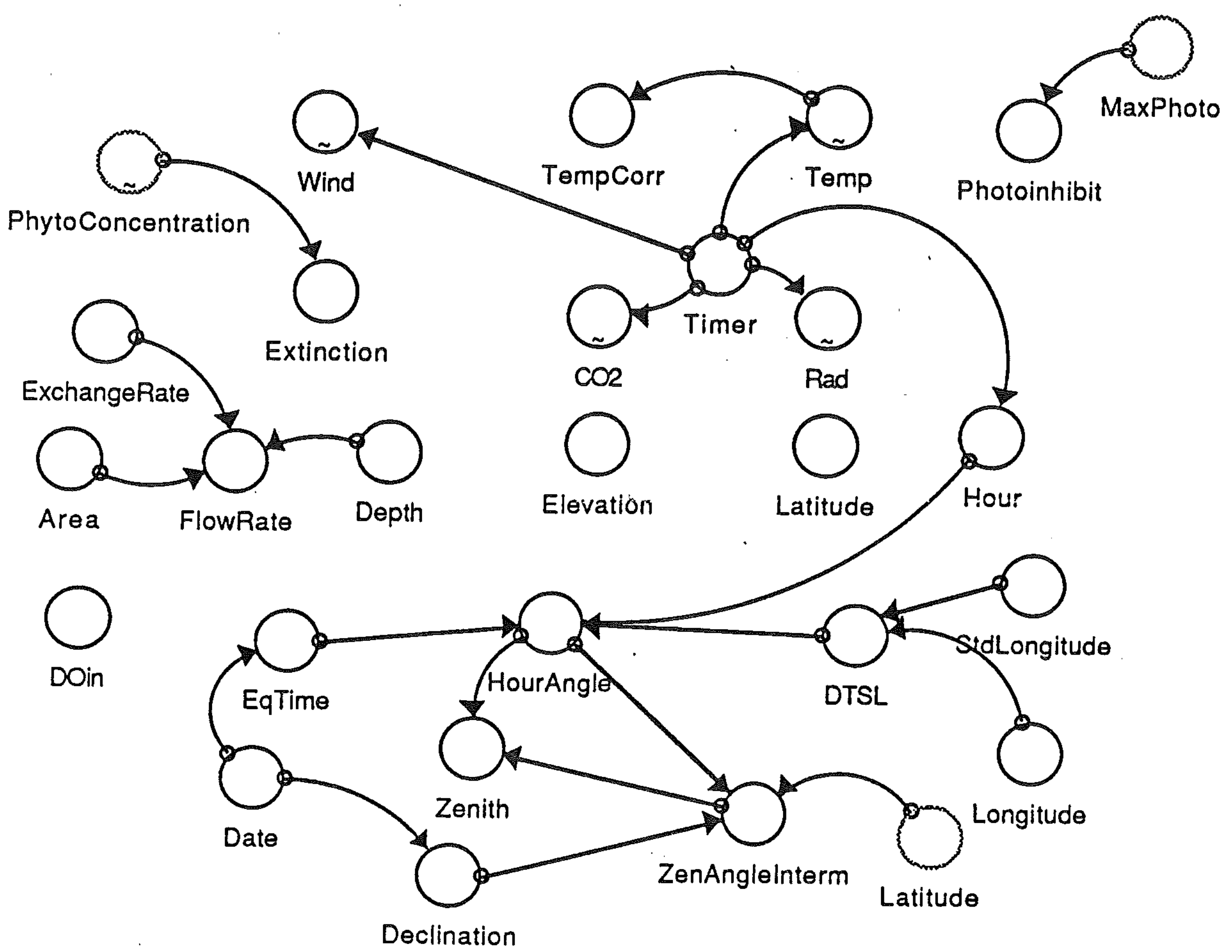
```
C        CLOUD  COVER  HOURLY
       READ(5,805)(CLOUD(I),I=1,24)
       WRITE(6,806)(CLOUD(I),I=1,24)
  805  FORMAT(12F5.2)
  806  FORMAT((12F5.2))
C          DAILY  HARVESTS  OF FISH  A,  B,  AND  C  ( NO. ? )
       READ(5,810)FHARA,FHARB,FHARC
       WRITE(6,810)FHARA,FHARB,FHARC
  810  FORMAT(3F8.5)
C        DAILY  WATER  EXCHANGE
       READ(5,820)FIN,FOUT
       WRITE(6,820)FIN,FOUT
  820  FORMAT(2F8.5)
C     ************************
C     -START  SOLUTION
       CALL  CLIMA(RADIA,DATET)
       WRITE(6,9210)(RADIA(I),I=1,24)
 9210  FORMAT(24(E10.4,"    "))
C Write  radiation  and  corrected  radiation  in  a  column  on  the  data  table
       ITIME=TIMEO
       DO  5000  I=1,24
C Calculate  changes  in  Pond  Volume  and  Depth.  FIN  and  FOUT  are  in  m3/h
         VOL  =  VOL  +  (FIN-FOUT)
         DEPTH  =  VOL  /  AREA
         RAD=RADIA(ITIME)*CLOUD(I)
         TW=TEM(I)
         VW=VWIND(I)
Cdebug           WRITE(*,'(A)')'SOLVING    FOR  THE  DATE  AND  TIME:'
Cdebug           WRITE(*,76)DATET,TIMET
   76  FORMAT(2(F5.0,"    "))
         CALL  SOLVE(RAD,TW,VW,CO2,UAMM,AREA,ELEV)
         WRITE(*,76)DATET,TIMET
C Write  the  radiation  for  time  T  on  a  column  to  simplify  plotting.
C Also  add  water  temperature  TW,  Wind  VW  and  CO2  to  use  in  adjunct
C Stella  model  (880803)
         WRITE(6,920)DATET,TIMET,RADIA(ITIME),RAD,TW,VW,CO2,(SV(J),J=1,22
     X  )
         WRITE(*,921)(SV(J),J=1,22)
  920  FORMAT(29(E10.4,"    "))
  921  FORMAT(8(E10.4,"    "))
       TIMET=TIMET+1
       IF  (TIMET.GT.24.)THEN
         TIMET  =  TIMET  -  24.
         DATET  =  DATET  +  1.
           IF  (I.LT.24)   THEN
           CALL  CLIMA  (RADIA,DATET)
           ENDIF
       ENDIF
       ITIME=TIMET
 5000  CONTINUE
       IF  (DATET.LT.DATEND)GOTO    4000
       CLOSE(UNIT=   5)
       CLOSE(UNIT=   6,STATUS='KEEP')
               END
C
C              LEA
C
C   SUBROUTINE  TO  READ  THE  DATA  THAT  IS  NOT  TIME  VARIANT.
C    AND  OPEN  AN  OUTPUT  FILE
C   1984/01/18
      SUBROUTINE   LEA(FI,DTSL,AREA,ELEV)
      REAL  VWIND(24),TEM(24),RADIA(24)
      DIMENSION   T(10),CMIN(10),SV(22),SVI(22),R(100),RK(100),D(18),TSV
     X(22),EDAT(3,7),E(3,10)
      CHARACTER*25   FNAME
      CHARACTER*25   DNAME
```

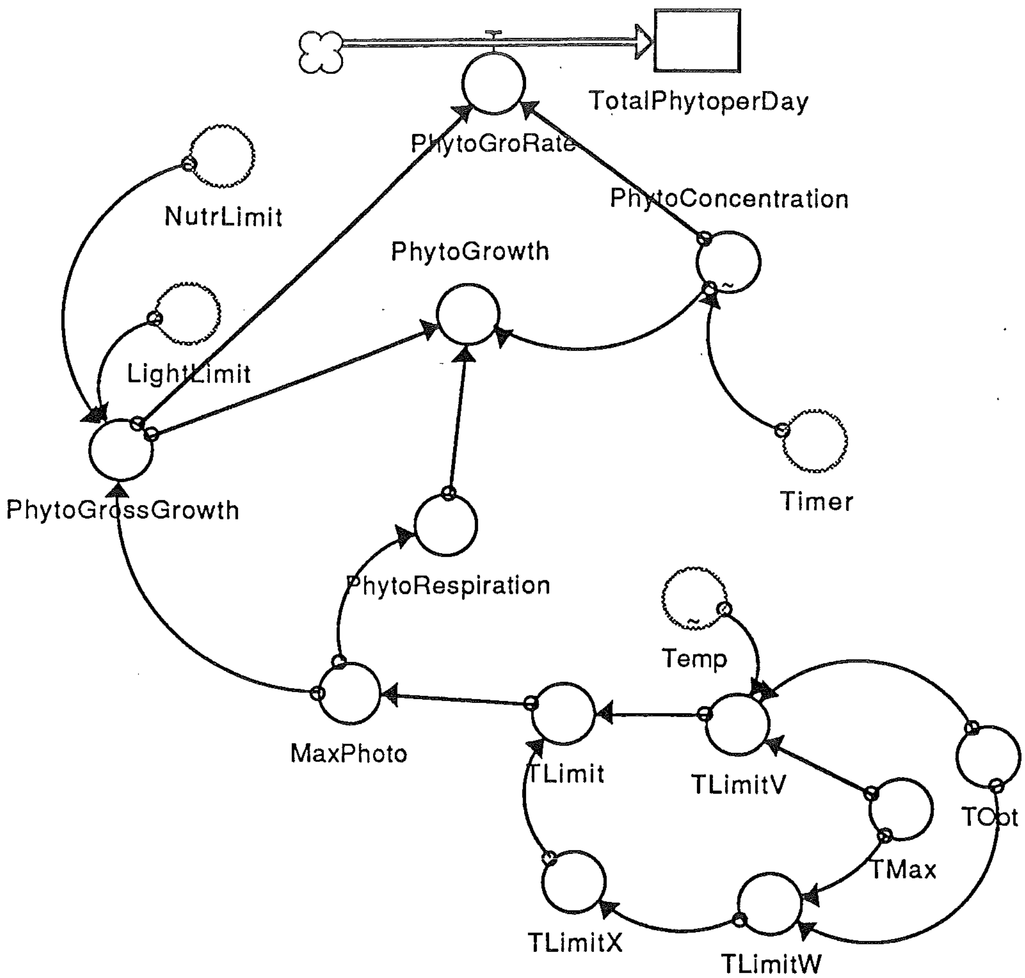
```
      COMMON/SHARE1/RC,EA,ER,EM,AEC,T,CMIN/SHARE2/SV/SHARE3/SVI,VOL,FI
     XN,FOUT,FHARA,FHARB,FHARC/SHARE4/R/SHARE5/RK,THETA/SHARE6/DEPTH/S
     XHARE7/D/SHARE8/TSV/SHARE9/FDAT/SHAR10/P
C     OPEN DATA FILE. ASSIGN NUMBER 5.
      WRITE(*,'(A)')'SPECIFY   INPUT FILE NAME '
      READ(*,'(A)')DNAME
      OPEN (UNIT= 5,FILE=DNAME,  STATUS= 'OLD')
C     OPEN OUTPUT FILE. ASSIGN NUMBER 6.
      WRITE(*,'(A)')'SPECIFY   OUTPUT FILE NAME '
      READ(*,'(A)')FNAME
      OPEN(UNIT= 6,FILE=FNAME,STATUS='NEW')
C    READ IN DATA FROM THE DATA FILE.AND WRITE TO THE OUTPUT FILE.
C     POND LOCATION,  DEG LATITUDE,  FLAG EAST(-1),WEST(1),DEG   LONGITUDE,
C     MERIDIAN OF STANDARD TIME, POND ELEV, DEPTH, AREA, TEMP CORRECTION
      READ(5,700)FID,E,TML,SML,ELEV,DEPTH,AREA,THETA
      WRITE(6,701)FID,E,TML,SML,ELEV,DEPTH,AREA,THETA
  700 FORMAT((4F8.2))
  701 FORMAT((4F9.2))
C    READ FISH GROWTH MODEL PARAMETERS
      READ(5,705)RC,EA,ER,EM,AEC
      WRITE(6,705)RC,EA,ER,EM,AEC
  705 FORMAT(5F8.5)
C    READ INTIAL RATE COEFFICIENTS
      READ(5,710)   (RK(I),  I = 1, 100)
      WRITE(6,710)(RK(I),I=1,100)
  710 FORMAT((5F8.5))
C    READ PLANKTON MODEL PARAMETERS
      READ(5,710)(D(I),I=1,18)
      WRITE(6,710)(D(I),I=1,18)
C  FISH FOOD DATA READ
      READ(5,730)((FDAT(I,J),I=1,3),J=1,7)
      WRITE(6,730)((FDAT(I,J),I=1,3),J=1,7)
  730 FORMAT((3F8.5))
      READ(5,710)(CMIN(I),I=1,10)
      WRITE(6,710)(CMIN(I),I=1,10)
      READ(5,750)((P(I,J),J=1,10),I=1,3)
      WRITE(6,750)((P(I,J),J=1,10),I=1,3)
  750 FORMAT((10F4.2))
C     LATITUDE OF SITE IN RADIANS.
      FI=3.14159*FID/180.
C     TIME DIFFERENCE BETWEEN STD MERIDIAN AND LOCAL MERIDIAN
      DTSL=E*(SML-TML)/15.
                RETURN
                END
C
C                 SALK
C
C
C SUBROUTINE  FOR THE ALKALINITY,CARBONATE,PH   CALCULATIONS
C START DATE: 1983-FEB-02.
C Modified:1987-May
C
      SUBROUTINE  SALK(TIMET,ALK,PH,CTCO3,AMM,DIP,T,UAMM,CO2)
      IMPLICIT  REAL(H,K)
      T=T+273.16
C CALCULATION  OF THE TEMPERATURE  DEPENDENT  EQUILIBRIUM  COEFF.
      CTCO3M=CTCO3/12.
      AMMM=AMM/14.
      DIPM=DIP/31.
      PWK=(4470.0/T)-6.0875+0.01706*T
      KW=10**(-PWK)
      P1KA=8.59-0.0075*T
      K1A=10**(-P1KA)
      P2KA=13.43-0.0104*T
      K2A=10**(-P2KA)
      PNKA=0.09018+(2729.92/T)
```

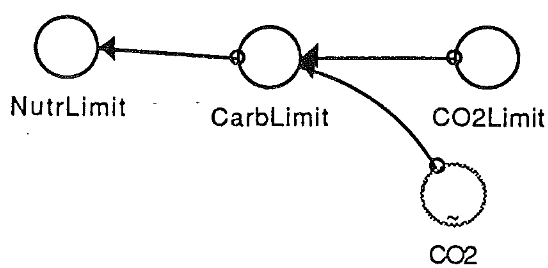
```
      KNA=10**(-PNKA)
      P3PK1=2.1
      P4PK2=7.2
      P5PK3=12.3
      K3P=10**(-P3PK1)
      K4P=10**(-P4PK2)
      K5P=10**(-P5PK3)
      COUNT=0.0
      ODIFF=10.0
C testing  new  solution  procedure,  increase  pH  by  0.1  per  step  until  diff
c goes  negtive.  First  set  initial  pH  value.
c Debug       PH=6.0
C GROUP  THE  CALCULATIONS  THAT  WILL  HAVE  TO  BE  REPEATED  FOR THE  ALK  CALC
  400   IF(COUNT.GE.100.)GOTO    800
      HCON=10**(-PH)
      E=HCON**2+HCON*K1A+K1A*K2A
      A0=(HCON**2.)/E
      A1=HCON*K1A/E
      A2=K1A*K2A/E
      OHCON=KW/HCON
      ANH3=KNA/(HCON+KNA)
      UAMM=ANH3*AMMM
      R=HCON**3+(HCON**2)*K3P+HCON*K3P*K4P+K3P*K4P*K5P
      AP2=HCON*K3P*K4P/R
      P2=AP2*DIPM
C   CALCULATE  ALK  FOR  TRIAL  AND  ERROR  DETERM.  OF  PH
      CALK=CTCO3M*(A1+2*A2)+UAMM+P2+OHCON-HCON
      COUNT=COUNT+1.
      DIFF=ALK-CALK
c Debug        IF  (DIFF.GT.0.0)THEN
c Debug        PH  =  PH  +  0.1
c Debug        GOTO  400
c Debug        ENDIF
      IF(DIFF.EQ.0.0)GOTO    800
        IF(ODIFF.LT.10.0)THEN
          IF(DIFF.GT.0.0)THEN
            IF(ODIFF.LT.0.0)GOTO    800
            PH=PH+0.1
            GOTO  500
          ENDIF
          IF(ODIFF.GT.0.0)GOTO    800
          PH=PH-0.1
  500     CONTINUE
        ENDIF
        ODIFF=DIFF
        GOTO  400
  800   CONTINUE
      UAMM=UAMM*14.
      CO2=  A0*CTCO3
      T=T-273.16
c Debug        Write  (6,8100)COUNT,ALK,CALK,PH,CTCO3M,UAMM,P2,OHCON,HCON
c Debug  8100  FORMAT(F5.0,E10.4,E10.4,F6.2,5(E10.4))
      RETURN
      END
C
C              CLIMA
C
C    PROGRAM  TO  CALCULATE  THE  WEATHER  PARAMETERS.
C    STARTED  ON  1983-09-27
C    BY  RAUL  H.  PIEDRAHITA
C    DEPARTMENT  OF  AGRICULTURAL  ENGINEERING,
C    UNIVERSITY  OF  CALIFORNIA,  DAVIS.
C    START  WITH  SOLAR  RADIATION  CALCULATIONS.
C
      SUBROUTINE  CLIMA(RADIA,DATEST)
C
```

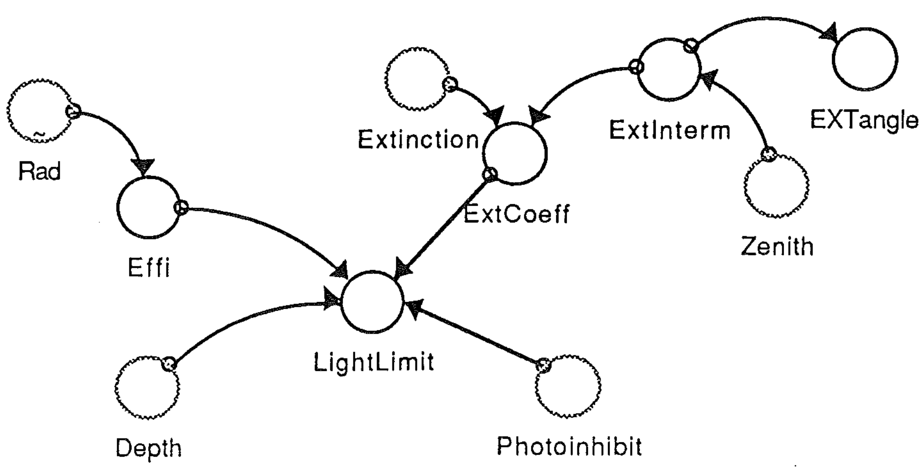
Appendix C-2
PondDO Model Listing and Flow Diagram

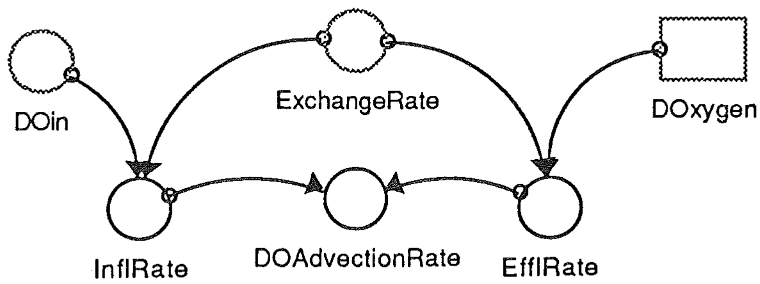


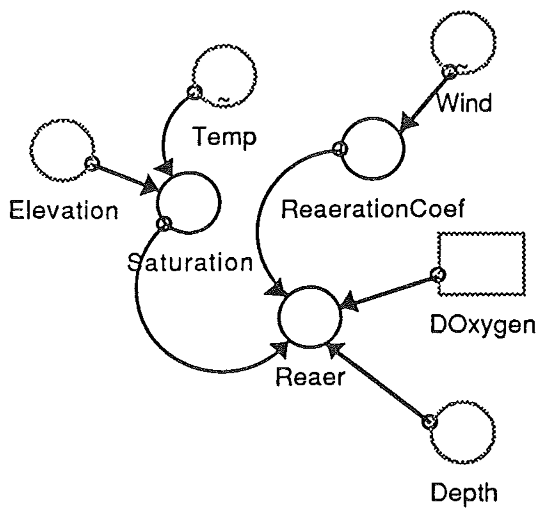


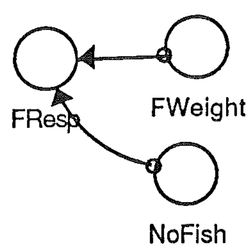

TotalPhytoperDay
PhytoGroRate
NutrLimit
PhytoConcentration
PhytoGrowth
LightLimit
PhytoGrossGrowth
Timer
PhytoRespiration
Temp
MaxPhoto
TLimit
TLimitV
TOpt
TMax
TLimitX
TLimitW

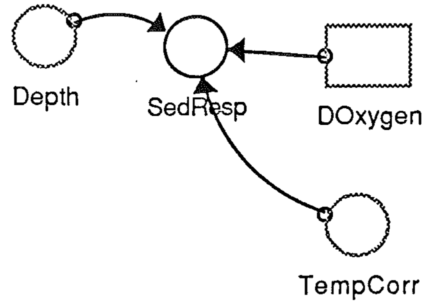

NutrLimit
CarbLimit
CO2Limit
CO2

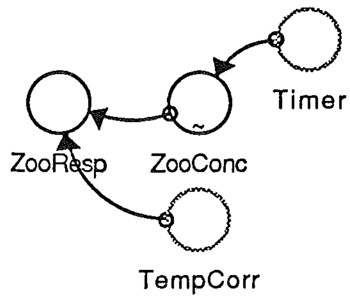

Rad
Extinction
ExtInterm
EXTangle
ExtCoeff
Zenith
Effi
LightLimit
Depth
Photoinhibit

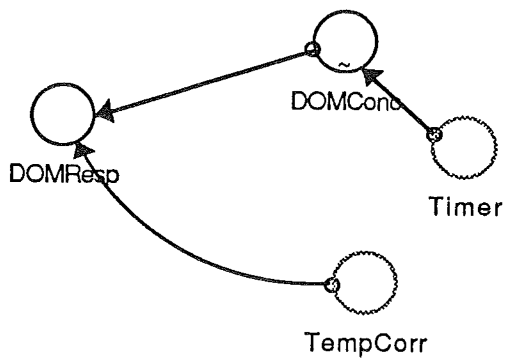

DOin
ExchangeRate
DOxygen
InflRate
DOAdvectionRate
EfflRate

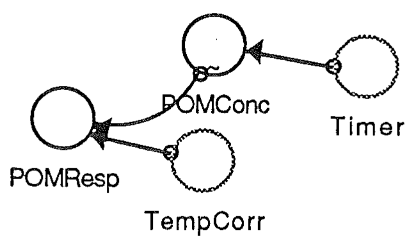

Temp
Wind
Elevation
ReaerationCoef
Saturation
DOxygen
Reaer
Depth

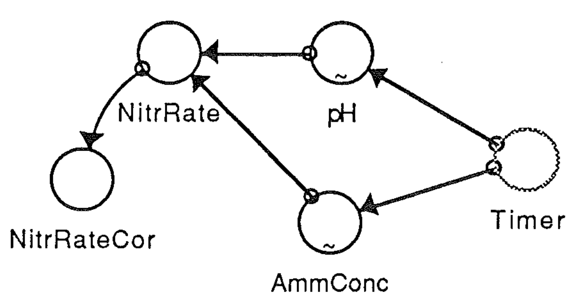

FResp
FWeight
NoFish


Depth
SedResp
DOxygen
TempCorr


Timer
ZooResp
ZooConc
TempCorr


DOMConc
DOMResp
Timer
TempCorr


POMConc
Timer
POMResp
TempCorr


NitrRate
pH
NitrRateCor
Timer
AmmConc

DOxygen = DOxygen + dt * (Phytoplankton - Zooplankton - POM - DOM - Nitrification - Sediment - Fish + Reaeration + Influent - Effluent)
INIT(DOxygen) = 3.5 {Initial Dissolved Oxygen, mg/L}

TotalPhytoperDay = TotalPhytoperDay + dt * (PhytoGroRate)
INIT(TotalPhytoperDay) = 0
{Temporary to calculate NPP per day}

Area = 200
{Pond Surface Area, m2}

CarbLimit = CO2/(CO2Limit+CO2)

CO2Limit = 0.05 {Half Saturation for Carbon Dioxide, mgC/L}

Date = 134 {Julian Date}

Declination = 0.4093*COS(0.0172*(172-Date))
{0.0172 = 3.14/365; and 172 is June 21, the point of peak declination for the northern hemisphere}

Depth = 1.0 {Water Depth, m}

DOAdvectionRate = InflRate - EfflRate
{Net oxygen transfer in water flow, mg/L/h}

DOin = 8.5
{D. O. Concentration in Incoming Water, mg/L}

DOM = DOMResp

DOMResp = .004*TempCorr*DOMConc

DTSL = (StdLongitude-Longitude)*(180/PI)/15
{Time difference, in hours, between standard and local meridians, converted back to degrees}

Effi = 1* (RAD)
{kJ/m2/h}

EfflRate = ExchangeRate * DOxygen /24
{mg/L/h}

Effluent =EfflRate
{mg/L/h}

Elevation = 5 {m}

EqTime = -(0.12357*SIN(0.0172*(DATE-1)) - 0.004289 * COS(0.0172*(DATE-1)) + 0.153809 * SIN(2*0.0172*(DATE-1)) + 0.060783 * COS(2*0.0172*(DATE-1)))

ExchangeRate = 0.2
{Pond Water Exchange Rate, Fraction of pond volume / day}

EXTangle = SQRT(ARCTAN(ExtInterm/SQRT(1-ExtInterm^2))^2)

ExtCoeff = Extinction/COS (ARCTAN (ExtInterm /SQRT (1-ExtInterm^2)))
{Addapted expression since ASIN is not available}

Extinction = 1.9/1.0 +0.17 * PhytoConcentration
{units of 1/m; Using the expression from my dissertation, the first term represents ext due to the color of the water, and the second due to phytoplankton}

ExtInterm = SIN(Zenith)/1.33
{Intermediate Calculation for Extinction Coefficient}

Fish = FResp

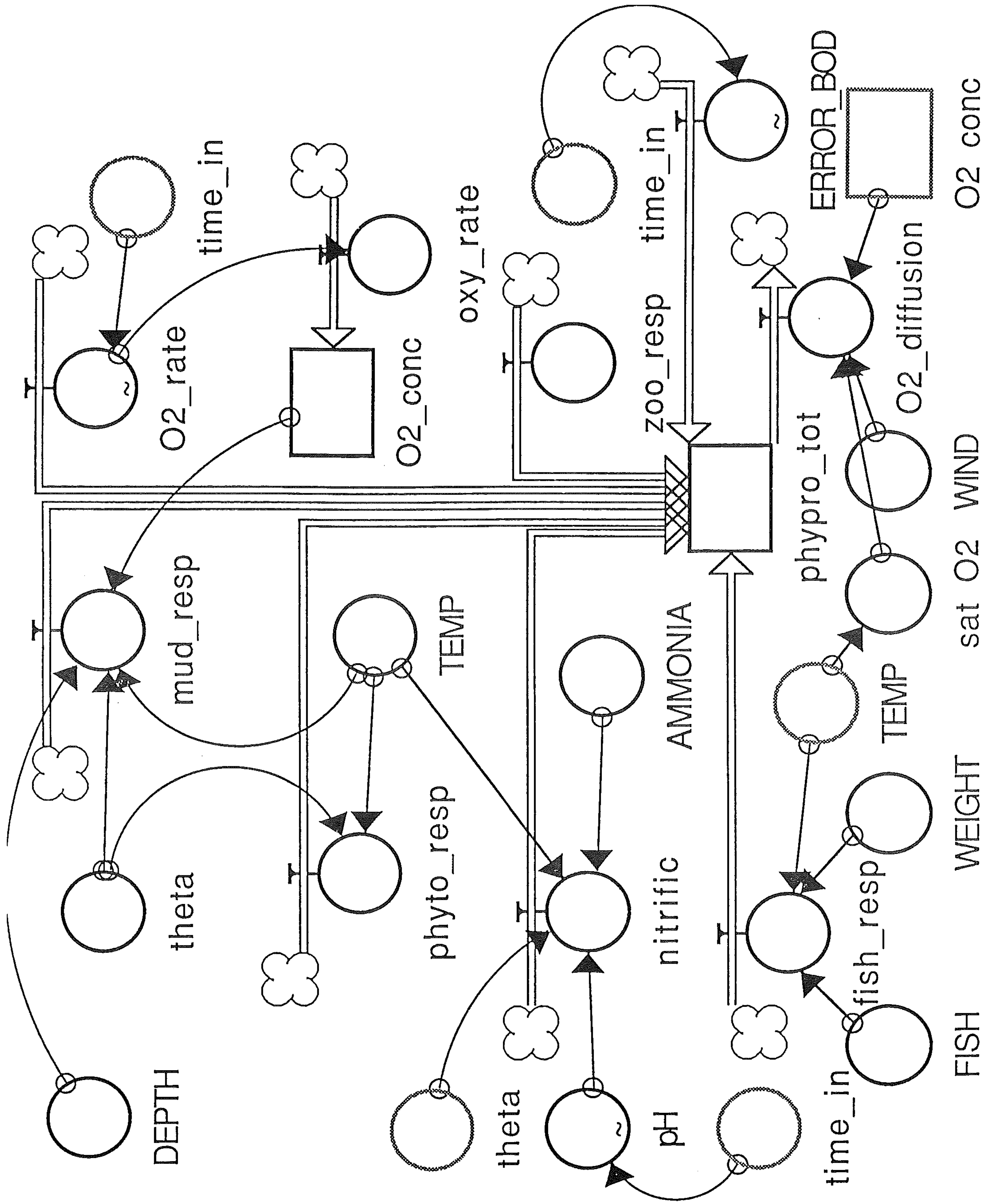
FlowRate = (Depth*Area)*ExchangeRate * 1000 / 24

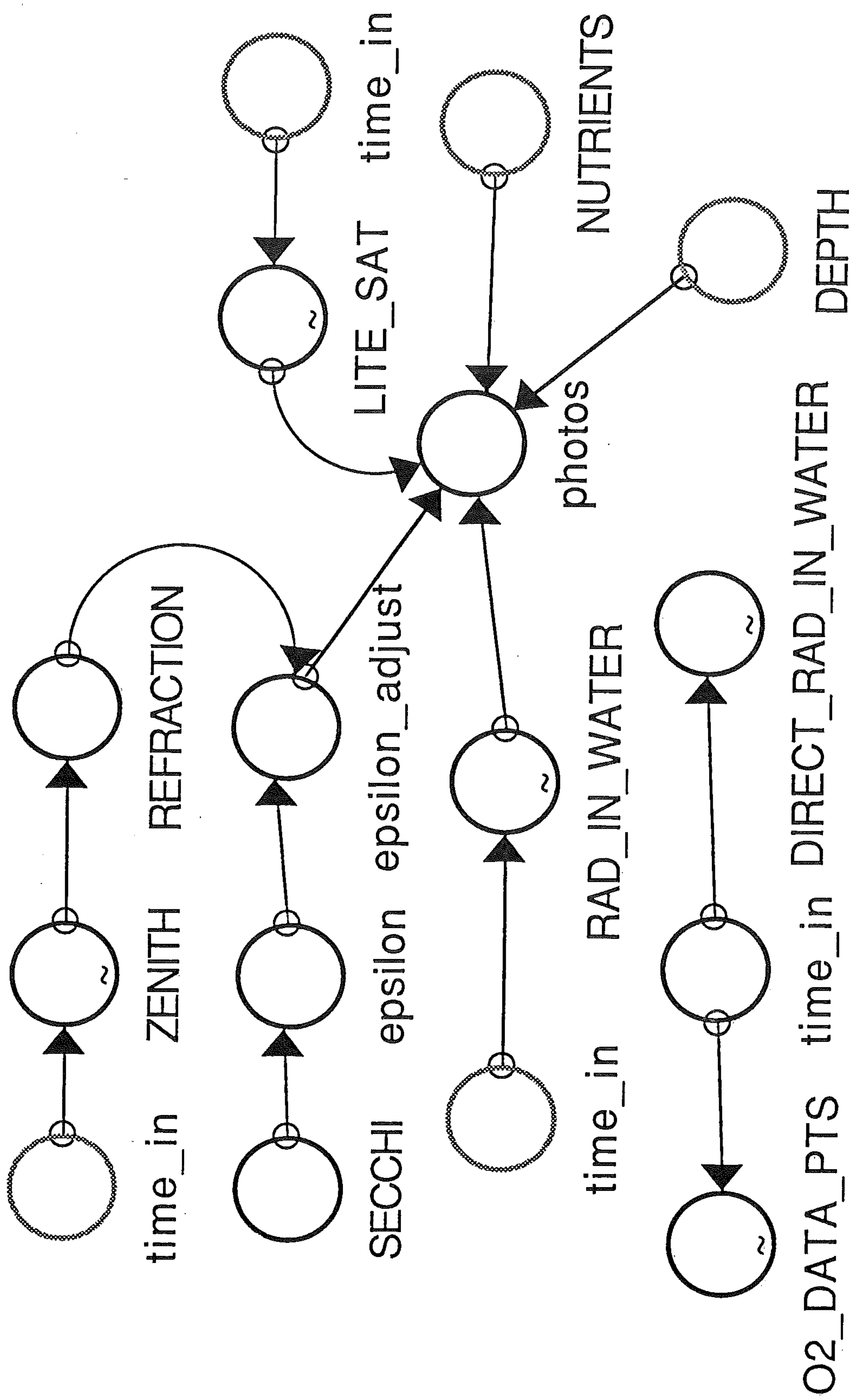
{L/hr}
○ FResp = 0.25*(0.003*(FWEIGHT^0.8)*(1+0.048)*(1000^(1-0.8)/24)*NoFish)
{g O2/m3/hr}
○ FWeight = 151 {g}
○ Hour = Timer
{To set the starting time of the run for hour angle calculations}
○ HourAngle =(12 - EqTime +DTSL - Hour) * 15*PI /180
{Hour angle measured from noon}
○ InflRate = DOin * ExchangeRate /24
{mg/L/h}
○ Influent = InflRate
{mg/L/hr}
○ Latitude = 14.18 *(PI/180)
{in degrees, North possitive, converted to radians}
○ LightLimit = IF (Effi >0) Then (2.72/(ExtCoeff*Depth))*(EXP((-Effi/Photoinhibit)*EXP(-ExtCoeff*Depth))-EXP(-Effi/Photoinhibit)) ELSE (0)
○ Longitude = -100.5 * (PI/180)
{degrees, West possitive, converted to radians}
○ MaxPhoto = TLimit*0.5
{1/hr}
○ Nitrification = NitrRateCor
{g / m3 /hr}
○ NitrRate = IF (pH <=8) and (pH >=7) THEN (0.001 * AmmConc *4.57) ELSE IF (pH < 7) THEN (.001 * (1.24*pH - 7.68)*AmmConc * 4.57) ELSE (.001*(9.16 - 1.02 * pH) * AmmConc * 4.57)
{g / m3 / hr}
○ NitrRateCor = IF (NitrRate<=0) Then (0) else (NitrRate)
○ NoFish = 1
{fish / m3}
○ NutrLimit = CarbLimit
○ Photoinhibit = 1 *MaxPhoto / 0.00075
{Calculated from the initial slope... kJ/m2/h}
○ PhytoGroRate = PhytoGrossGrowth * 1.67*(1/1.5)*PhytoConcentration
{Temporary to calculate total Net Primary Production per day}
○ PhytoGrossGrowth = NutrLimit*LightLimit*MaxPhoto
○ PhytoGrowth =(PhytoGrossGrowth-PhytoRespiration) * PhytoConcentration *(1/1.5) * 1.67
{Net phytoplankton growth rate in terms of gO2 / m3 / hr
the 1.5 term is to adjust for phyto = 1.5 % chlorophyll}
○ Phytoplankton = PhytoGrowth
○ PhytoRespiration = 0.042 * MaxPhoto
{1/hr, after Scavia and Park 1976}
○ POM = POMResp
○ POMResp = 0.005*TempCorr*POMConc
{gO2/m3/hr}

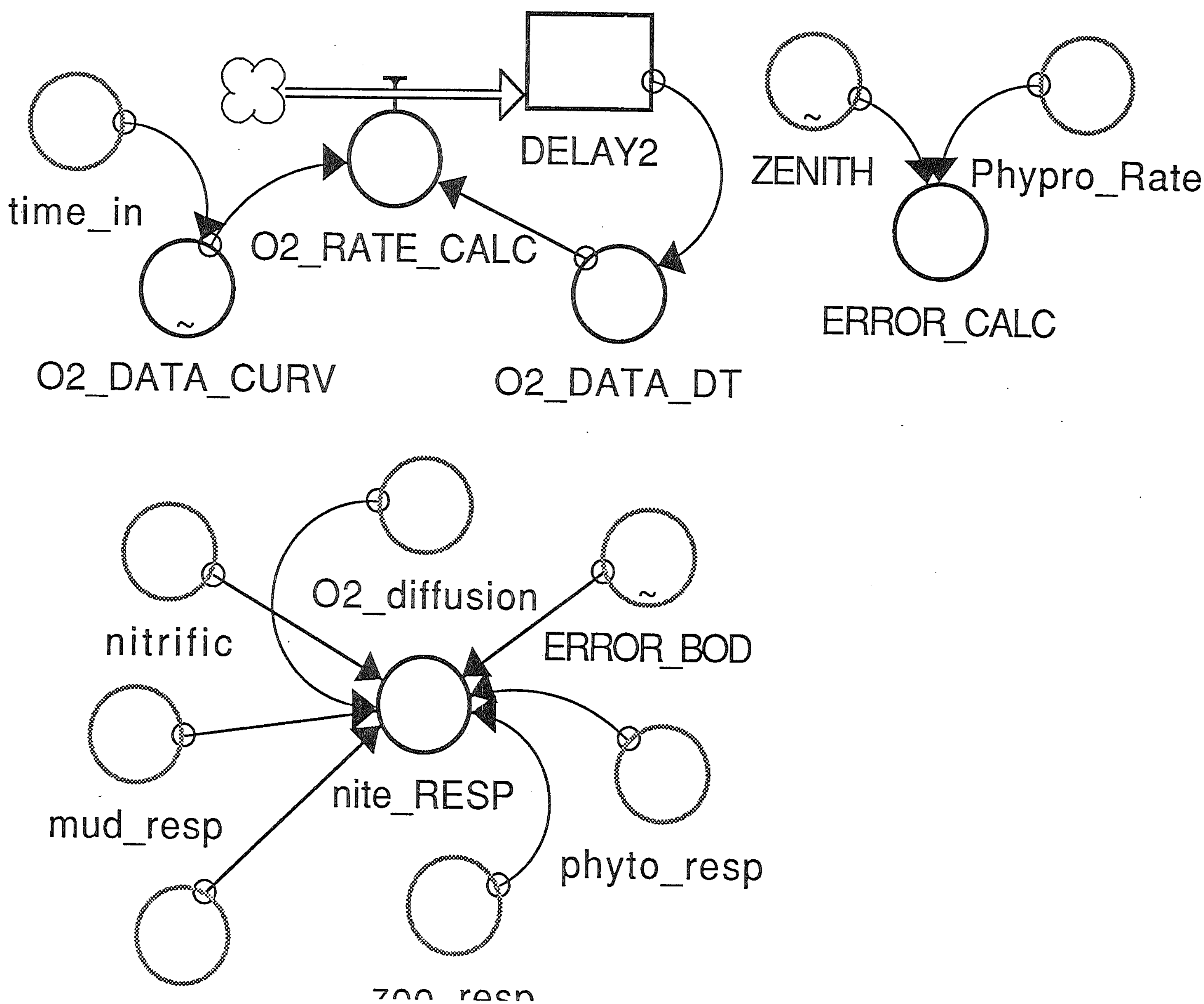
○ Reaer = ReaerationCoef*(Saturation-DOxygen)/Depth
○ Reaeration = Reaer
○ ReaerationCoef = IF (Wind≤0.1) THEN 0.005 ELSE 0.001*Wind^2
○ Saturation = (14.652-0.41022*Temp+0.007991*Temp^2-0.000077774*Temp^3)*(1-0.000104*Elevation)
{g/m3 from Dissertation}
○ Sediment = SedResp
○ SedResp = TempCorr*0.004*(DOxygen^.3)/Depth
{gO2/m3/hr}
○ StdLongitude =-105 * (PI/180)
{in degrees, West possitive, converted to radians}
○ TempCorr = 1.05 ^ (Temp-20) {Temperature Correction}
○ Timer = time
○ TLimit = (TLimitV^TLimitX)*EXP(TLimitX*(1-TLimitV))
○ TLimitV = (TMax-Temp)/(TMax-TOpt)
○ TLimitW = .69*(TMax-TOpt)
○ TLimitX = (1.1*TLimitW)^2/20
○ TMax = 35 {maximum temperature for phytoplankton °C}
○ TOpt = 28 {Optimum temperature for phytoplankton °C}
○ ZenAngleInterm = (sin(Declination)*sin(Latitude)) +(cos(Declination)*cos(Latitude) Cos(HourAngle))
○ Zenith = IF (HourAngle>1.4)OR(HourAngle<-1.4) THEN (1.4) ELSE ARCTAN ((sqrt (1- (ZenAngleInterm)^2)) / ZenAngleInterm)
○ Zooplankton = ZooResp
○ ZooResp = .01*TempCorr*ZooConc*1.6
⊘ AmmConc = graph(Timer)
(6.00,0.340),(7.00,0.300),(8.00,0.260),(9.00,0.220),(10.00,0.180),(11.00,0.150),
(12.00,0.120),(13.00,0.100),(14.00,0.0800),(15.00,0.0700),(16.00,0.0800),
(17.00,0.100),(18.00,0.150),(19.00,0.210),(20.00,0.270),(21.00,0.330),
(22.00,0.390),(23.00,0.450),(24.00,0.500),(25.00,0.550),(26.00,0.600),
(27.00,0.640),(28.00,0.680),(29.00,0.720)
⊘ CO2 = graph(Timer)
(6.00,0.0570),(7.00,0.0570),(8.00,0.0450),(9.00,0.0340),(10.00,0.0340),
(11.00,0.0420),(12.00,0.0320),(13.00,0.0320),(14.00,0.0310),(15.00,0.0190),
(16.00,0.0240),(17.00,0.0240),(18.00,0.0400),(19.00,0.0510),(20.00,0.0670),
(21.00,0.109),(22.00,0.141),(23.00,0.290),(24.00,0.469),(25.00,0.755),
(26.00,0.965),(27.00,1.23),(28.00,1.55),(29.00,1.94)
⊘ DOMConc = graph(Timer)
(6.00,0.0270),(7.00,0.0540),(8.00,0.0810),(9.00,0.108),(10.00,0.136),(11.00,0.165),
(12.00,0.195),(13.00,0.225),(14.00,0.257),(15.00,0.289),(16.00,0.321),
(17.00,0.354),(18.00,0.387),(19.00,0.419),(20.00,0.450),(21.00,0.482),
(22.00,0.512),(23.00,0.542),(24.00,0.571),(25.00,0.599),(26.00,0.626),
⊘ pH = graph(Timer)
(6.00,9.00),(7.00,9.00),(8.00,9.10),(9.00,9.20),(10.00,9.20),(11.00,9.10),
(12.00,9.20),(13.00,9.20),(14.00,9.20),(15.00,9.40),(16.00,9.30),(17.00,9.30),

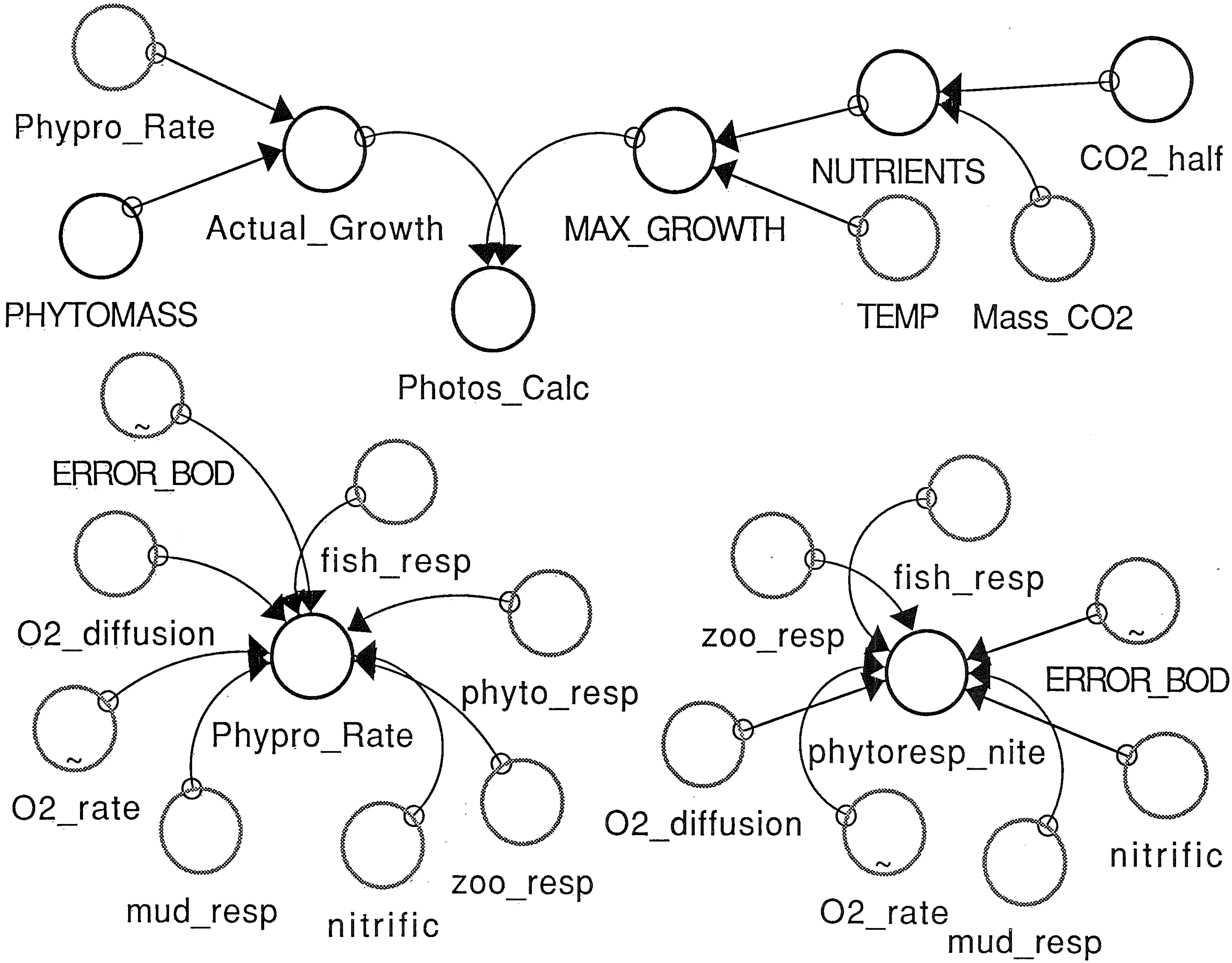
Appendix C-3

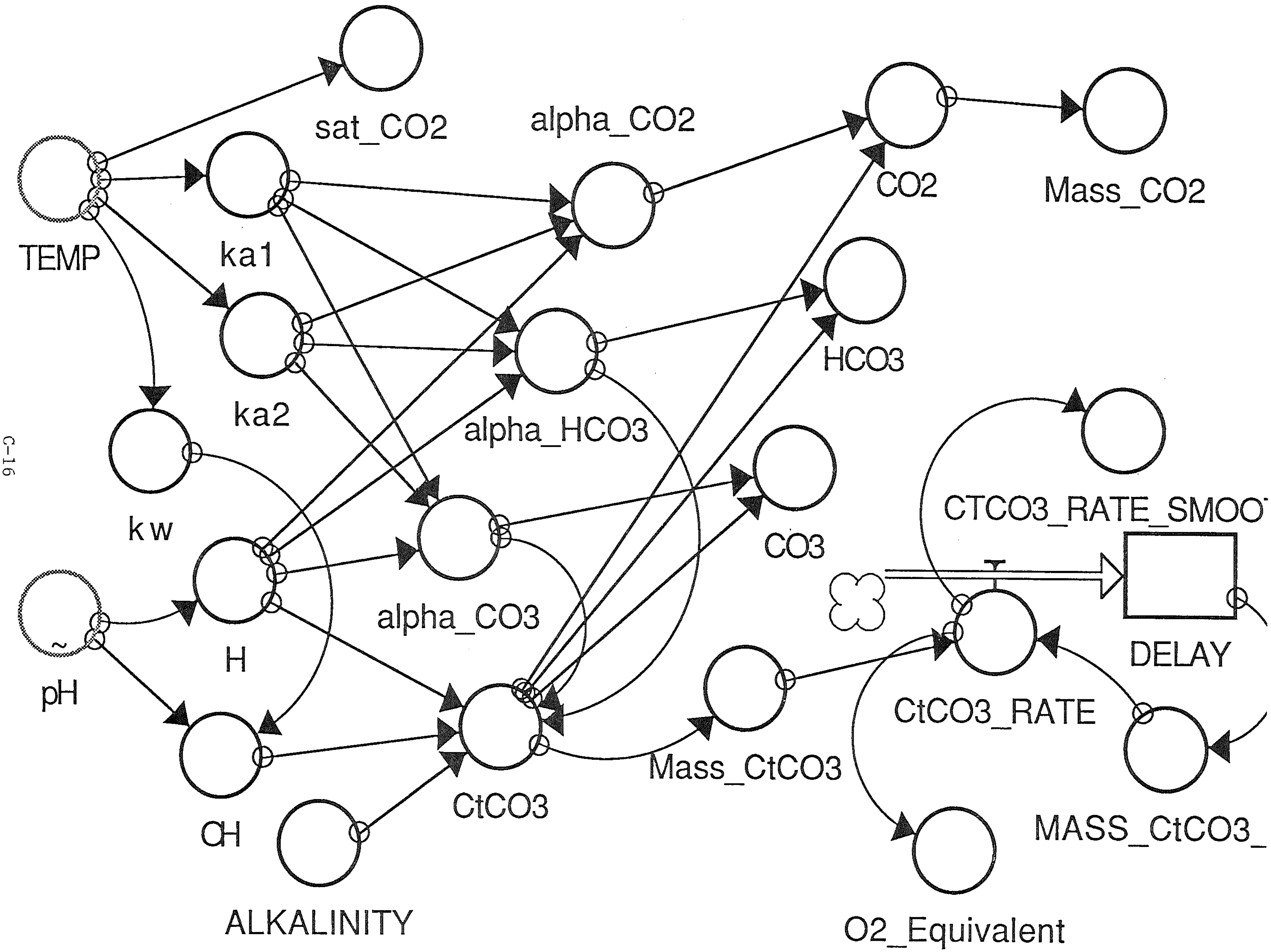
WholePond Model Listing and Flow Diagram

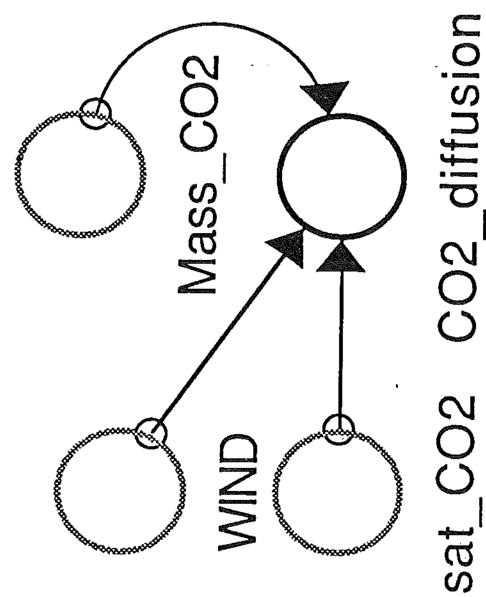


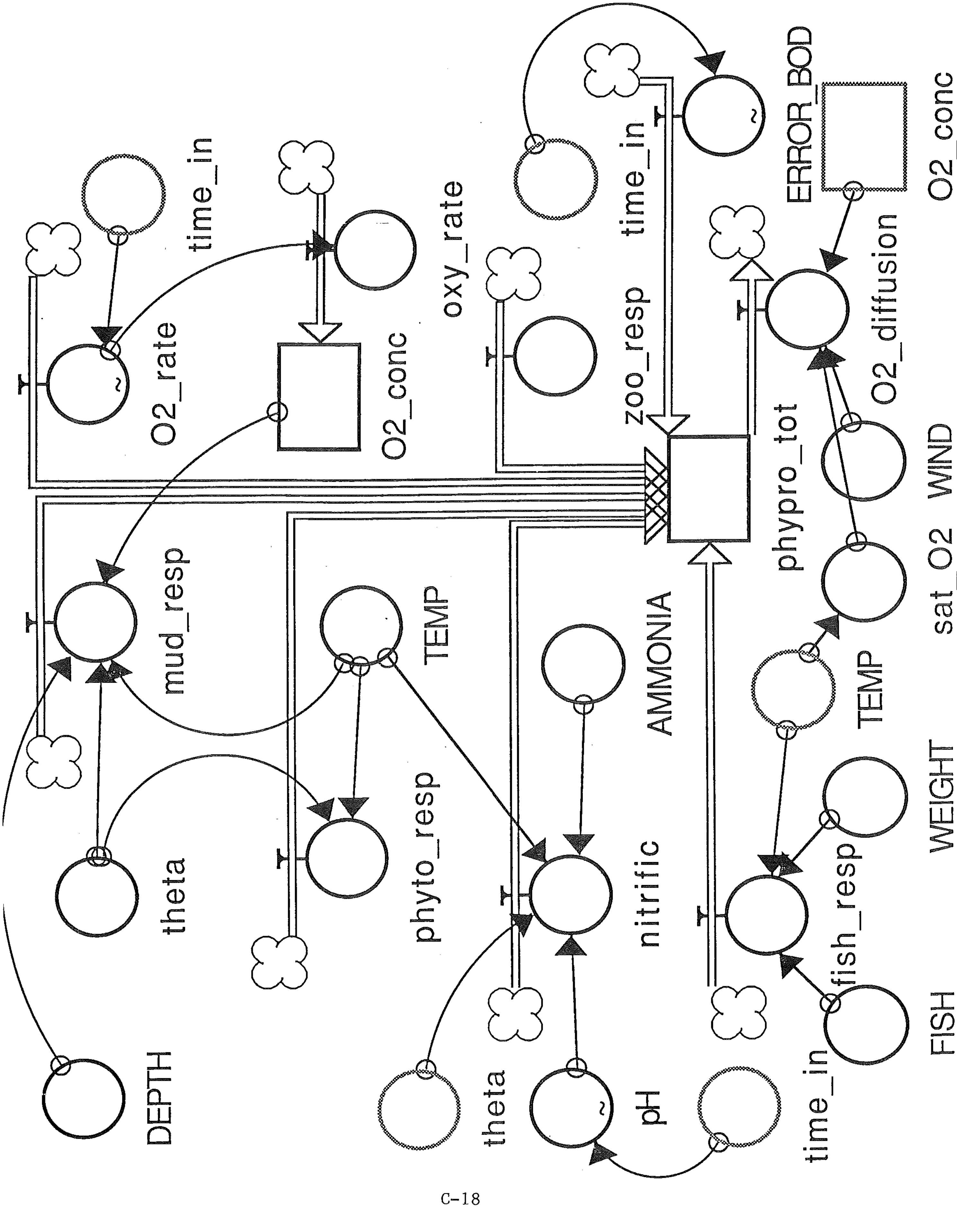

time_in
ZENITH
REFRACTION
SECCHI
epsilon
epsilon_adjust
time_in
RAD_IN_WATER
O2_DATA_PTS
time_in
DIRECT_RAD_IN_WATER
LITE_SAT
time_in
photos
NUTRIENTS
DEPTH


time_in
DELAY2
ZENITH
Phypro_Rate
O2_RATE_CALC
ERROR_CALC
O2_DATA_CURV
O2_DATA_DT
O2_diffusion
nitrific
ERROR_BOD
nite_RESP
mud_resp
phyto_resp


Phypro_Rate
PHYTOMASS
Actual_Growth
Photos_Calc
MAX_GROWTH
NUTRIENTS
CO2_half
TEMP
Mass_CO2
ERROR_BOD
fish_resp
O2_diffusion
O2_rate
Phypro_Rate
phyto_resp
mud_resp
nitrific
zoo_resp
fish_resp
zoo_resp
ERROR_BOD
phytoresp_nite
O2_diffusion
nitrific
O2_rate
mud_resp


sat_CO2
alpha_CO2
CO2
Mass_CO2
TEMP
ka1
ka2
HCO3
alpha_HCO3
kw
CO3
CTCO3_RATE_SMOO
pH
H
alpha_CO3
DELAY
CtCO3_RATE
OH
CtCO3
Mass_CtCO3
MASS_CtCO3_
ALKALINITY
O2_Equivalent


Mass_CO2
CO2_diffusion
WIND
sat_CO2



time_in
O2_rate
O2_conc
oxy_rate
time_in
zoo_resp
ERROR_BOD
O2_conc
O2_diffusion
phypro_tot
WIND
sat_O2
mud_resp
TEMP
AMMONIA
TEMP
WEIGHT
theta
phyto_resp
nitrific
fish_resp
FISH
DEPTH
theta
pH
time_in

```
○ kw = 10^(-((4470/(TEMP+273.16))-6.0875+0.01706*(TEMP+273.16)))
○ Mass_CO2 = CO2*44 {mg CO2/mmole} {=mg CO2/L}
○ Mass_CtCO3 = CtCO3*12 {mg C/mmole} {=mg C/L}
○ MASS_CtCO3_dt = DELAY
○ MAX_GROWTH = ( ( (10^( .0275 * TEMP - .23 ) ) / 24 ) * 1.67 ) * NUTRIENTS  {mg O2/mg phyto/h - at a given
  nutrient  level}
○ mud_resp = (theta^(TEMP-20) * 0.004 * (O2_conc ^.3))/DEPTH {mg O2/L/h}
○ nite_RESP = -phyto_resp + O2_diffusion + ERROR_BOD - fish_resp - mud_resp - nitrific - zoo_resp  {mg O2/L/h
○ nitrific = IF (pH < 6.19) THEN 0 ELSE
  IF(pH < 7)THEN. .001*(1.24*pH-7.68)*theta^(TEMP-20)*AMMONIA
  ELSE IF (pH < 8) THEN .001*theta^(TEMP-20)*AMMONIA*4.57
  ELSE IF (pH < 8.98) THEN .001 * (9.16-1.02*pH) * theta^(TEMP-20) *AMMONIA ELSE 0 {mg O2/L/h}
○ NUTRIENTS = Mass_CO2 / ( CO2_half + Mass_CO2 )
○ O2_DATA_DT = DELAY2
○ O2_diffusion = (0.03*(WIND^.5) - (0.0132*WIND) +  0.0015*(WIND^2)) * (sat_O2 - O2_conc) {mg O2/L/h}
○ O2_Equivalent = SMTH1(CtCO3_RATE,2) * (-32/12)  {mg O2/L/h equivalent production}
○ O2_RATE_CALC = (O2_DATA_CURV - O2_DATA_DT) / DT
○ OH = 10^(-(-LOG10(kw)-pH))
○ oxy_rate = O2_rate {mg O2/L/h}
○ photos = (EXP(1)/epsilon_adjust * (EXP(-RAD_IN_WATER/LITE_SAT * EXP(-epsilon_adjust * DEPTH)) - EXP(-
  RAD_IN_WATER/LITE_SAT))) * NUTRIENTS
○ Photos_Calc = Actual_Growth / MAX_GROWTH
○ Phypro_Rate = O2_rate + mud_resp + fish_resp + zoo_resp + nitrific + phyto_resp - O2_diffusion - ERROR_BOD
  mg O2/L/h}
○ PHYTOMASS = 46.4 {mg phyto/L}
○ phytoresp_nite =(O2_rate - zoo_resp - fish_resp - mud_resp +ERROR_BOD - nitrific + O2_diffusion)  {mg O2/L/
  h}
○ phyto_resp = .83 * theta^(TEMP-29) {mg O2/L/h}
○ REFRACTION = ARCTAN((SIN ( ZENITH) / 1.33)  / (SQRT(1 - (SIN(ZENITH) / 1.33)^2 ) ) ) {ANGLE OF REFRACTION -
  radians}
○ sat_CO2 = 1.0858 - .04336*TEMP + .0011191*(TEMP)^2 - .000019218*(TEMP)^3 + .00000015975*(TEMP)^4 {mg
  CO2/L - from: Table 4, Colt,1984}
○ sat_O2 = 14.652 - 0.41022*TEMP + 0.007991*TEMP^2 - 0.000077774*TEMP^3 {mg O2/L}
○ SECCHI = .32{m}
```

```
○ TEMP = 36.413-3.5157*TIME + .4155*TIME^2 - .0173*TIME^3 +.0002303*TIME^4 {degrees C}
○ theta = 1.05
○ time_in = TIME {h}
○ WEIGHT = 373 {g/fish}
○ WIND = .55 {m/s}
○ zoo_resp = .0001 {mg O2/L/h}
⊘ DIRECT_RAD_IN_WATER = graph(time_in)
   ( 0.0, 0.0),(0.100, 0.0),(0.200, 0.0),(0.300, 0.0),(0.400, 0.0),(0.500, 0.0),(0.600, 0.0),(0.700, 0.0),(0.800, 0.0),
   (0.900, 0.0),(1.00, 0.0),(1.10, 0.0),(1.20, 0.0),(1.30, 0.0),(1.40, 0.0),(1.50, 0.0),(1.60, 0.0),(1.70, 0.0),(1.80, 0.0),
   (1.90, 0.0),(2.00, 0.0),(2.10, 0.0),(2.20, 0.0),(2.30, 0.0),(2.40, 0.0),(2.50, 0.0),(2.60, 0.0),(2.70, 0.0),(2.80, 0.0),
   (2.90, 0.0),(3.00, 0.0),(3.10, 0.0),(3.20, 0.0),(3.30, 0.0),(3.40, 0.0),(3.50, 0.0),(3.60, 0.0),(3.70, 0.0),(3.80, 0.0),
   (3.90, 0.0),(4.00, 0.0),(4.10, 0.0),(4.20, 0.0),(4.30, 0.0),(4.40, 0.0),(4.50, 0.0),(4.60, 0.0),(4.70, 0.0),(4.80, 0.0),
   (4.90, 0.0),(5.00, 0.0),(5.10, 0.0),(5.20, 0.0),(5.30, 0.0),(5.40, 0.0),(5.50, 0.0),(5.60, 0.0),(5.70, 0.0),(5.80, 0.0),
   (5.90, 0.0),(6.00, 0.0),(6.10,0.00800),(6.20,0.380),(6.30,2.75),(6.40,9.40),(6.50,21.90),(6.60,41.40),(6.70,68.00),
   (6.80,101.00),(6.90,140.00),(7.00,184.00),(7.10,234.00),(7.20,287.00),(7.30,343.00),(7.40,403.00),(7.50,464.00)
   (7.60,527.00),(7.70,592.00),(7.80,657.00),(7.90,723.00),(8.00,790.00),(8.10,856.00),(8.20,922.00),(8.30,989.00)
   (8.40,1054.00),(8.50,1119.00),(8.60,1184.00),(8.70,1247.00),(8.80,1309.00),(8.90,1371.00),(9.00,1431.00),
   (9.10,1491.00),(9.20,1549.00),(9.30,1605.00),(9.40,1660.00),(9.50,1714.00),(9.60,1766.00),(9.70,1817.00),
   (9.80,1866.00),(9.90,1913.00),(10.00,1959.00)...
⊘ ERROR_BOD = graph(time_in)
   (5.00,-0.171),(6.00, 0.0),(7.00, 0.0),(8.00, 0.0),(9.00, 0.0),(10.00, 0.0),(11.00, 0.0),(12.00, 0.0),(13.00, 0.0),
   (14.00, 0.0),(15.00, 0.0),(16.00, 0.0),(17.00, 0.0),(18.00, 0.0),(19.00,0.0117),(20.00,0.0719),(21.00,0.133),
   (22.00,0.213),(23.00,0.268),(24.00,0.251),(25.00,0.116),(26.00,-0.0433),(27.00,-0.225),(28.00,-0.361)
⊘ LITE_SAT = graph(time_in)
   (5.00,2734.50),(6.00,2719.75),(7.00,2675.50),(8.00,2513.25),(9.00,2070.75),(10.00,1805.25),(11.00,1761.00),
   (12.00,1746.25),(13.00,2011.75),(14.00,2498.50),(15.00,2926.25),(16.00,2985.25),(17.00,2985.25),
   (18.00,2985.25),(19.00,3000.00),(20.00,2941.00),(21.00,2955.75),(22.00,2955.75),(23.00,2970.50),
   (24.00,2941.00),(25.00,2941.00),(26.00,2941.00),(27.00,2941.00),(28.00,2941.00)
⊘ O2_DATA_CURV = graph(time_in)
   (5.00,4.50),(6.00,3.87),(7.00,3.51),(8.00,3.24),(9.00,3.60),(10.00,4.10),(11.00,5.04),(12.00,6.03),(13.00,7.02),
   (14.00,8.01),(15.00,8.91),(16.00,9.99),(17.00,11.16),(18.00,12.24),(19.00,13.20),(20.00,13.59),(21.00,13.14),
   (22.00,12.33),(23.00,11.52),(24.00,10.60),(25.00,9.45),(26.00,8.37),(27.00,7.20),(28.00,6.10)
⊘ O2_DATA_PTS = graph(time_in)
   (5.00,3.20),(6.00, 0.0),(7.00, 0.0),(8.00, 0.0),(9.00, 0.0),(10.00,5.80),(11.00, 0.0),(12.00, 0.0),(13.00, 0.0),
```

(14.00,15.30),(15.00, 0.0),(16.00, 0.0),(17.00, 0.0),(18.00, 0.0),(19.00,13.90),(20.00, 0.0),(21.00, 0.0),(22.00, 0.0),(23.00, 0.0),(24.00,10.00),(25.00, 0.0),(26.00, 0.0),(27.00, 0.0),(28.00,6.00)

⊘ O2_rate = graph(time_in)

(5.00,-0.878),(6.00,-0.634),(7.00,-0.134),(8.00,0.566),(9.00,1.63),(10.00,2.22),(11.00,2.62),(12.00,2.69),(13.00,2.23),(14.00,1.57),(15.00,0.579),(16.00,-0.249),(17.00,-0.732),(18.00,-1.04),(19.00,-1.02),(20.00,-0.939),(21.00,-0.847),(22.00,-0.732),(23.00,-0.640),(24.00,-0.617),(25.00,-0.709),(26.00,-0.824),(27.00,-0.962),(28.00,-1.05)

⊘ pH = graph(time_in)

(5.00,8.60),(6.00,8.60),(7.00,8.63),(8.00,8.68),(9.00,8.74),(10.00,8.86),(11.00,8.99),(12.00,9.13),(13.00,9.25),(14.00,9.30),(15.00,9.29),(16.00,9.23),(17.00,9.18),(18.00,9.10),(19.00,9.04),(20.00,8.98),(21.00,8.92),(22.00,8.83),(23.00,8.74),(24.00,8.60),(25.00,8.43),(26.00,8.15),(27.00,7.87),(28.00,7.50)

⊘ RAD_IN_WATER = graph(time_in)

(0.0, 0.0),(0.100, 0.0),(0.200, 0.0),(0.300, 0.0),(0.400, 0.0),(0.500, 0.0),(0.600, 0.0),(0.700, 0.0),(0.800, 0.0),(0.900, 0.0),(1.00, 0.0),(1.10, 0.0),(1.20, 0.0),(1.30, 0.0),(1.40, 0.0),(1.50, 0.0),(1.60, 0.0),(1.70, 0.0),(1.80, 0.0),(1.90, 0.0),(2.00, 0.0),(2.10, 0.0),(2.20, 0.0),(2.30, 0.0),(2.40, 0.0),(2.50, 0.0),(2.60, 0.0),(2.70, 0.0),(2.80, 0.0),(2.90, 0.0),(3.00, 0.0),(3.10, 0.0),(3.20, 0.0),(3.30, 0.0),(3.40, 0.0),(3.50, 0.0),(3.60, 0.0),(3.70, 0.0),(3.80, 0.0),(3.90, 0.0),(4.00, 0.0),(4.10, 0.0),(4.20, 0.0),(4.30, 0.0),(4.40, 0.0),(4.50, 0.0),(4.60, 0.0),(4.70, 0.0),(4.80, 0.0),(4.90, 0.0),(5.00, 0.0),(5.10, 0.0),(5.20, 0.0),(5.30, 0.0),(5.40, 0.0),(5.50, 0.0),(5.60, 0.0),(5.70, 0.0),(5.80, 0.0),(5.90, 0.0),(6.00,27.14),(6.10,64.74),(6.20,101.31),(6.30,138.47),(6.40,176.41),(6.50,216.86),(6.60,260.65),(6.70,307.93),(6.80,359.08),(6.90,413.50),(7.00,472.00),(7.10,532.00),(7.20,596.00),(7.30,661.50),(7.40,727.80)(7.50,796.00),(7.60,865.00),(7.70,934.00),(7.80,1004.00),(7.90,1073.00),(8.00,1143.00),(8.10,1213.00),(8.20,1281.00),(8.30,1349.00),(8.40,1416.00),(8.50,1483.00),(8.60,1548.00),(8.70,1612.00),(8.80,1675.00),(8.90,1737.00),(9.00,1797.00),(9.10,1857.00),(9.20,1915.00),(9.30,1971.00),(9.40,2026.00),(9.50,2080.00),(9.60,2131.00),(9.70,2182.00),(9.80,2230.00),(9.90,2277.00),(10.00,2323.00)...

⊘ ZENITH = graph(time_in)

(0.0,1.57),(0.100,1.57),(0.200,1.57),(0.300,1.57),(0.400,1.57),(0.500,1.57),(0.600,1.57),(0.700,1.57),(0.800,1.57),(0.900,1.57),(1.00,1.57),(1.10,1.57),(1.20,1.57),(1.30,1.57),(1.40,1.57),(1.50,1.57),(1.60,1.57),(1.70,1.57),(1.80,1.57),(1.90,1.57),(2.00,1.57),(2.10,1.57),(2.20,1.57),(2.30,1.57),(2.40,1.57),(2.50,1.57),(2.60,1.57),(2.70,1.57),(2.80,1.57),(2.90,1.57),(3.00,1.57),(3.10,1.57),(3.20,1.57),(3.30,1.57),(3.40,1.57),(3.50,1.57),(3.60,1.57),(3.70,1.57),(3.80,1.57),(3.90,1.57),(4.00,1.57),(4.10,1.57),(4.20,1.57),(4.30,1.57),(4.40,1.57),(4.50,1.57),(4.60,1.57),(4.70,1.57),(4.80,1.57),(4.90,1.57),(5.00,1.57),(5.10,1.57),(5.20,1.57),(5.30,1.57),(5.40,1.57),(5.50,1.57),(5.60,1.57),(5.70,1.57),(5.80,1.57),(5.90,1.57),(6.00,1.55),(6.10,1.53),(6.20,1.50),(6.30,1.48),(6.40,1.46),(6.50,1.43),(6.60,1.41),(6.70,1.38),(6.80,1.36),(6.90,1.33),(7.00,1.31),(7.10,1.29),(7.20,1.26),(7.30,1.24),(7.40,1.21),(7.50,1.19),(7.60,1.16),(7.70,1.14),(7.80,1.11),(7.90,1.09).(8.00,1.06),(8.10,1.04),(8.20,1.02),(8.30,0.990),(8.40,0.970),(8.50,0.940),(8.60,0.920),(8.70,0.890),(8.80,0.870),(8.90,0.840),(9.00,0.820),(9.10,0.790),(9.20,0.770),(9.30,0.740),(9.40,0.720),(9.50,0.690),(9.60,0.670),(9.70,0.640),(9.80,0.620),(9.90,0.590),(10.00,0.570)...

APPENDIX D. LIST OF ACRONYMS

Administrative Council (for a CRSP)	a group of university administrators, composed of a representative from each U.S. institution in a CRSP; sometimes called Board of International Representatives; each member represents the interests of higher institutions as well as the CRSP
AID	Agency for International Development
ALA	Latin American Aquaculture Association (1st Symposium Venez. 1977; 2nd Mexico 1972)
ANDAH	Honduran National Aquaculture Association (Associacion Nacional de Acuicultura Hondùras)
AU	Auburn University
BAC	Brackishwater Aquaculture Center
Baseline Data	that information and data base in some sector or aspect of a developing country which is necessary to measure change in the future
BFAR	Board for Food and Agriculture Research
BIFAD	Board for International Food and Agricultural Development, U.S.
Bilateral Programs	assistance programs involving arrangements between a single developing country and a single donor country
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
CIFAD	Consortium for International Fisheries and Aquaculture Development
COFINA	Development Finance Corporation
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
DINAAC	Direccion Nacional de Acuicultura (National Department of Aquaculture), Panama
DST	Data Synthesis Team (also called Data Synthesis and Analysis Team)
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
FEBROEXAAH	Honduran Federation for Agricultural Exports (Federacion Para Programa de Exportacion Agricola Honduras)
FTE	Full Time Equivalent
Global Plan	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; improvements, may include physical facilities, equipment, furnishings, transportation, organization, but refers primarily to development and training of professional cadre
IPB	Institut Pertanian Bogor, Indonesia
JCARD	Joint Committee on Agricultural Research and Development (formerly Joint Research Committee), BIFAD
JRC	Joint Research Council, USAID
LDC	Lesser Developed Countries
LUPE	Land Use and Conservation Program (Honduras)
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
ME	Management Entity
MIDA	Ministerio de Desarrolo Agropecuario (Ministry of Agricultural Development), Panama
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
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 institution which receives the AID grant
PD/A CRSP	Pond Dynamics/Aquaculture Collaborative Research Support Program
PI	Principle Investigators - scientists in charge of the research for a defined segment or a scientific discipline of a CRSP
PMO	Program Management Office
Program Manager	an official AID employee designated to oversee a CRSP on behalf of AID
RENARE	Directorate of Renewable Natural Resources, Honduras
S&T Bureau (S&T AGR)	Bureau of Science and Technology, a central bureau of AID in Washington, charged with administering worldwide technical and research programs for the benefit of U.S. AID-assisted countries
SELA	Latin American Economic System
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
TDY	Temporary Duty
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
UC Davis	University of California at Davis
UH	University of Hawaii
UM	University of Michigan

UNR	Universite Nationale de Rwanda (National University of Rwanda)
UPV	University of the Philippines in the Visayas
USAID	United States Agency for International Development