



RESEARCH SUMMARY

Research conducted under the *Eighth Work Plan* includes nine of the fifteen themes outlined in the *Continuation Plan 1996-2001* (see also Tables 1-4 on pp. 4-7 of the present report). In the reporting period (1 August 1997 through 31 July 1998), 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 4 for a tabular overview of reports received, themes addressed, and study completion dates (where these differ from completion dates listed in the *Eighth Work Plan*, it is owing to schedule changes requested and approved in the reporting period).

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

To provide baseline data regarding the pond ecosystems of PD/A CRSP sites and generate theory regarding the development of pond soils and a systematic method of pond soil classification, researchers continued to direct their efforts toward identifying pond soil characteristics and understanding the dynamics of soil organic matter and nutrients. This study examined soil cores extracted from newly renovated ponds in Sagana, Kenya, and contains data pertaining to basic soil characteristics, results of ammonia and carbon dioxide dynamics in soils incubated under aerobic conditions, ammonia dynamics of soil incubated under anaerobic conditions, and phosphorus equilibrium concentrations in laboratory soil-water mesocosms. Soil data collected in Kenya were then compared with data collected from other CRSP sites in the US, Honduras, Thailand, and Egypt. The profile of Kenya soils was not as developed as other CRSP sites, possibly due to recent pond renovations—the S horizon was well-developed and extended to 6 cm, but M, T, and P horizons were poorly developed. Soil pH was near neutral, with carbon concentrations between 2 and 5%. Carbon:nitrogen ratios were between 10 and 20, sulfur concentrations were 0.5%, and phosphorus concentrations were low. Incubation rates for pond soils from Kenya, Thailand, and Honduras revealed relatively low microbial respiration rates in comparison with terrestrial soils and net negative nitrogen mineralization had occurred. Phosphorus equilibrium concentrations of soil water mesocosms from freshwater ponds in Thailand and Kenya and from fresh and brackishwater ponds in Honduras indicated that ponds at each of these sites would be sinks for phosphorus added in fertilizer. Additionally, it appears that pond soil profiles become more distinct in a shorter period of time than terrestrial soil profiles.

RESEARCH AREA: PRODUCTION OPTIMIZATION
RESEARCH THEME: POND DYNAMICS
PR2/New site development and characterization/Kohler [Final report]

Researchers provided a descriptive overview of the PD/A CRSP site located in Iquitos, Peru. Physical, meteorological, and hydrological characteristics of the site are presented in addition to a description of the hatchery facility and ponds.

[This study was carried out in lieu of the Global Experiment (FFR1), as work with tilapia in Peru is prohibited by the Peruvian government.]

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

In late March of 1997, the CRSP initiated research at Sagana Fish Farm, Kenya, a recently established prime site in Africa. (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 are summarized in this abstract. Data were collected pertaining to solar radiation, photosynthetic active radiation, precipitation, relative humidity, wind speed, and air temperature. Preliminary soil analyses are also presented.

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

For aquaculture ponds with heavy clay dikes and bottoms, mud turbidity is a significant concern. High mud turbidity may inhibit plankton growth, cause acidity, limit light penetration for photosynthesis, and lead to a decline in nutrients. Additionally, turbidity problems prevail in countries such as Thailand, Cambodia, and Laos where there are many rain-fed ponds. Thus, a study was designed to assess the effects of different mitigation techniques on fish growth and identify suitable approaches for the mitigation of turbidity. Five different turbidity mitigation techniques were tested during the dry season: a control; a black plastic covering placed at the top of the dike and extending 50 cm down the pond edge; green manure (terrestrial weeds) to cover pond bottoms and alter texture; netting to cover pond bottoms; and lime applied biweekly at a rate of 200 kg ha⁻¹. Ponds that were limed had the best growth performance, except for survival, and the green manure treatment ponds had the lowest survival and the lowest fish yields. This may have been attributable to low dissolved oxygen concentrations caused by the decomposition of weeds during the first month of the experiment. The treatment that used netting to cover pond bottoms was successful at preventing turbidity due to fish

disturbance, which resulted in reduced phosphorus regeneration but not reduced fish production. The treatment that covered pond edges was not significantly different from the control in terms of fish growth performance; however, this treatment may be more effective during the wet season. Further research is advised to elucidate the relationship between pond bottom soil characteristics and water quality management in semi-intensive fish ponds.

RESEARCH AREA: PRODUCTION OPTIMIZATION

RESEARCH THEME: POND DYNAMICS

TR2/Management of organic matter and nutrient regeneration in pond bottoms/Diana [Final report]

During grow-out the accumulation of organic matter in pond bottom soils can lead to severe oxygen depletion at the sediment-water interface. A small amount of organic matter is beneficial; however, an abundance of organic matter in pond soils can cause anaerobic conditions. Throughout Asia polyculture and pond drying are practiced to mitigate the accumulation of organic matter on pond bottoms; however, very little research has been done in this area. A study was therefore initiated to assess the effect of polyculture and pond drying on organic matter accumulation and to develop a better understanding of the link between bottom soil characteristics and management. Two experiments were conducted. The first experiment assessed the effects of aerobic and anaerobic conditions of pond bottoms on organic matter decomposition and nutrient release and the effectiveness of common carp in removing organic matter from pond sediments and recycling nutrients for tilapia. The second experiment was designed to assess the physical and chemical conditions during microbial decomposition of organic matter and the resultant release of nutrients during pond drying. Results of these two experiments indicated that the polyculture of Nile tilapia (*Oreochromis niloticus*) and common carp (*Cyprinus carpio*) was effective in recycling nutrients and may be potentially effective in removing organic matter if common carp are stocked at higher densities. Also, although prior research has indicated that pond drying can retard the rate of organic matter accumulation due to the enhanced availability of oxygen that allows for greater rates of microbial decomposition of organic matter, it was found that pond drying did not result in significant oxidation of organic matter and releases of nutrients. This may have been because ponds were not completely dried and deep cracks had not completely developed to allow for enhanced oxygen availability.

RESEARCH AREA: PRODUCTION OPTIMIZATION

RESEARCH THEME: FEEDS AND FERTILIZERS

HR1/Intensification of tilapia production: Effects of feeding at different stocking rate on pond water/Green [No report submitted; please see Editor's Note, p. 49.]

RESEARCH AREA: PRODUCTION OPTIMIZATION

RESEARCH THEME: FEEDS AND FERTILIZERS

FFR1H/Global Experiment: Optimization of nitrogen fertilization rates in freshwater tilapia production ponds/Green [Final report]

Nile tilapia (*Oreochromis niloticus*) are often semi-intensively cultured using fertilizers to increase primary productivity, thereby increasing fish food availability. PD/A CRSP research over the years has addressed primary production in tilapia ponds through the addition of inorganic and organic fertilizers; however, findings pertaining to optimal nitrogen, phosphorus, and carbon inputs necessary for increased production are

inconsistent. Thus researchers undertook a study—the Global Experiment—to be carried out at all PD/A CRSP sites, 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 rates; and 3) develop a full-cost enterprise for the most profitable nitrogen fertilization rate identified. At the El Carao National Fish Culture Research Center in Honduras a dry- and wet-season study was conducted in which 8 kg P ha⁻¹ wk⁻¹ plus 0, 10, 20, or 30 kg N ha⁻¹ wk⁻¹ were added to 0.1-ha earthen ponds. During the wet-season study, tilapia yields varied curvilinearly in response to increased nitrogen inputs. Significant differences in tilapia yields were not detected for the dry-season study. The treatment receiving 20 kg N ha⁻¹ wk⁻¹ had the highest total revenues during both the dry- and wet-season studies, and partial budget analysis demonstrated that this treatment was the most economically optimal given the current economic situation of Honduras. Additionally, the full-cost enterprise budget for this treatment showed that income above variable costs was \$991 ha⁻¹ per five-month production cycle.

RESEARCH AREA: PRODUCTION OPTIMIZATION

RESEARCH THEME: FEEDS AND FERTILIZERS

KR3/Relative contribution of supplemental feed and inorganic fertilizers in semi-intensive tilapia production/Bowman [Progress report]

To characterize the productive capacity of ponds, evaluate the relative contributions of inorganic fertilizers and supplemental feeds to fish production, 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: 1) urea and 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 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. 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.

RESEARCH AREA: PRODUCTION OPTIMIZATION

RESEARCH THEME: FEEDS AND FERTILIZERS

KR3A/Nutritional contribution of natural and supplemental foods for Nile tilapia: Stable carbon isotope analysis/Lochmann [Progress report]

In an effort to develop economical feed and fertilizer practices that maximize fish production, a study involving stable carbon isotope analysis to determine the nutritional contribution of natural and supplemental foods for Nile tilapia was conducted. Fish (*Clarias* sp. and *Oreochromis niloticus*) were fed one of the following treatment diets: 1) urea and 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 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. The most distinctive trend in the isotope data was the more positive values for plankton, *Clarias* sp., and *O. niloticus* in treatment 1 versus treatments 2 through 4 for initial and midpoint samples; however, there may have been an undefined pre-treatment effect. At the onset of the

study, isotope values of plankton were more positive in treatment 1 than in the other treatments. Further, significantly higher chlorophyll *a* concentrations were observed in treatment 1 than in the other treatments. Rice bran was not the only nutrient affecting the isotope ratios of plankton given the more negative value for the midpoint isotope ratio of plankton (-29.6‰) in comparison with the isotope ratio of rice bran (-27.8‰). Researchers plan to collect more isotope data in order to develop a more comprehensive discussion of the effects of various nutrient inputs on the production of *O. niloticus* and *Clarias*.

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

Nile tilapia (*Oreochromis niloticus*) are often semi-intensively cultured using fertilizers to increase primary productivity, thereby increasing fish food availability. PD/A CRSP research over the years has addressed primary production in tilapia ponds through the addition of inorganic and organic fertilizers; however, findings pertaining to optimal nitrogen, phosphorus, and carbon inputs necessary for increased production are inconsistent. Thus, researchers undertook a study—the Global Experiment—to be carried out at all PD/A CRSP sites, to accomplish the following objectives: 1) determine the optimal rate of nitrogen fertilization (in the presence of adequate phosphorus and carbon) to obtain optimum primary productivity and yields of Nile tilapia in freshwater production ponds; 2) determine the most profitable nitrogen fertilization rates; and 3) develop a full-cost enterprise for the most profitable nitrogen fertilization rate identified. Researchers at Sagana Fish Farm in Kenya initiated a cool season experiment which is in progress. Prior to filling, 100 kg of TSP was broadcast over the bottom of each pond. Ponds were stocked with fish of an average weight of 17 g at an initial density of 1 t ha⁻¹. Treatments for this experiment consisted of nitrogen (urea and DAP) additions to ponds at 0, 10, 20, and 30 kg ha⁻¹ wk⁻¹ and phosphorus additions at 8 kg ha⁻¹ wk⁻¹. (The ponds that did not receive any nitrogen fertilization were given TSP whereas ponds receiving nitrogen fertilization were given DAP.) Preliminary observations indicated that nitrite levels were very high (with mortality in one pond) in the treatment receiving 30 kg N ha⁻¹ wk⁻¹.

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

Nile tilapia (*Oreochromis niloticus*) are often semi-intensively cultured using fertilizers to increase primary productivity, thereby increasing fish food availability. PD/A CRSP research over the years has addressed primary production in tilapia ponds through the addition of inorganic and organic fertilizers; however, findings pertaining to optimal nitrogen, phosphorus, and carbon inputs necessary for increased production are inconsistent. Thus researchers undertook a study—the Global Experiment—to be carried out at all PD/A CRSP sites, to accomplish the following objectives: 1) determine the optimal rate of nitrogen fertilization (in the presence of adequate phosphorus and carbon) to obtain optimum primary productivity and yields of Nile tilapia in freshwater production ponds; 2) determine the most profitable nitrogen fertilization

rates; 3) develop a full-cost enterprise for the most profitable nitrogen fertilization rate identified; and 4) investigate the relationship between initial fish size and pond carrying capacity. In Thailand two experiments were conducted. In the first experiment treatment ponds were fertilized with TSP at a rate of 8 kg P ha⁻¹ wk⁻¹ and with urea at 0, 10, 20, and 30 kg N ha⁻¹ wk⁻¹ and stocked with sex-reversed Nile tilapia (10.1 to 10.9 g in size) at 1,000 kg ha⁻¹. For the second experiment, 4.6 to 4.8 g, 10.1 to 10.5 g, and 21.3 to 21.8 g fish were stocked in ponds receiving urea and TSP at a rate of 30 kg N and 8 kg P ha⁻¹ wk⁻¹. Both experiments indicated that the treatments with higher N inputs showed better growth performance of Nile tilapia. In the first experiment the treatment receiving 30 kg N ha⁻¹ wk⁻¹ produced the highest yields (2,409.6 ± 46.4 kg ha⁻¹ wk⁻¹). Results of the second experiment showed that survival was best in the treatments stocked with large fish. The treatments stocked with medium- and large-size fish had the best growth performance; however, fish biomass and yields were highest in the treatment stocked with medium-size fish.

RESEARCH AREA: PRODUCTION OPTIMIZATION
RESEARCH THEME: FEEDS AND FERTILIZERS
 PHR1/Development of low-cost supplemental feeds for tilapia in pond and cage culture/Fitzsimmons [Progress report]

The nutrients of supplemental feeds are necessary when the productivity of a water body is insufficient to sustain a desired fish growth. Thus, low-cost high-quality feeds are requisite in ponds when farmers wish to produce more fish than is attainable given the fertilization system or when fish are cultured in cages and do not have access to an entire water body for feeding. For many small-scale farmers who have decided to cage-culture tilapia in order to increase their household income and nutrition, the cost of feed becomes the major cost for fish production. Supplemental feeds are intended to provide nutrients that would otherwise be limiting to fish growth, and often protein is the limiting nutrient in fertilized ponds. Providing additional protein can be a cost-effective method for increasing growth rates and increasing stocking density; however, dietary protein—typically fishmeal and soybean oil meal—is often expensive to incorporate into the diet. To address these concerns associated with supplemental feeding, two feeding trials were conducted to determine the viability of using yeast and composted rice straw as alternative protein sources for tilapia diets. Experimental diets were fed to both tilapia in ponds and tilapia in cages in a common pond. Results of this study showed that tilapia growth rates were best in the treatments that received the diet which incorporated composted rice straw. From the study results, CRSP researchers concluded that low-cost supplemental feeds would increase pond production and that composted rice straw would be a better source of protein than yeast to replace fishmeal.

RESEARCH AREA: PRODUCTION OPTIMIZATION
RESEARCH THEME: REPRODUCTION CONTROL
 RCR1A and RCR1C/Methods for strain variations in sex ratio inheritance and methods for contribution from the male and female genome to sex inheritance/Phelps [Progress report; results of studies RCR1A and RCR1C submitted as one report]

Uncontrolled reproduction can be a significant factor constraining the culture of tilapia. Intraspecific breeding programs for YY male tilapia are one method for producing all male populations and effectively controlling reproduction; however, sex ratios of progeny from single pair spawnings are skewed despite an expected 50:50 sex ratio (female tilapia are homogametic and male tilapia are heterogametic). To address

this issue a study was conducted to identify strains of *O. niloticus* that exhibit minimal variation in sex ratio inheritance. Three strains of *O. niloticus* were used: Egypt, Ghana, and Ivory Coast. Brooders ranged from 50 to 250 g in size, and paired matings were facilitated by placing fish at a ratio of male to three females in 2-m² hapas located in outdoor tanks. Progeny from spawns were then randomly selected and raised at two temperatures (35.3 and 28.3°C). The mean percentage of males, females, and intersex fish did not differ among the strains evaluated, but there was considerable variation in the sex ratios of individual spawns. Sex ratios of the Ivory Coast strain spawns exhibited the greatest variation followed by the Ghana and Egypt strains. In terms of temperature, no one strain appeared to be more sensitive to temperature; however, individual spawns did respond differently to temperature. Siblings reared at higher temperatures showed a range of response to temperature—siblings from four spawns reared at higher temperature had a > 10% increase in males while the percent males from siblings from four spawns differed by < 10%, illustrating that a degree of individual variation may occur in response to temperature and that it is important to select fish of known spawning histories for use in a YY breeding program.

RESEARCH AREA: PRODUCTION OPTIMIZATION
RESEARCH THEME: REPRODUCTION CONTROL

RCR1B/Nile tilapia gamete management for chromosome manipulation/Shelton [Progress report; report title different than study title in *Eighth Work Plan*]

Refinement of chromosome manipulation techniques continued during the last year's reproduction control research and included: 1) improvement of the efficiency of collecting freshly ovulated eggs from Nile tilapia; 2) development of a tau curve over the spawning temperature range; 3) generation of preliminary data on the UV treatment of eggs for induction of androgenesis; and 4) progeny tests to identify genetic markers in the broodstock of Nile tilapia at the University of Oklahoma. Spawning of Nile tilapia was maintained for a year through photoperiod manipulation. In addition to photoperiod manipulation, preliminary trials of hormonal induction of ovulation evaluated the use of three hormones: gonadotropin-releasing hormone analogue (GnRH_a), luteinizing hormone-releasing hormone analogue (LHRH_a), and human chorionic gonadotropin (HCG). Eggs stripped from tilapia were naturally and artificially fertilized and incubated at a closely regulated temperature in order to monitor developmental rate. Tau curves were then derived using the mean interval from the initiation of the first and third mitoses in 5 to 10% of the eggs; these intervals were recorded at temperatures within the usual developmental range (20 to 30°C). Eggs were also treated with differential UV exposure (100 to 500 J m⁻²), fertilized, and then development was monitored through hatching and swim-up stages. A comparison of hatch rates between artificial and natural spawning indicated that both were variable. Photoperiod manipulation appeared to be a reasonable technique for predicting ovulation and time of stripping, whereas hormone induction of ovulation was less reliable. The tau curve from this experiment was calculated to be $\tau = 10^{5.4167} C^{-2.7009}$ ($r^2 = 0.90$), where C is temperature (°C), and the time to first mitosis was $T = 10^{4.9663} C^{-2.1208}$ ($r^2 = 0.91$). These curves can be used to standardize shock treatments. Results of testing of UV exposure to inactivate the DNA indicated that hatch rates were generally near zero at a dose of UV between 400 and 500 J m⁻²; survival to swim-up was zero with UV dosages of 300 to 400 J m⁻². Future research will involve the use of the tau data collected from this study to test thermal shock times.

RESEARCH AREA: PRODUCTION OPTIMIZATION
RESEARCH THEME: REPRODUCTION CONTROL

RCR1D/Methods for development of YY lines of male and female *O. Niloticus*/Phelps [No report submitted; please see Editor's Note, p. 35.]

RESEARCH AREA: PRODUCTION OPTIMIZATION
RESEARCH THEME: REPRODUCTION CONTROL

RCR2A/Steroid immersion for masculinization of tilapia: Immersion of tilapia fry in MDHT/Fitzpatrick [Final report]

Steroid immersion for the masculinization of Nile tilapia (*Oreochromis niloticus*) is another method (in addition to androgenesis) for the control of unwanted reproduction and the production of all-male tilapia populations. Usually hormones are administered through feeds; however, this method tends to be inefficient. Further, there may be hazards associated with worker exposure to steroids and/or the leakage of steroids into the surrounding environment and non-target organisms. As an alternative to hormone-impregnated feed technology, immersion technology research continued with refinements to short-term hormone immersion techniques. Tilapia were immersed for two hours in 500 mg l⁻¹ 17 α -methylidihydrotestosterone (MDHT) at 280, 310, or 364 CTU (10, 11, and 13 dpf; days post fertilization) or twice at 280 and 364 CTU in 500 mg l⁻¹ MDHT at 28°C (CTU refers to the dpf multiplied by the temperature (°C)). Two immersions in MDHT at 280 and 364 CTU resulted in a population of 82.9% males and a single immersion at 364 CTU resulted in 79.3% males, thus demonstrating that masculinization of Nile tilapia was equally effective with a single immersion at 364 CTU or with two immersions at 280 and 364 CTU.

RESEARCH AREA: PRODUCTION OPTIMIZATION
RESEARCH THEME: REPRODUCTION CONTROL

RCR2B/Effect of fish density on efficacy of masculinization by immersion in MDHT/Fitzpatrick [Final report]

To identify the optimal treatment conditions for short-term immersions of Nile tilapia, density, hormone dosage, and length of exposure were tested in two experiments. In the first experiment fry were stocked in 3.8-l glass jars at densities of 33, 66, 100, or 200 fish l⁻¹ and immersed in 500 μ g l⁻¹ MDHT at 280 and 364 CTU (10 and 13 dpf). In the second experiment, using a fractional factorial design, fry were stocked at 12, 25, 50, 100, and 200 fish l⁻¹ and immersed in trenbolone acetate (TBA) at 364 and 392 CTU (13 and 14 dpf); hormone dosages were 62.5, 125, 250, 500, or 1,000 μ g l⁻¹ at exposures of 0.75, 1.5, 3, 6, and 12 h. For the first experiment, the immersion treatment in which fish were stocked at 33 fish l⁻¹ resulted in 80.3% males, which was significantly higher than the control (56.7% males). Data for the second experiment were not analyzed because all controls and treatment groups contained 100% males. Although recommendations from this research can be made regarding stocking density for steroid immersion treatments, it is important to test the effects of hormone dosage, length of exposure, and density in a fractional factorial study to broaden the information base regarding steroid immersion technology.

RESEARCH AREA: PRODUCTION OPTIMIZATION
RESEARCH THEME: REPRODUCTION CONTROL

RCR2C/Masculinization of tilapia fry by immersion in trenbolone acetate (TBA) at a production level/Phelps [Final report; report title different than study title in *Eighth Work Plan*]

Research has indicated that steroid immersion is a viable method for inducing masculinization in Nile tilapia; however, the effects of immersion technology are unknown at production levels with tilapia. Thus, to test the efficacy of immersion technology at a production level, researchers examined the masculinization effects of tilapia treated for six hours in a stock solution of trenbolone acetate (TBA) dissolved in ethanol. Broodfish were stocked at a ratio of one male to three females in 2-m² hapas; eggs or sac fry were removed (hapas were checked every 10 days) and incubated; swim-up fry were collected as soon as they were able to swim out of the incubator and held until 9, 11, 13, or 15 days post-hatch. Fry were then stocked at a density of 33 fish l⁻¹ and immersed in 500 µg l⁻¹ TBA for six hours. After steroid immersion, fry were fed four times per day until an age of 20 days and then restocked in outdoor 20-m² tanks and reared to 5 cm. Treatment effects were not observed—the non-TBA treatment had a mean of 49.1% males and TBA-treated tilapia ranged from 43.7 to 54.3% males. Results of this study suggest that tilapia with post-hatch ages of 3, 7, 9, 11, 13, and 15 days do not masculinize when immersed in 500 µg l⁻¹ TBA for two to six hours, although the lack of intersex fish and/or water quality may have had some bearing on the outcome of this study. Additional studies are suggested to assess the effects of water chemistry on androgens applied as a bath treatment.

RESEARCH AREA: PRODUCTION OPTIMIZATION
RESEARCH THEME: REPRODUCTION CONTROL
 RCR3A/Detection of MT in aquarium water after treatment with MT food/Fitzpatrick [Final report]

The treatment of tilapia feeds with 17α-methyltestosterone to achieve all-male populations is common throughout the world; however, despite the success of this practice there is concern that there is significant “leakage” of MT into the environment. This potential for leakage of MT into the environment poses a threat of exposure to hatchery workers and fish or other non-target aquatic organisms. In a study using model pond systems that tested whether MT was detectable within the pond environment, researchers demonstrated that considerable amounts of MT leak into the environment during dietary treatment. Levels of MT in the water peaked between approximately 1 and 2 µg l⁻¹ at 14 and 21 days after the onset of feeding and decreased to background level by day 35. In contrast, however, the level of MT in the soil was 1.4 to 1.7 µg kg⁻¹ at 28 days after the onset of feeding with MT treated feed and was detectable in the soil at levels between 0.8 and 1.6 µg kg⁻¹ through day 49 (three weeks after ending the treatment with MT-impregnated food).

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

In addition to the above laboratory research to test for the presence of 17α-methyltestosterone (MT) in the treatment environment, an additional field study is in progress. Nile tilapia are stocked in two hapas at 2,000 fish per hapa. The hapas are approximately 50 cm apart in a 400-m² earthen pond. Tilapia in one hapa will be fed a commercial trout ration that does not contain MT and tilapia in the other hapa will be given a feed containing 60 mg MT kg⁻¹ of feed. Soil samples which have no history of exposure to MT were collected prior to the experiment and MT soil assays were performed. These assays

will then be compared with MT assays of soil samples collected during the experimental treatment period to determine if MT is detectable in the soil after the use of MT-treated feeds. In addition to soil samples, water samples will be analyzed as well.

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

In collaboration with reproduction control researchers (see Phelps report RCR1A and RCR1C, pp. 34-35), a study was initiated to determine the sex ratio inheritance of Nile tilapia (*Oreochromis niloticus vulcani*). Spawning success and survival, however, were too low to obtain the number of fingerlings required to complete the study.

RESEARCH AREA: PRODUCTION OPTIMIZATION
RESEARCH THEME: AQUACULTURE SYSTEMS MODELING
 ASMR1A/Model evaluation and application to the ecological analysis of integrated aquaculture/agriculture systems/Piedrahita [Progress 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 past year of research within the aquaculture systems modeling component has involved the evaluation of this model using sensitivity analysis and model verification methods. Additionally, a modeling study was initiated to examine the effects of cycling pathways on system nitrogen retention and productivity and long-term dynamics of pond sediment organic matter. Results of the sensitivity analysis indicate that the model is most sensitive to changes in water infiltration rate, maximum specific phytoplankton production rate per unit of carbon, oxygen threshold for aerobic conditions, organic matter sedimentation rate, and aerobic sediment depth. Based on model verification results, research in the following areas related to processes and management activities would prove beneficial: initial fish weight, aerobic sediment depth, non-phytoplankton light extinction coefficient, crop irrigation rate, water infiltration rate, and mineral soil organic matter decomposition rate coefficient. Simulation of long-term organic matter dynamics in pond sediments revealed that concentrations of organic matter increased over time and were highest for chicken manure and plant waste, followed by chicken manure alone, and then artificial feed. The outcome of this study indicates that the integrated aquaculture/agriculture model will be valuable for the design of integrated aquaculture/agriculture sediment management experiments and the overall management of nitrogen and organic matter in aquaculture ponds.

RESEARCH AREA: PRODUCTION OPTIMIZATION
RESEARCH THEME: AQUACULTURE SYSTEMS MODELING
 ASMR1B/Modeling of temperature, dissolved oxygen, and fish growth rate in stratified ponds using stochastic input variables/Piedrahita [Progress report; report title different than study title in *Eighth Work Plan*]

In addition to the development of an integrated aquaculture/agriculture systems model, researchers have been in the

process of validating and modifying a model designed to predict water temperature, dissolved oxygen, and fish growth using stochastically generated input weather variables. Data from three PD/A CRSP sites—Rwanda, Honduras, and Thailand—were used to calibrate and validate the model. Simulation results of water temperature and DO were in good agreement with the data collected in Rwanda and Honduras, but not with the data obtained from the Thailand site. Results of simulations also revealed that maximum and minimum DO values had the potential to be out of the tolerance range or the no-effects range for some species. Simulations also were sensitive to changes in fertilization rates, indicating that simulation results may be useful for studying the impacts of fertilization rates along with the economic, environmental, and social constraints associated with a given fertilizer. Poor simulation results for chlorophyll *a* at the Thailand site highlight the limitations of the model and suggest that an improved understanding of pond-sediment interactions, phytoplankton dynamics, and fish nutrition should be emphasized in future research.

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

PR1/Development of sustainable pond aquaculture practices for *Piaractus brachyomus* in the Peruvian Amazon/Kohler [Final report; report title different than study title in *Eighth Work Plan*]

As an initial effort to evaluate the aquaculture potential of local and native species and to develop appropriate culture technologies, researchers in Peru conducted a study to evaluate stocking densities of *Piaractus brachyomus* that would be most economic and efficient for the production of market-size fish. Two densities were tested (3,000 and 4,000 fish ha⁻¹) in ponds that ranged in size from 1,015 to 5,320 m², and fish were fed a locally available feed at 5% body weight per day. Results of this study indicated that there were no significant differences in grow-out performance. Fish growth rates were 3.0 g d⁻¹; feed conversion ratios were excellent; and water quality remained within an acceptable range for the culture of *P. brachyomus*. Traditionally, stocking densities of *P. brachyomus* are 2,000 to 3,000 fish ha⁻¹ in this region. Results of this study indicate that it may be possible to increase the stocking density of *P. brachyomus* to 4,000 fish ha⁻¹ with supplemental feeding, but further research is required.

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

A long-term water quality monitoring project initiated in 1993 continued in the shrimp producing regions of Honduras. The goal of this project is to provide a scientific basis for estuarine management and sustainable development of shrimp culture in Honduras through the detection of changes in estuarine water quality. Data from this study will then be used to formulate and validate predictive models for estuarine water quality. Additionally the data, in conjunction with farm chemical budgets and estuarine fluid dynamics data, will be used to estimate assimilative capacity of selected estuaries of the shrimp producing regions of Honduras. During the past year water quality was monitored at 20 sites located on 12 estuaries. Study results indicated that water quality in riverine estuaries continues to be influenced directly by seasonal

variation in river discharge and watershed runoff, while embayment estuaries of the Gulf of Fonseca experience less seasonal variation in water quality. Overall, data collected from riverine or embayment estuaries during the period from 1993 to 1998 did not evidence any trends of total nitrogen or total phosphorus enrichment.

RESEARCH AREA: ENVIRONMENTAL EFFECTS
RESEARCH THEME: EFFLUENTS AND POLLUTION
 HR2-2/Analysis of Honduran shrimp farm impacts on channel estuaries of the Gulf of Fonseca/Ward [Progress report; report title different than study title in *Eighth Work Plan*]

Due to the concern regarding intensive development of the shrimp farming industry and the accumulation of waste by-products associated with mariculture, research was initiated to: 1) detect changes in estuarine water quality over time; 2) formulate and validate predictive models for estuarine water quality; and 3) estimate assimilative capacity for shrimp mariculture in the Rio Choluteca delta areas of Honduras, on the Gulf of Fonseca. In these reports, water quality trends are discussed in light of the data collected since 1993 and the model development is highlighted as well. Two mathematical models were formulated—a section-mean tidal hydrodynamic model and a section-mean longitudinal mass budget model for the concentration of a parameter (such as salinity, dissolved oxygen, and nutrients) along the axis of the estuary. Preliminary trials of the models using estimates of estuary physiography, hydromechanics, kinetics, and hydrology, and based upon full development of the farm concession extant in 1995, predicted that both the Pedregal and Jagua estuaries would have levels of dissolved oxygen below the critical value of 3 mg l⁻¹. These results, in addition to the expression of concern by CRSP researchers and individuals with interests in the shrimp farm industry, have lead to a moratorium on new farm development. Future modeling work will include incorporation of field data pertaining to physiographic and hydrographic inputs and minor modifications to model nitrogen and phosphorus nutrients, specific toxicants such as ammonia, or indicators such as chlorophyll *a*, and will allow the evaluation of a number of different shrimp-farm development scenarios.

RESEARCH AREA: ENVIRONMENTAL EFFECTS
RESEARCH THEME: EFFLUENTS AND POLLUTION
 HR3/Influence of daily water exchange volume on water quality and shrimp production/Green [Final report]

Shrimp culture practices in Honduras are semi-intensive, i.e., final stocking rates range from 5 to 11 shrimp m⁻² and daily water exchange rates average 10% of the pond volume. Water exchange is performed to correct low early morning oxygen concentrations and discharge metabolites; however, research has brought into question the usefulness of this practice. Additionally, there are environmental concerns associated with excessive water exchange such as fuel waste, the sedimentation of water supply canals and ponds, and increased nutrient discharge from ponds. Two experiments were conducted in Honduras to develop a more complete picture of the effects of daily water exchange and emergency water exchange on shrimp production and to develop nitrogen and phosphorus chemical budgets. The following two water exchange regimes were evaluated during both the rainy and dry seasons—water exchange at 10% pond volume per day, six days per week (daily) and water exchanged only in response to early morning dissolved oxygen concentrations

$\leq 2.0 \text{ mg l}^{-1}$ (emergency). Gross yields, growth, survival, and feed conversion ratios of *Penaeus vannamei* were not significantly affected by the different water regimes tested; however, pond water quality was significantly affected and tended to be better for ponds that received daily water exchange. Based on results of this study and the risks perceived by shrimp producers regarding the use of an emergency water exchange regime (especially during the last four to six weeks of the rainy-season culture period), a compromise water exchange regime is suggested—a delayed initiation of daily water exchange until week 10 of the production cycle.

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

Based on the results of the above study, which found that emergency water exchange did not significantly affect shrimp production but did significantly affect water quality, CRSP researchers initiated a study, which is in progress, to evaluate the effect of time of initiation of water exchange on pond dissolved oxygen, water quality, and shrimp production. Nine 0.93-ha ponds located on a commercial shrimp farm in southern Honduras are being used in the completely randomized design study and both rainy- and dry-season experiments will be completed. A daily water exchange rate at 10% of pond volume (six days per week) will be tested beginning four, seven, and ten weeks after stocking.

RESEARCH AREA: ENVIRONMENTAL EFFECTS
RESEARCH THEME: EFFLUENTS AND POLLUTION
 TR3-2/Management to minimize the environmental impacts of pond draining: Effect of harvest draining technique on water quality and fish growth/Diana [Final report; report title different than study title in *Eighth Work Plan*]

Concern has been raised regarding the decrease in water quality of effluents discharged at harvest from aquaculture ponds. Additionally, the seining of ponds prior to draining further increases pollutants in effluent waters. To identify draining and harvest strategies that minimize environmental impacts, researchers initiated a study that tested five harvest draining techniques. The five harvest techniques evaluated were as follows: A) ponds were not drained, fish were anesthetized and harvested by seine net; B) ponds filled with canal water were completely drained after liming and fish were removed from a harvesting pit; C) ponds filled with canal water were completely drained and fish were removed from a harvesting pit; D) ponds filled with drainage water from the harvest of adjacent ponds were drained halfway, seined twice, and then completely drained to collect remaining fish; and E) ponds filled with canal water were drained halfway, seined twice, and then completely drained to collect remaining fish. Means for water quality parameters of all treatments were not significantly different, and fish growth, net fish yield, and survival did not differ among treatments. Fish growth and net fish yields were similar for undrained ponds and ponds filled with drainage water from other ponds. Although there were no significant differences in harvest techniques the results suggest that either harvesting fish without draining or collecting harvest drainage water to fill empty ponds are feasible techniques for minimizing environmental impacts without affecting water quality for fish growth.

RESEARCH AREA: SOCIAL AND ECONOMIC ASPECTS
RESEARCH THEME: MARKETING AND ECONOMIC ANALYSIS
 MEAR1 and MEAR2/Economic and social returns to technology and investment and risk analysis of pond management strategies/Engle [Progress report; results of studies MEAR1 and MEAR2 submitted as one report]

An analysis is underway to ascertain the economic and social returns of PD/A CRSP research for shrimp farmers in Honduras. The preliminary results of 21 interviews with shrimp farm owners and managers, representing approximately one-third of the total number of shrimp farmers in the country, are presented in this report. The shrimp farmers interviewed had yields that ranged from 1,501 to 2,000 lb shrimp ha⁻¹ yr⁻¹. Farmers who stocked a higher density of postlarval shrimp obtained greater yields; large-scale shrimp farmers tended to rely on hatchery-raised postlarval shrimp more so than small- and medium-scale farmers. Farmers with yields greater than 2,000 lb shrimp ha⁻¹ yr⁻¹ provided more than 15 lb feed ha⁻¹ d⁻¹ during the dry season. Most small- and medium-scale shrimp farmers fertilized, while almost no large-scale shrimp farmers fertilized their systems. An economics of scale also appeared to characterize shrimp farm operations—large farms tended to have lower costs per hectare than smaller farms.

RESEARCH AREA: SOCIAL AND ECONOMIC ASPECTS
RESEARCH THEME: ADOPTION/DIFFUSION
 ADR1A/Tilapia producer perceptions and practices in five PD/A CRSP countries/Molnar [Progress report; report title different than study title in *Eighth Work Plan*]

Adoption diffusion research continued to develop a socioeconomic profile of tilapia farmers from five PD/A CRSP sites: Kenya, Rwanda, Honduras, Thailand, and the Philippines. (Most recently, surveys were conducted in Sagana, Kenya.) The surveys focus on overall respondent characteristics (e.g., gender, age, marital status, and number and age of children), land-holdings, farm enterprise, pond culture techniques, fingerling sources, water management, marketing and its constraints, fish culture impacts, problems associated with tilapia culture, prospects for future fish culture, and technical assistance. Thus far, results of this research indicate that income level affects the amount of capital investment by tilapia farmers and their willingness to undertake risk. Factors such as off-farm employment and life cycle considerations influence the production strategies employed in and the benefits sought from the fish culture enterprise.

RESEARCH AREA: SOCIAL AND ECONOMIC ASPECTS
RESEARCH THEME: ADOPTION/DIFFUSION
 ADR2/The influence of fish culture technology, extension methodology, and socioeconomic on success of fish culture on limited-resource farms/Lovshin [Progress report]

In addition to the development of socioeconomic profiles of tilapia farmers at five PD/A CRSP sites, an investigation was conducted to study the effects of a fish culture project that provided technical assistance to rural communities in Panama and Guatemala by USAID and Auburn University in the late 1980s. Thirty-nine fish projects were contacted in Guatemala and twenty-one cooperative fish pond projects were contacted in Panama. Preliminary results of this research revealed that in Guatemala fifteen family ponds were considered abandoned, eighteen ponds still contained water and a few fish but were not directly important to household food supply, and five ponds were well-attended and considered important to the

household. In Panama six community fish pond projects had been abandoned and the remaining fifteen projects still had ponds in use but the use varied. Six fish culture projects had converted their ponds into rice paddies whereas the remaining nine projects continued to culture fish and fertilize their ponds with manure. Only the ponds of two projects were considered well-managed. Further analysis regarding the reasons for success or failure of fish culture projects is planned and it is intended that this information will assist in developing research agendas and the dissemination of CRSP research results.

RESEARCH AREA: SOCIAL AND ECONOMIC ASPECTS
RESEARCH THEME: ADOPTION/DIFFUSION
 KR4/Training/Bowman [Final report]

To ensure the overall success of CRSP work in Kenya the following activities were conducted: 1) training of station field personnel in fish sampling, handling, and transport; 2) training of technicians in the areas of water, soil, and feed sampling, laboratory glassware cleansing, and computer operation; and 3) training of university students in topics relevant to aquaculture in Africa. Details of these training activities are presented in this report.

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

Regional outreach activities were initiated under the Eighth Work Plan in order to disseminate information obtained via CRSP research; provide CRSP researchers with opportunities to learn about fish culture practices, research priorities, and activities in other parts of Africa; encourage efforts to create linkages between research and extension activities in the region; and continue the process of networking and regionalizing CRSP efforts in Africa. This report describes the various connections and linkages that the CRSP has solidified since its arrival in Kenya and the constraints encountered in establishing extension agent short courses. Additionally, this report lists the meetings attended by CRSP scientists.

RESEARCH AREA: SOCIAL AND ECONOMIC ASPECTS
RESEARCH THEME: ADOPTION/DIFFUSION
 TR4/High-input green water on-farm trials in Northeast Thailand/Diana [Final report; report title different than study title in *Eighth Work Plan*]

In 1995/96 the Asian Institute of Technology (AIT) Aquaculture Outreach Project (AOP) in Thailand and the Department of Fisheries (DOF) carried out a high-input on-farm trial with 12 farmers from three provinces in Northeast Thailand. In a number of on-station trials at AIT, researchers found that daily supplements of inorganic fertilizers at the rate of 4 kg N and 1 kg P ha⁻¹ as urea and TSP, respectively, produced optimum yields. Based on these results, a package of technical recommendations for high-input green water trials was developed and recommended for trial by small-scale farmers. Included in this report are details regarding the farming systems of project farmers, aquaculture subsystems of farmers, pond characteristics, the type of support provided by the DOF and AOP, nursing of fry, and information regarding fish culture (e.g., stocking density, culture period, fertilization, culture species, harvest, and yield). Additionally, the significance of the on-farm trials is discussed in terms of the physical quality of pond water, farmers' perceptions of the success of technical recommendations, production, socio-

economic aspects of the trial, and environmental concerns. Overall the trial was quite successful. Expected yield was approximately 600 kg rai⁻¹; however, the average yield recorded was much higher (944 kg rai⁻¹), and virtually all farmers experienced a substantial increase in fish yield which was associated with the change in pond water color from turbid to green or dark green.

RESEARCH AREA: SOCIAL AND ECONOMIC ASPECTS
RESEARCH THEME: DECISION SUPPORT SYSTEMS
 DSSR1A, DSSR1B, and DSSR1C/POND[®] software development and refinement/Bolte [Final report; results of studies DSSR1A, DSSR1B, and DSSR1C submitted as one report; report title different than study title in *Eighth Work Plan*]

Continued refinement of POND[®] software characterized the work of the Decision Support Systems component during the second year of the Eighth Work Plan period. In addition to improvements made to the user interface, "wizards" were developed for the automation and completion of frequently utilized tasks and a water budget model was also incorporated into POND[®] software. The following wizards are now in place: pond setup, lot setup, fertilizer, liming, feed optimizer, water balance, economics, and simulation. The water budget model, used for forecasting water requirements for aquaculture ponds, considers the following water sources: precipitation and runoff. Water losses include evaporation, seepage, effluent discharge, and overflow; water sinks include water discharge, overflow, and evaporation. It is anticipated that the refinements made to POND[®] will improve simulation of production facility dynamics in addition to enhancing model usability via the newly incorporated wizard interfaces.

RESEARCH AREA: SOCIAL AND ECONOMIC ASPECTS
RESEARCH THEME: DECISION SUPPORT SYSTEMS
 DSSR1D/Macro-level agroecological systems analysis and socioeconomics of pond aquaculture/Bolte [Final report]

Recently Decision Support Systems researchers completed a collaborative project with the Food and Agriculture Organization of the United Nations. POND[®] software was incorporated into a GIS product to assess the suitability of particular agroecological regions in South America and Africa to aquaculture production. For further information regarding this collaboration, the following two reports are available: Aguilar-Manjarrez, J. and S. Nath, 1998. A Strategic Reassessment of Fish Farming Potential in Africa. CIFA Technical Paper No. 32. FAO, Rome, 170 pp. Kapetsky, J.M. and S.S. Nath, 1997. A Strategic Assessment of the Potential for Freshwater Fish Farming in Latin America. FAO COPESCAL Technical Paper No. 10, FAO, Rome, 124 pp.

One of the limitations of this study was that it was unable to compare the suitability of alternative land uses with aquacultural production. Thus, a study was initiated to identify methods for generating terrestrial crop production estimates. Artificial neural networks were used to estimate crop yields, water requirements, fertilizer requirements, and grow-out period or time to harvest. Work in progress includes the development of a framework to analyze and prioritize international development needs and the identification and classification of indicators relating to sustainable development. The overall tool developed from this study will be used to explore alternate land/water use strategies in relation to different crops, which include fish farming, and is intended for use in the inland regions of Honduras.