



RESEARCH SUMMARY

Research conducted under the Eighth and Ninth Work Plans includes nine of the fifteen themes outlined in the *Continuation Plan 1996–2001* (see also Tables 1 through 4 on pp. 6–9 of the present report). In the reporting period (1 August 1998 through 31 July 1999), CRSP scientists conducted research in the following areas: pond dynamics, feeds and fertilizers, reproduction control, aquaculture systems modeling, new aquaculture systems/new species, effluents and pollution, marketing and economic analysis, adoption/diffusion, and decision support systems.

A summary of each study report received during the reporting period is presented below. Reports are identified by research area, research theme and code, project leader, and report title. In addition, information about the status (i.e., final vs. progress) of each report is also provided. For example, a final report was owed if the completion date for a study fell within the reporting period; similarly, if a study was not scheduled to be completed until after the close of the reporting period, a progress report was owed on 31 July. Please see Appendix 5 for a tabular overview of reports received, themes addressed, and study completion dates (where these differ from completion dates listed in the *Eighth* or *Ninth Work Plan*, it is owing to schedule changes requested and approved in the reporting period).

RESEARCH AREA: PRODUCTION OPTIMIZATION
RESEARCH THEME: POND DYNAMICS RESEARCH
8PDR1/Pond soil characteristics and dynamics of soil organic matter and nutrients/Boyd [Final report]

The final results from the Eighth Work Plan study appear in the progress report for 9PDR2.

RESEARCH AREA: PRODUCTION OPTIMIZATION
RESEARCH THEME: POND DYNAMICS RESEARCH
9PDR2/Pond soil characteristics and dynamics of soil organic matter and nutrients/Boyd [Progress report]

Historically, little work has been conducted on pond bottom soils. As production levels have increased, the importance of pond bottom soils has been recognized. This study is a continuation of Eighth Work Plan studies to characterize the pond soils at all CRSP sites. One goal of the research is to bring pond soils into the existing system of Soil Taxonomy. In support of a set of horizons developed by CRSP researchers, the layers found in the soil cores collected at freshwater PD/A CRSP sites in Iquitos, Peru, and Sae Kao, Thailand, show the typical layering seen in other CRSP sites and in the US, although layers in the Peru cores were weakly developed. The soils in both locations were highly weathered. Soil incubations were found to provide little useful information on pond nutrient dynamics and will no longer be conducted. An additional study examined soil respiration in soils from freshwater catfish ponds in Auburn, Alabama, and brackish-water shrimp ponds in Ecuador. Results suggest that studies to correlate pond water quality with soil organic matter content should sample the upper 1 to 2 cm of soil.

RESEARCH AREA: PRODUCTION OPTIMIZATION
RESEARCH THEME: POND DYNAMICS RESEARCH
8KR1/New site development and characterization/Bowman [Final report]

In late March of 1997, the CRSP initiated research at Sagana Fish Farm, Kenya. (Development of the Kenya site was initiated in 1994 and continued through the Interim Work Plan, culminating with a formalized Memorandum of Understanding in March 1997.) Site enhancement activities

included renovating ponds, supplying laboratories, and installing a weather monitoring system. Beginning in December 1997, weather data were collected on solar radiation, photosynthetically active radiation, precipitation, relative humidity, wind speed, and air temperature. The first year's data suggest that Sagana belongs to a Köppen Aw climate type (tropical wet and dry). Pond soil analyses indicate that the black cotton soils at Sagana are clay-rich, will require liming to prevent carbon-limitation, and have a high phosphorus adsorption capacity. Pond source water chemistry was also described.

RESEARCH AREA: PRODUCTION OPTIMIZATION
RESEARCH THEME: POND DYNAMICS RESEARCH
8TR1/Effect of mud turbidity on fertilization, and an analysis of techniques to mitigate turbidity problems in wet season/Diana [Final report]

Turbidity of pond water is a problem in areas where bottom soils and dikes contain heavy clays or where clays are introduced by run-off or source water. Turbidity can adversely affect water quality and fish growth by inhibiting light penetration, increasing acidity, and binding with mineral nutrients and with phytoplankton cells. A number of pond management techniques can mitigate turbidity and thus allow normal phytoplankton growth in response to fertilizer inputs. This study continues prior research that evaluated turbidity mitigation techniques in the dry season. This experiment was conducted in the wet season in ponds stocked with Nile tilapia at the Asian Institute of Technology, Thailand. The five treatments were: 1) no cover (control); 2) pond dikes covered with black plastic to prevent turbidity from run-off; 3) pond bottoms covered with green manure to alter soil texture; 4) pond bottoms covered with fine plastic mesh to prevent disturbance by fish; and 5) pond dikes covered with straw. Compared to the warm-season experiment, the plastic-covered treatment was more effective at decreasing turbidity, likely because it decreased turbidity from run-off. The weed-covered treatment resulted in high fish mortality in the dry season; better timing of fish stocking prevented mortality in the wet-season experiment. Fish growth was significantly higher in the straw- and weed-covered treatments than in the other treatments. The decay

of both straw and weeds, although it depressed DO concentrations, released nutrients for plankton growth. In addition, the straw decreased turbidity from run-off, thus making it the best mitigating technique in the wet season.

RESEARCH AREA: PRODUCTION OPTIMIZATION
RESEARCH THEME: FEEDS AND FERTILIZERS RESEARCH
 8HR1/Intensification of tilapia production: Effects of feeding at different stocking rates on pond water quality/Green [Final report]

A study was designed to examine the effects of three stocking rates on tilapia yield, profitability, and pond nutrient budgets. Fish mortality due to an interrupted water supply delayed the study. Fingerlings raised in a second attempt escaped in the floods following tropical storm Mitch. As a result of damages from the flood, the study was not completed.

RESEARCH AREA: PRODUCTION OPTIMIZATION
RESEARCH THEME: FEEDS AND FERTILIZERS RESEARCH
 8KR3/Relative contribution of supplemental feed and inorganic fertilizers in semi-intensive tilapia production/Bowman [Final report]

One of the constraints to the development of aquaculture in Kenya has been the scarcity of nutritionally complete feeds. The application of chemical fertilizers may address this constraint by enhancing food production and indirectly providing protein to complement energy-rich rice bran. To characterize the productive capacity of ponds and identify lowest-cost combinations of rice bran and inorganic fertilizer, researchers in Kenya initiated a 20-week experiment to test four feed and fertilization regimes applied to ponds stocked with *Oreochromis niloticus* and *Clarias gariepinus*: 1) urea and diammonium phosphate (DAP) to provide 16 kg N ha⁻¹ wk⁻¹ and 4 kg P ha⁻¹ wk⁻¹; 2) urea and DAP applied to give 8 kg N ha⁻¹ wk⁻¹ and 2 kg P ha⁻¹ wk⁻¹, plus rice bran fed at 60 kg ha⁻¹ d⁻¹; 3) rice bran fed at 120 kg ha⁻¹ d⁻¹; and 4) rice bran as in treatment 3 and fertilizer as in treatment 2. As reported in last year's progress report, the net fish yields averaged 1,127, 1,582, 1,607, and 2,098 kg ha⁻¹ for treatments 1 through 4, respectively. Treatment 1 was the most cost-effective treatment, although costs for treatments 2 through 4 were comparable. The costs of treatments 1 and 2 will be of most interest to farmers; however, treatment 1 fish may not reach marketable size due to the absence of fertilizer. The relative profitability of different fertilization schemes depended heavily on the cost of rice bran.

RESEARCH AREA: PRODUCTION OPTIMIZATION
RESEARCH THEME: FEEDS AND FERTILIZERS RESEARCH
 8KR3A/Nutritional contribution of natural and supplemental foods for Nile tilapia: Stable carbon isotope analysis/Lochmann [Final report]

The optimization of nutrient utilization can result in lower feed costs, higher production, and reduced effluent loads. In this study, carbon isotope analysis was used to determine the contribution of different natural and supplemental food sources to the nutrition of Nile tilapia, analyzing inputs and fish (*Oreochromis niloticus* and *Clarias gariepinus*) from the

companion study 8KR3. Fish were preconditioned by feeding them corn, which has a less negative isotope ratio than bran. The most distinctive trend in the isotope data was the more positive values for plankton, *Clarias*, and *Oreochromis* in treatment 1 (no rice bran) versus treatments 2 through 4 (rice bran) for midpoint and final samples. Plankton had more positive values in treatment 1 versus the other treatments in the initial samples as well, possibly due to a pretreatment effect. Significantly higher chlorophyll *a* concentrations were observed in treatment 1 than in the other treatments. Given that the isotope ratios of plankton and rice bran were generally more negative than those of the fish, it was difficult to distinguish their relative nutritional contributions. Future studies might benefit by dividing plankton into different categories before isotope analysis, because utilization of zooplankton and phytoplankton varied between treatments. Isotope analysis might also clarify the trophic relationship between *Clarias* and *Oreochromis* in different treatments, given that gut content data do not.

RESEARCH AREA: PRODUCTION OPTIMIZATION
RESEARCH THEME: FEEDS AND FERTILIZERS RESEARCH
 8FFR1K/Global Experiment: Optimization of nitrogen fertilization rate in freshwater tilapia production ponds/Bowman [Progress report]

Prior PD/A CRSP research has addressed primary production in tilapia ponds through the addition of inorganic and organic fertilizers. While increased fertilization generally increases primary productivity (and thus tilapia yield) in aquaculture ponds, experiments to find optimal levels of inorganic fertilization rates are lacking. Researchers at all PD/A CRSP sites undertook the Eighth Work Plan Global Experiment to accomplish the following objectives: 1) determine the optimal rate of nitrogen fertilization (in the presence of adequate phosphorus and carbon) to obtain optimal primary productivity and yields of Nile tilapia in freshwater production ponds; 2) determine the most profitable nitrogen fertilization rate; and 3) develop a full-cost enterprise budget for the most profitable nitrogen fertilization rate identified. Researchers at Sagana Fish Farm in Kenya undertook two experiments, one in the cool season and one in the warm season. In both experiments, ponds were stocked with *Oreochromis niloticus* at an initial density of 1 t ha⁻¹ and with *Clarias gariepinus*. Treatments for this experiment consisted of nitrogen (urea and diammonium phosphate) applied at 0, 10, 20, and 30 kg ha⁻¹ wk⁻¹ and phosphorus applied at 8 kg ha⁻¹ wk⁻¹. In both experiments, a highly significant quadratic correlation existed between nitrogen input rate and gross fish yield, with better correlation in the cool-season experiment. Fish production was much lower in the warm-season experiment, with gross yield (at a nitrogen fertilization rate of 20 kg ha⁻¹ wk⁻¹) of 1,901 kg ha⁻¹ versus 3,229 kg ha⁻¹ in the cool season. The highest marginal return occurred at 20 kg N ha⁻¹ wk⁻¹ in both experiments. These results are similar to those reported from the Honduras site. Another finding indicated that production of a given pond over both experiments was related to cumulative nitrogen input; that is, a carry-over effect of fertilization was suggested. The final report for this study will carry results of the full-cost enterprise budget of the most profitable treatment.

RESEARCH AREA: PRODUCTION OPTIMIZATION
RESEARCH THEME: FEEDS AND FERTILIZERS RESEARCH
 8PHR1/Development of low-cost supplemental feeds for tilapia in pond and cage culture/Fitzsimmons [No report submitted; last year's report satisfies final report requirement]

RESEARCH AREA: PRODUCTION OPTIMIZATION
RESEARCH THEME: FEEDS AND FERTILIZERS RESEARCH
 8FFR1Ph/Global Experiment: Optimization of nitrogen fertilization rates in freshwater tilapia production ponds during cool season/Brown [Study not begun; work plan schedule change filed]

RESEARCH AREA: PRODUCTION OPTIMIZATION
RESEARCH THEME: FEEDS AND FERTILIZERS RESEARCH
 8FFR1T/Global Experiment: Optimization of nitrogen fertilization rates in freshwater tilapia production ponds during cool season/Diana [Final report]

Prior PD/A CRSP research has addressed primary production in tilapia ponds through the addition of inorganic and organic fertilizers. While increased fertilization generally increases primary productivity (and thus tilapia yield) in aquaculture ponds, experiments to find optimal levels of inorganic fertilization rates are lacking. Researchers at all PD/A CRSP sites undertook the Eighth Work Plan Global Experiment to accomplish the following objectives: 1) determine the optimal rate of nitrogen fertilization (in the presence of adequate phosphorus and carbon) to obtain optimal primary productivity and yields of Nile tilapia in freshwater production ponds; 2) determine the most profitable nitrogen fertilization rate; and 3) develop a full-cost enterprise budget for the most profitable nitrogen fertilization rate identified. In last year's progress report for the same study, the results from a warm-season experiment addressing these three objectives were reported, as well as the results of an additional study that examined the relationship between initial fish size and pond carrying capacity. The final report for this investigation summarizes results from the cool-season experiment conducted at the Asian Institute of Technology, Thailand. Ponds were stocked with sex-reversed male *Oreochromis niloticus* at an initial density of 1 t ha⁻¹. Treatments for this experiment consisted of nitrogen (urea) applied at 0, 10, 20, and 30 kg ha⁻¹ wk⁻¹ and phosphorus (TSP) applied at 8 kg ha⁻¹ wk⁻¹. Gross fish yield increased with increasing nitrogen fertilization rate, to a maximum (at 30 kg N ha⁻¹ wk⁻¹) of 1,938 kg ha⁻¹. This was lower than that reported in the warm-season experiment, 2,409 kg ha⁻¹. Fish growth ceased around day 70, but the ponds were not harvested until day 91. The partial budget analysis showed that the 30 kg N ha⁻¹ wk⁻¹ treatment was most profitable. A full-cost enterprise budget analysis indicated that a net profit of US\$2.13 could be produced from a 200-m² pond, compared to US\$11.90 in the warm-season experiment. If fish had been harvested before growth ceased, profits could have been much higher. The results of this study also suggest that farmers can optimize resource utilization and maximize profits by starting tilapia in densely stocked ponds and moving them to less densely stocked ponds when fish growth ceases.

RESEARCH AREA: PRODUCTION OPTIMIZATION
RESEARCH THEME: FEEDS AND FERTILIZERS RESEARCH
 9FFR4/Timing of the onset of supplemental feeding of tilapia in ponds/Brown [Progress report]

Based on socioeconomic studies carried out by CRSP researchers, tilapia production has intensified and farmers in Central Luzon, Philippines, are receptive to adoption of new technology. In an attempt to provide guidance to farmers who seek to increase production in a cost-effective manner, a study was initiated to test the effects on tilapia production of low-level feeding or feeding during only a part of the production cycle. This study builds on CRSP research conducted in Thailand, which demonstrated that initiating feeding of Nile tilapia after 80 days in pond resulted in the same yield as initiating at 38 days. In this study, seven farmers compared production in two ponds in which supplemental feeding commenced at 45 and 75 days post-stocking. The study was still underway at the time the report was written, but preliminary results showed that in four out of seven farms, growth was better in ponds that received supplemental feeding 45 days post-stocking. Water quality appeared uncorrelated to time of initiation of feeding.

RESEARCH AREA: PRODUCTION OPTIMIZATION
RESEARCH THEME: REPRODUCTION CONTROL RESEARCH
 8RCR1A/Methods for strain variations in sex ratio inheritance/Phelps [No report submitted; pending work plan change approval, last year's report will satisfy final report requirement]

RESEARCH AREA: PRODUCTION OPTIMIZATION
RESEARCH THEME: REPRODUCTION CONTROL RESEARCH
 8RCR1B/Methods for androgenesis techniques applicable to tilapia/Shelton [Final report]

Chromosome manipulation techniques to yield YY male tilapia have been the focus of this investigation. Previous progress reports outlined techniques of photoperiod and temperature manipulation to manage spawning, determined tau curves describing temperature dependence of mitotic interval, and established optimal UV doses to inactivate the DNA of unfertilized Nile tilapia eggs. The past year's work builds on prior research, applying the protocols developed earlier to manage spawning and to inactivate the DNA of eggs. The phenotypic marker used was the recessive blond color of males used for fertilization. Ova from normal-colored Nile tilapia of a Ghana stock were UV-treated, fertilized with milt from blond males, and subjected to cold shock (11°C) for 60 min at 59, 69, or 79 min post-activation. The development of non-pigmented androgenotes through hatching and swim-up was tracked. The highest hatch rate (22% of control) occurred in the 69-min post-activation treatment, which was just prior to the first mitotic cytokinesis. Out of 157 androgenotes that hatched, only 57 survived to swim-up. Juvenile mortality rates remained high, and only five of these androgenotes had survived to July. Progeny testing, assuming sufficient survival, and the optimization of shock time and type will constitute the focus of future investigations.

RESEARCH AREA: PRODUCTION OPTIMIZATION
RESEARCH THEME: REPRODUCTION CONTROL RESEARCH
 8RCR1C/Methods for contribution from the male and female genome to sex inheritance/Phelps [No report submitted; please see Editor's Note, p. 37.]

RESEARCH AREA: PRODUCTION OPTIMIZATION
RESEARCH THEME: REPRODUCTION CONTROL RESEARCH
 8RCR1D/Methods for development of YY lines of male and female *O. niloticus*/Phelps [No report submitted; please see Editor's Note, p. 37.]

RESEARCH AREA: PRODUCTION OPTIMIZATION
RESEARCH THEME: REPRODUCTION CONTROL RESEARCH
 8RCR3B/Detection of MT in pond water after treatment with MT food/Phelps [Final report]

Administering food impregnated with 17 α -methyltestosterone (MT) can be used to produce male-biased populations of tilapia, resulting in faster growth and reduced reproduction. However, the steroid may be lost into the environment from uneaten or unmetabolized food. Non-target organisms may then be at risk of exposure. This study complements a laboratory study completed by other CRSP researchers last year. Nile tilapia fry were stocked in adjacent cages and fed for 28 days a diet containing 60 mg MT kg⁻¹ or a non-treated feed. Effectiveness of MT to produce all males within both groups of tilapia was determined. Water and soil samples were collected prior to, during, and after the treatment period and analyzed for MT residues. The treated fish were effectively masculinized (91% male), while the sex ratio of fish raised in a cage 50 cm away was unaffected (48% male). In the laboratory study conducted at Oregon State University, MT was detected in water and soil samples during treatment, in water for one week after treatment, and in soils for four weeks after treatment. In this field experiment, very little evidence of MT escapement into the water column was measured. Radioimmunoassay results from soil samples indicate cross-reaction with other materials in addition to MT; the apparent initial MT content of soil in these ponds with no prior application of MT was 875 pg g⁻¹. The aggressive feeding behavior of tilapia, combined with rapid breakdown in conditions of high light intensity and temperature plus metabolism by fungi and bacteria of excreted, unmetabolized steroids, is proposed as an explanation for the lack of apparent contamination of pond water and soils with MT.

RESEARCH AREA: PRODUCTION OPTIMIZATION
RESEARCH THEME: REPRODUCTION CONTROL RESEARCH
 8KR2/Strain variations in sex ratio inheritance/Bowman [Final report]

Populations of Nile tilapia give the expected mean sex ratios of 50:50, but the ratio can vary considerably when individual pair spawns are considered. This study was planned in collaboration with reproduction control researchers (see Phelps report "Methods for strain variations in sex ratio inheritance," 8RCR1A) to determine the sex ratio inheritance of the strain of Nile tilapia (*Oreochromis niloticus vulcani*) cultured at Sagana Fish Farm. Spawning success and survival were too low in the first year of the study to obtain the number of fingerlings required to complete the study.

During the second year, it was determined that the strain of tilapia at Sagana may not be pure and that it may be contaminated with *O. spirulis*. At this point, the researchers decided not to perform additional pair spawns.

RESEARCH AREA: PRODUCTION OPTIMIZATION
RESEARCH THEME: REPRODUCTION CONTROL RESEARCH
 9RCR5A/Effect of treatment timing and dose on masculinization with trenbolone acetate/Fitzpatrick [Final report]

Tilapia tend to reproduce prolifically in ponds, which results in a harvest of many small fish instead of fewer, more marketable fish. Stocking single-sex populations addresses this problem, and because males grow faster than females, male-biased populations are preferred. The use of masculinizing hormones has been the topic of CRSP reproduction control research. Earlier studies on the hormones 17 α -methyl dihydrotestosterone (MDHT) and 17 α -methyl testosterone (MT) reported variable success with masculinizing tilapia. Treatment timing and dose with the synthetic androgen trenbolone acetate (TA) are tested in this study. A series of three experiments varying the timing of exposure revealed that Nile tilapia were significantly masculinized when immersed in 500 mg TA l⁻¹ for three hours at 13 or 14 days post-fertilization. These results differ from those found in an earlier study, suggesting that the window of sensitivity to masculinizing hormones is short and may vary between broods. Two experiments that varied the dose were hampered by small brood sizes and high mortality, but suggest that minor increases in dosage (e.g., 500 to 1,000 mg TA l⁻¹) do not significantly increase masculinization. A final experiment, with a fractional factorial design, was also hindered by small sample size. However, the fractional factorial design offers promise as a means to rapidly and efficiently determine optimal timing, dose, exposure time, and fish density.

RESEARCH AREA: PRODUCTION OPTIMIZATION
RESEARCH THEME: REPRODUCTION CONTROL RESEARCH
 9RCR5B/Masculinization of tilapia by immersion in trenbolone acetate: Growth performance of trenbolone acetate-immersed tilapia/Fitzpatrick [Study not begun; work plan schedule change filed]

RESEARCH AREA: PRODUCTION OPTIMIZATION
RESEARCH THEME: AQUACULTURE SYSTEMS MODELING RESEARCH

8ASMR1A/Aquaculture pond modeling for the analysis of environmental impacts and integration with agriculture: Model evaluation and application to the ecological analysis of integrated aquaculture/agriculture systems/Piedrahita [Final report; report title different than study title in *Eighth Work Plan*]

CRSP researchers designed a model to analyze the environmental impacts of aquaculture and the ecological functioning of integrated aquaculture/agriculture systems. The first two years of research under this investigation involved the development of a model to analyze and predict organic matter and nitrogen flows in aquaculture ponds and the evaluation of this model using sensitivity analysis and model verification methods. The verified model was then

used to prioritize future research areas in integrated agriculture/aquaculture. The final report for this investigation gives additional information about the model validation and application. The results suggest a number of field experiments that would be valuable: to examine effects of pond water removal (timed with agricultural cycles, not pond cycles) on pond water quality and fish yield; to assess the effects of varying stocked fish size and stocking density; and to determine the effects of varied prestocking practices to improve food availability at time of stocking. A 120-day simulation using dry-season data from CRSP research in Honduras modeled the effects of different organic matter and nitrogen cycling pathways on tilapia and corn production. It was found that merely increasing the number of nitrogen cycling pathways did not increase nitrogen retention and productivity and that applying pond sediment to crops that have also received inorganic fertilizer did not increase productivity.

RESEARCH AREA: PRODUCTION OPTIMIZATION
RESEARCH THEME: AQUACULTURE SYSTEMS MODELING RESEARCH

8ASMR1B/Aquaculture pond modeling for the analysis of environmental impacts and integration with agriculture: Modeling of temperature, dissolved oxygen, and fish growth rate in stratified ponds using stochastic input variables/Piedrahita [Final report; report title different than study title in *Eighth Work Plan*]

The development of data tools to be used in planning and managing fish ponds is one goal of PD/A CRSP research. Many models are deterministic; that is, the same results will be generated each time a given set of input data is run through the model. Stochastic modeling, as in this investigation, generates varying inputs and results in a probability distribution of possible outcomes. The earlier progress reports for this study described refinements to and validation of a model designed to predict water temperature, dissolved oxygen, and fish growth under the effects of random weather variables. The final report for this investigation describes the model and each of its components. The weather generation module was developed using daily clearness indices measured at three PD/A CRSP sites. Generated weather variables were in satisfactory agreement with data from CRSP sites. However, the quality of fish-growth and water-quality simulations varied between sites and treatments. Variability between replicate ponds, particularly in Thailand, was not well predicted by the simulations; identifying the cause of that variability is recommended as a goal of future research efforts. In spite of its limitations, the model can be used to generate stochastic weather values at sites with limited weather data and to identify possible probability distributions for water quality and fish growth.

RESEARCH AREA: PRODUCTION OPTIMIZATION
RESEARCH THEME: NEW AQUACULTURE SYSTEMS/NEW SPECIES RESEARCH

9NS2/Culture of mixed-sex Nile tilapia with predatory snakehead/Diana [Abstract]

Overpopulation of tilapia ponds due to uncontrolled reproduction can result in stunting due to food shortage.

Overpopulation can be controlled by stocking single-sex populations, culture in cages, culture with predators, intermittent harvesting, and induction of sterility. Little research has been conducted to date on the stocking of predatory fish. A study begun in May 1999 will compare growth and production of Nile tilapia in ponds stocked with monoculture of sex-reversed tilapia, monoculture of mixed-sex tilapia, or polyculture of mixed-sex tilapia and predatory snakehead at ratios of 10:1, 20:1, 40:1, and 80:1.

RESEARCH AREA: ENVIRONMENTAL EFFECTS
RESEARCH THEME: EFFLUENTS AND POLLUTION RESEARCH
 8HR2-1/Estuarine water quality monitoring and estuarine carrying capacity/Green [Final report]

A long-term water quality monitoring project in estuaries in shrimp-producing regions of Honduras was initiated in 1993 by the PD/A CRSP. The project's goal was to add to the estuarine water quality database, providing a scientific basis for estuarine management and sustainable development of shrimp culture. In the current project, samples were collected from 20 sites on 12 estuaries. Samples were analyzed for total settleable solids, nitrate-nitrogen, ammonia-nitrogen, filterable reactive phosphorus, chlorophyll *a*, total alkalinity, salinity, BOD₂, and reactive silicate. Salinity, total nitrogen, and chlorophyll *a* concentrations increased in comparison to 1996-1997 levels, as a result of the 1997-1998 El Niño in Honduras.

RESEARCH AREA: ENVIRONMENTAL EFFECTS
RESEARCH THEME: EFFLUENTS AND POLLUTION RESEARCH
 8HR2-2/Evaluation of shrimp farming impacts in Golfo de Fonseca region, Honduras/Ward [Final report; report title different than study title in the *Eighth Work Plan*]

This study is the continuation of a data collection and modeling study underway for the past several years in two of the channel estuaries draining into the Gulf of Fonseca, Honduras. In this study, the capacity of these two estuaries to assimilate dissolved oxygen (DO) was examined. Using data collected mainly in 1995, biochemical oxygen demand (BOD) loadings from shrimp farms were estimated, and a transport model for salinity and DO in the estuaries was applied to the data to predict mean concentrations of salinity and DO in the estuaries. The model was found to satisfactorily predict DO concentrations, and future loadings based on full shrimp farm development along the two estuaries were then input to determine the resulting DO under these conditions. It was found that 1995 BOD levels already press the carrying capacity in both systems, and at full development DO levels will be worsened.

RESEARCH AREA: ENVIRONMENTAL EFFECTS
RESEARCH THEME: EFFLUENTS AND POLLUTION RESEARCH
 8HR4/Water exchange to rectify low dissolved oxygen/Green [Final report]

This experiment builds on a previous experiment, "Influence of daily water exchange volume on water quality and shrimp production" (HR3), which indicated that daily or emergency water exchange did not significantly affect shrimp production, but that water quality was better in

ponds that received daily water exchange. This experiment examines the effects of time of initiation of water exchange on early morning dissolved oxygen, water quality, and shrimp production. Water was exchanged in experimental ponds at a rate of 10% per day, six days per week, beginning at four, seven, or ten weeks after stocking. While treatment effects began to appear, the torrential rains of tropical storm Mitch on 30–31 October 1998 resulted in the flooding of experimental ponds and the loss of data. It is impossible, therefore, to draw any conclusions regarding the effects of treatment.

RESEARCH AREA: ENVIRONMENTAL EFFECTS
RESEARCH THEME: EFFLUENTS AND POLLUTION RESEARCH
 9ER1/Use of pond effluents for irrigation in an integrated crop/aquaculture system/Wood [Progress report]

Research has shown pond effluents to be valuable in flood irrigation of crops, but there has been little research conducted to address the use of pond water in more efficient irrigation systems of high-value vegetable crops. In this study, an experiment was conducted at Sagana, Kenya, to determine the suitability of polyculture (tilapia (*Tilapia aureus*) and African catfish (*Clarias gariepinus*)) fish-pond effluent for drip irrigation of French bean (*Phaseolus vulgaris* cv. Samantha). A variety of treatments was used, testing various combinations of irrigation and fertilizer treatments. A decline in yield with increasing amounts of pond effluent was observed, possibly owing to particulates that clog drip line emitters. The results of this study indicate that pre-treatment filtration or alternative irrigation methods are required before application of nutrient-enriched pond water will be advantageous.

RESEARCH AREA: ENVIRONMENTAL EFFECTS
RESEARCH THEME: EFFLUENTS AND POLLUTION RESEARCH
 9ER2A/Fate of methyltestosterone in the pond environment: Detection of MT in soil after treatment with MT food/Fitzpatrick [Final report]

Treating tilapia with 17 α -methyltestosterone (MT) to produce all-male populations has become a common practice in aquaculture, and concerns have been raised about production of steroid wastes and metabolites that are potential environmental contaminants. This study examined the persistence of MT in soil after treatment of tilapia with MT. Fry were treated with MT for four weeks beginning at the initiation of feeding in 60-l tanks that contained 5 kg of soil, gravel, or no soil. Water and soil samples were taken before treatment and at weekly intervals beginning on the last day of treatment. In tanks with soil or gravel, MT concentrations in water decreased to background levels by 35 days after the beginning of treatment (one week after the end of treatment). In the tanks with no soil, MT concentrations remained above background levels through 49 days. In tanks with soil, MT was detectable in the soil after 84 days (eight weeks after ending treatment). In tanks with gravel or no soil, MT was detected in a fine sediment that formed after the end of treatment. The results of this experiment demonstrate the persistence of MT in soil for up to eight weeks after ending treatment, raising the possibility of unintended MT exposure.

RESEARCH AREA: ENVIRONMENTAL EFFECTS
RESEARCH THEME: EFFLUENTS AND POLLUTION RESEARCH
 9ER2B/Fate of methyltestosterone in the pond environment: Detection of MT in pond soil from a CRSP site/Fitzpatrick [Abstract]

This study, currently underway at the Universidad Juárez Autónoma de Tabasco, Mexico, will examine persistence of 17 α -methyltestosterone (MT) in the environment after its use for tilapia masculinization at one or more PD/A CRSP sites. Fry have been treated with MT for four weeks beginning at the initiation of feeding, and water and soil samples were taken from the pond before treatment and one day after treatment. Samples will also be taken four weeks after the end of treatment, and concentrations of MT will be determined by radioimmunoassay. A similar sampling design may also be used at Sagana Fish Farm, Kenya, with subsequent analysis of samples at Oregon State University.

RESEARCH AREA: ENVIRONMENTAL EFFECTS
RESEARCH THEME: EFFLUENTS AND POLLUTION RESEARCH
 9ER3/Integrated recycle systems for catfish and tilapia culture/Diana [Study not begun; work plan schedule change filed]

RESEARCH AREA: SOCIAL AND ECONOMIC ASPECTS
RESEARCH THEME: MARKETING AND ECONOMIC ANALYSIS
 8MEAR1/Nonparametric estimation of returns to investment in Honduras shrimp research/Engle [Final report]

This study sought to estimate the economic returns to the investment in shrimp research by the PD/A CRSP in Honduras using a nonparametric approach. A survey was used to collect data on yield, input application, and prices for shrimp farms in Honduras for their first year of operation and for the year 1997. Results showed increases in productivity between 1995 and 1997, indicating technical progress due to research. The internal rate of return to public and private investment in research was 45%, but the internal rate of return to public-sector investment in research was more than 6,352%, indicating an effective leveraging of public funds and private-sector capital to generate technological progress.

RESEARCH AREA: SOCIAL AND ECONOMIC ASPECTS
RESEARCH THEME: MARKETING AND ECONOMIC ANALYSIS
 8MEAR2/Risk analysis of shrimp farming in Honduras/Engle [Final report]

While Honduras has established itself as the leading producer of farm-raised shrimp in the Central American region and shrimp farming represents the third staple of the national economy of Honduras, few economic analyses have been conducted to date. In this study, production data were collected from 21 farms for the year 1997. These data include technical aspects of farms such as stocking densities, feeding rates, and feed conversion ratios, as well as financial performance data such as production costs and farm revenue. A risk analysis was conducted from these data using three scenarios defined according to farm size and a fourth to

aggregate farms with uncommonly high yields. Results indicate that risk is more associated with low yields than with high production costs and that, regardless of size, farms should target a minimum acceptable yield; production of less than 450 kg ha⁻¹ was associated with a large potential for loss.

RESEARCH AREA: SOCIAL AND ECONOMIC ASPECTS
RESEARCH THEME: MARKETING AND ECONOMIC ANALYSIS
 9MEAR3/Development of Central American markets for tilapia produced in the region/Engle [Progress report]

This study will seek to identify and characterize existing market channels for fish and seafood in Honduras through the use of a survey instrument, which has been developed and is currently under review. Using the survey instrument, profiles will be developed of the types of markets that sell tilapia in Honduras, and the factors related to increased tilapia sales and the likelihood of other markets adding tilapia will be determined. Contacts have been made to identify a graduate student and enumerators to assist with the project, and the surveys will be conducted from September through December 1999.

RESEARCH AREA: SOCIAL AND ECONOMIC ASPECTS
RESEARCH THEME: MARKETING AND ECONOMIC ANALYSIS
 9MEAR4/Economic and social returns to technology and investment in Thailand/Engle [Progress report]

A survey will be conducted in this study to measure rates of adoption of CRSP-developed technologies in northeastern Thailand. The rates of adoption will be used in a quantitative model to measure the internal rate of return to the investment in aquaculture research in Thailand. This study follows Eighth Work Plan research measuring the returns to research investment for CRSP-sponsored shrimp research in Honduras.

RESEARCH AREA: SOCIAL AND ECONOMIC ASPECTS
RESEARCH THEME: ADOPTION/DIFFUSION
 8ADR1-1/Fish culture in the Peruvian Amazon: Producer perceptions and practices in three river systems/Molnar [Final report; report title different than study title in the *Eighth Work Plan*]

In this study, research was conducted to discover the nature of small-scale, community-based aquaculture employed in the Peruvian Amazon. Rural communities were visited, and fish farmers, community residents, and public and private agency officials were interviewed to determine the various strategies and approaches to aquaculture employed in this region. A high degree of variability was observed in the species used and the level of management applied. Variations were also found in the quality of pond construction and culture conditions. The data show few barriers to aquaculture in this region, and local fish farmers appear to be in an advantageous situation for fish culture. Fish farmers were also found to be receptive to technical assistance. The results further indicate that additional research is needed to identify and communicate production practices that will reduce risk and enhance aquaculture benefits.

RESEARCH AREA: SOCIAL AND ECONOMIC ASPECTS
RESEARCH THEME: ADOPTION/DIFFUSION
 8ADR1-2/Sources of technical assistance for fish farmers in the Peruvian Amazon/Molnar [Progress report; report title different than study title in the *Eighth Work Plan*]

In this study, survey data were collected from a sample of 146 fish farmers near Iquitos, Peru, in selected communities served by NGOs, in an effort to determine relative desire for and exposure to extension efforts in the region. The survey results address varying perceptions of need for technical assistance based on gender and the type of operating arrangements for aquaculture. Results indicate that about 38% of the women surveyed had no contact with extension efforts, compared to 9% of the men. All the women and 95% of the men participating in the survey indicated that they desired extension contact in the future. The results of this study suggest that NGOs can be productive and enduring mechanisms for supporting family-based fish culture in rural areas of the Peruvian Amazon.

RESEARCH AREA: SOCIAL AND ECONOMIC ASPECTS
RESEARCH THEME: ADOPTION/DIFFUSION
 8ADR2/Impacts of integrated fish culture on resource-limited farms in Guatemala and Panama: An ex-post evaluation/Lovshin [Final report]

This study evaluated the current status of tilapia pond projects initiated in the 1980s by the governments of Guatemala and Panama with financial support from the US Agency for International Development, in an attempt to determine the technological, economic, and social factors that influenced the success or failure of integrated fish culture projects there. In both Guatemala and Panama, aquaculture did not have the intended impact on household nutrition and income for a variety of technical, domestic, economic, social, and broad political reasons. In both countries, although aquaculture projects did not meet intended goals related to fish culture, many project participants found ways to profit from the existence of ponds by using ponds for irrigation, animal watering, or rice paddies. In Guatemala, 28 of 46 individual household ponds were still used at some level of proficiency. In Panama, 15 of 21 cooperatively managed ponds were still used at some level of proficiency.

RESEARCH AREA: SOCIAL AND ECONOMIC ASPECTS
RESEARCH THEME: ADOPTION/DIFFUSION
 8KR5/Regional outreach in Africa/Bowman [Final report]

In order to disseminate information obtained from PD/A CRSP research, learn about fish culture practices and research priorities and activities in Kenya and neighboring African countries, and encourage the establishment of regional linkages between research and extension, CRSP researchers attended meetings of the Organization of African Unity's Scientific, Technical and Research Commission (OAU/STRC) Inter-African Committee and Symposium on Oceanography, Sea and Inland Fisheries; the East African Environmental Network (EAEN); and the Fisheries Society of Africa. Representatives from seven African nations and numerous international organizations attended the OAU/STRC Inter-African Committee meeting where CRSP

researchers set up a display to publicize the program. At the EAEN Conference, CRSP researchers presented an invited paper entitled "An overview of aquaculture practices in East Africa: Potential environmental impacts and prospects for sustainable livelihoods," which was published in a proceedings volume. CRSP researchers gave nine presentations (oral and poster), which spanned topics such as the feeding and fertilization of semi-intensive tilapia monoculture and polyculture systems, the status of fisheries in Kenya and specifically of Lake Baringo, fish smoking, fish diversity in Lake Tanganyika, and parasitic fauna of tilapia species in Lake Naivasha and the Oloidien Bay.

RESEARCH AREA: SOCIAL AND ECONOMIC ASPECTS

RESEARCH THEME: ADOPTION/DIFFUSION

9ADR3/Aquaculture training for Kenyan fisheries officers and university students/Bowman [Progress report]

To increase the pond management skills of fisheries personnel currently involved in aquaculture extension and enhance the research and extension capabilities of university students likely to be employed in the aquaculture sector, PD/A CRSP researchers in Kenya developed training sessions relevant for university students, fisheries officers, fish farmers, and extension agents. Five graduate-level university students conducted their thesis research and four undergraduate students did their six-week "attachment" (or internship) at Sagana Fish Farm under the supervision of CRSP researchers. Fisheries officers at Sagana Fish Farm have taken on their own research projects (e.g., *Clarias* fingerling production techniques, feed electivity indices for *Clarias* and tilapia in fertilized ponds, and construction and testing of fish graders) under the guidance of CRSP researchers at Sagana Fish Farm, while other staff members have been selected for professional training in work with computers and applied biology. Additionally, a farmer education day was designed that addressed topics such as regulation of water flow, predator and weed control, feeds and fertilizers, stocking rates and carrying capacity, integration of farm practices with fish ponds, fish harvest techniques, and fish drying and smoking. Seven fisheries officer/farmer training sessions were also conducted throughout the Central Province of Kenya.

RESEARCH AREA: SOCIAL AND ECONOMIC ASPECTS

RESEARCH THEME: ADOPTION/DIFFUSION RESEARCH

9ADR4/Establishment of companion sites in the Africa region/Bowman [Progress report]

To verify program research results obtained at the CRSP prime site in Kenya and expand the breadth of CRSP research, researchers in Kenya are seeking to identify and establish one or more companion sites in the East Africa region and design and implement investigations at the newly identified companion site. Recently the Project Leader (and former PD/A CRSP researcher) of the International

Center for Living Aquatic Resources Management (ICLARM) in Malawi visited Sagana Fish Farm and explored the possibility of a three-way collaboration between the PD/A CRSP, Bunda College in Malawi, and ICLARM. Representatives of Bunda College are currently reviewing a proposal for a student from Bunda College to conduct research at the National Aquaculture Center in Malawi, which is managed by ICLARM. This creates an excellent opportunity for regionalization, because Malawi is the seat of the Fisheries Office for the Southern African Development Community (SADC) and Bunda College is the fisheries and aquaculture training site for SADC countries.

RESEARCH AREA: SOCIAL AND ECONOMIC ASPECTS

RESEARCH THEME: ADOPTION/DIFFUSION RESEARCH

9ADR5/Regional outreach in Africa/Bowman [Progress report]

In order to promote the dissemination of information emanating from PD/A CRSP research results, learn about fish culture practices and research priorities and activities in Kenya and neighboring African countries, and encourage the establishment of regional linkages between research and extension, CRSP researchers attended the following meetings: Shallow Water Bodies in the Tropics, held in Naivasha, 12–16 April 1999; the Fisheries Society of Africa Executive Officer's Meeting, held in Nairobi, 22 April 1999; and East African Environmental Network Conference, held in Nairobi, 28–29 May 1999. At the Shallow Water Bodies in the Tropics Conference four presentations were made by graduate students conducting CRSP research. An abstract on pond effluent use for crop irrigation was submitted to the Seventeenth Conference and Silver Jubilee of the Soil Science Society of East Africa, to be held in Kampala, Uganda, in September 1999. CRSP researchers also plan to attend and present research results at a conference on the Lake Victoria Basin in November 1999.

RESEARCH AREA: SOCIAL AND ECONOMIC ASPECTS

RESEARCH THEME: DECISION SUPPORT SYSTEMS

9DSSR3/Enhancing the POND[®] decision support system for economics, education, and extension/Bolte [Progress report]

This report discusses the latest design, functional modules, and application areas of POND[®], a software decision support tool for analyzing and projecting cultural and economic aspects of warmwater aquaculture production systems. Current efforts focused on completing POND[®] Version 4.0, which has expanded enterprise budget capabilities compared to previous versions. The results of this study will enable continued improvement of analytical tools for managing warmwater aquaculture facilities and enhance understanding of the economic implications of various facility configurations and management options.