II. Research Program Accomplishments

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

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

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

Global Studies and Activities

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

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

To assess the fate of nutrients added to brackish water systems, scientists from Auburn University,

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

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

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

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

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

POND© was also used to revise fertilization guidelines originally developed through PONDCLASS. These revisions included the use of gross rather than net primary productivity to estimate nutrient requirements for algae, the consideration of nitrogen and phosphorus cycling in ponds, and the functional representation of the effects of nutrient concentrations and temperature on algal growth. Results of a model verification of the revised fertilization guidelines revealed that the revised guidelines were more conservative than PONDCLASS fertilization guidelines. This

finding is consistent with fertilization strategy research indicating that strategies accounting for ambient pond water conditions are more likely to be superior in terms of cost and efficiency of fertilizer use compared with fixed input strategies.

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

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

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

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

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

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

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

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