MANAGEMENT OF AQUACULTURAL EFFLUENTS FROM PONDS

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PROJECT OBJECTIVES

1. Develop additional information to characterize the components of aquaculture effluents that represent the greatest potential risk of deleterious environmental impact (e.g. suspended solids, total phosphorus).

2. Evaluate the impact of aquaculture pond effluent discharge on receiving stream water quality.

3. Evaluate a range of water management techniques appropriate for ponds as a means of reducing the quantity and improving the quality of discharged water.

4. Develop and evaluate models for predicting risks to the environment and the costs and benefits of implementing Best Management Practices (BMPs).

5. Based upon existing information, supplemented by project findings, develop a comprehensive set of BMPs that can be implemented to reduce the environmental impacts

of pond aquaculture in general. Develop supplemental BMPs particular to the various pond cultured species in the region that will complement the generic, pond-system BMPs. These BMPs would include best culture practices, waste handling and management, and water quality management and reuse.

6. Convene a series of workshops to educate and inform producers and regulators on the characteristics and management of aquaculture effluents from ponds, including BMPs, based on the best available information and that minimize environmental impact and satisfy regulatory compliance requirements.

ANTICIPATED BENEFITS

Results of this project will provide simple management alternatives to reduce the volume and improve the quality of effluents, possibilities for water reuse, and inexpensive treatment methods based on sedimentation. This project will provide beneficial effluent management practices to producers of channel catfish, striped bass, baitfish, crawfish, and marine shrimp. Development of practical, environmentally sound management practices that minimize the effect of pond effluents on receiving streams will reduce the environmental impact and contribute to the sustainability of the regional aquaculture industry. Information generated by this project can be used by regulators and permit writers to provide effective and coherent regulation of aquaculture effluents.

PROGRESS AND PRINCIPAL ACCOMPLISHMENTS

Objective 1. *Develop additional information to characterize the components of aquaculture effluents that represent the greatest potential risk of deleterious environmental impact (e.g. suspended solids, total phosphorus).*

Auburn University. About 53% of total suspended solids, total phosphorus, total nitrogen, and biochemical oxygen demand are associated with particles less than 5 micrometers in diameter. A water retention time in settling basins of 8 hours will improve effluent quality significantly and a settling time of 2 to 4 hours is sufficient to reduce total suspended solids in effluents to 75 to 90% of original concentrations. Solids removal is associated with declines in the mineral fraction with little change in organic solids concentrations in effluents. Application of aluminum sulfate at 25 to 50 ppm does not improve the efficiency of solids.

Estimates of runoff from watersheds suggest that settling basins to treat storm runoff from watershed-type catfish ponds require volumes of 30 to 40% of pond volume in order to provide a retention time of 8 hours. Thus, because of the large volume required, settling basins do not appear to be feasible for treating storm runoff. Settling basins for treating intentional discharge from partial drawdown or complete draining would need to be only 10 to 20% of the volume of the largest pond on the farm because the quality of catfish pond effluents is relatively high except for the final 20 to 25% of water released when ponds are drained completely.

Most existing catfish farms in Alabama extend to property lines or streams, and there seldom is space for installing settling basins. However, settling basins could be considered an essential component in the design of new farms. On farms without settling basins, it is possible to use the pond being harvested as its own settling basin. Water levels should be lowered to 20 to 25% of full volume, drains should be closed and fish harvested by seining. Once fish have been removed, the water should be allowed to stand until most of the suspended solids have settled, usually within 2 to 3 days. The water should then be released slowly to prevent resuspension of solids. It is recommended that the valve only be opened to 25% of its maximum capacity during final draining. The valve should be closed at the beginning of rainfall and not reopened until water has cleared.

> ## *Results at a glance...*
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> ✩ *Treatment of the final 20% of water discharged when ponds are drained can be accomplished with sedimentation basins designed with a hydraulic retention time of 8 hours. However, a settling time of 2 to 4 hours is sufficient to reduce total suspended solids in effluents to 75 to 90% of original concentrations.*

Alabama channel catfish farmers try to maintain chloride concentrations of 50 to 100 mg/L in ponds by annual salt applications. The average and standard deviation for chloride concentration in salt-treated ponds was 87.2 ± 37.5 mg/L. The maximum chloride concentration was 189 mg/L. The maximum limit for chloride concentration in Alabama streams allowed by the Alabama Department of Environmental Management is 230 mg/L. It is unlikely that effluents from salt-treated catfish ponds would violate the in-stream chloride standard of 230 mg/L or harm aquatic life in streams. Nevertheless, chloride concentrations in ponds should be measured before salt application as a safeguard against excessive salt application and chloride concentrations above the in-stream chloride standard.

Mississippi State University. In commercial channel catfish ponds dominated by a dense bloom of the blue-green alga *Oscillatoria agardhii*, about 51% of total suspended solids have a diameter of less than 5 micrometers. Similar results are obtained from fractionation of solids in water collected from ponds dominated by inorganic turbidity (55% of the total suspended solids are less than 5 micrometers). Treatment of water collected from a pond dominated by a dense bloom of *O. agardhii* with alum between 0 and 50 ppm results in a solids reduction rate of 1.11 grams of solids per gram of alum. Size fractionation of pond water following alum treatment indicates that the proportional removal of solids less than 5 micrometers was greatest, although the greatest absolute solids reduction rate occurs in whole (not fractionated) pond water. The proportion of solids in the smallest size fractions increases with alum dose, suggesting that larger solids are selectively settled by alum treatment.

North Carolina State University. Fractionation of solids in overflow water from hybrid striped bass ponds shows that approximately 95% of total solids and 65% of total suspended solids are less than 5 micrometers in diameter. More than 80% of biochemical oxygen demand, total phosphorus and total nitrogen in pond water is associated with particles less than 5 micrometers. More than 90% of the solids in the pond water overflow are dissolved and about 25% of total solids are volatile. Suspended solids, which account for 10% of total solids, are approximately 63% volatile, with solids in the smaller particle fractions more volatile than in the larger fractions. The amount of settleable solids in hybrid striped bass pond water overflow is negligible, suggesting that sedimentation alone, without the use of chemical amendments to coagulate and precipitate solids, would not be an effective treatment of this fraction of pond water.

Effluents from the initial and final stages of pond draining collected and characterized during pond harvest indicate that total suspended solids concentrations are 40% higher in the final 10% of water drained from the ponds compared to the first 10%. This increase in total suspended solids is primarily from small particles of the mineral fraction of the pond sediment. Where almost all of the suspended solids in the first 10% of water drained are volatile, only 60% of the suspended solids in the final water are volatile. Because total suspended solids account for only approximately 10% of total solids in these waters, the concentration of total solids is only slightly higher (less than 8%) in effluent from the final stages of pond draining than in the initial stages. Concentrations of total phosphorus and total nitrogen in the effluent do not increase significantly from the beginning of pond draining to the end.

University of Arkansas at Pine Bluff. A field study characterized suspended solids and 5-day biochemical oxygen demand (BOD_5) in baitfish pond effluents by serial fractionation, and evaluated exiting drainage ditches as possible solids settling systems. Total suspended solids (TSS) concentration in effluents at the point of discharge from ten ponds on five farms averaged 36 ppm during the draining of the first 10% of pond volume and increase by approximately 70% during the last 10% of the effluent volume. Volatile suspended solids (VSS) concentration is more variable but average about 50% of TSS. Organic matter (BOD_5) concentration averages 9.0 ppm and does not increase significantly in the last 10% of effluent volume. Screening through a 10-micrometer mesh removes more mineral than organic solids, and reductions in TSS, although small, are statistically significant. Volatile suspended solids and BOD_5 generally do not change with reductions in TSS, except small but significant reductions in the first 10% of effluent after screening through a 41-micrometer mesh. Based on averages, 75 to 82% of suspended particles are less than 5-micrometers and smaller particles are more organic. The last 10% of effluent is characterized by smaller particles than the first 10% of effluent volume. Volatile suspended solids concentration in the last 10% of effluent had a stronger correlation ($r = 0.91$) with BOD_5 than the first 10% ($r = 0.71$). Total suspended solids concentration is weakly correlated with BOD_5 ($r = 0.55$ in the first 10% and 0.71 in the last 10%).

Louisiana State University. Water budgets calculated over three production seasons in experimental crawfish ponds indicate that the average annual water requirement is 7.5 feet. More than 71% of intentional water inflow over the three production seasons replaces losses from evaporation, evapotranspiration by rice planted as crawfish forage, and seepage, with intentional and unintentional effluent release accounting for the remainder. Precipitation is a significant water inflow in these shallow-water ecosystems, contributing nearly 40% of the total over three production seasons. Intentional water discharge during summer drawdown (an established management practice) is consistent, averaging 10.8 inches. Unintentional discharge is highly correlated with the magnitude of precipitation events. Precipitation from October to June in year one (25.1 inches) and year three (27.2 inches) resulted in very low unscheduled water release (3.6 and 2.5 inches, respectively). Unintentional water release in the second production season, representative of normal precipitation patterns in southern Louisiana (53.6 inches) was 17.7 inches (24% of annual water budget).

A water budget model was developed to determine seasonal effluent quantity and mass loading for solids and nutrients representative of crawfish production systems in south-central and southwest Louisiana. Precipitation, evaporation, evapotranspiration, and infiltration data for southern Louisiana was obtained from the National Climatic Data Center and published research. Model output closely agreed with annual water budgets calculated from the experimental crawfish ponds over three crawfish production seasons, with an average deviation of 11% (range: 3 to 25%). Unintentional and intentional effluent discharge and seasonal mass loading for TSS, TP, TN, and $CBOD_5$ were determined under various simulation scenarios which include type of crawfish production system (permanent, rice-crawfish double-cropping, and rice-crawfish rotational system), annual precipitation (average, wet, and dry years), added pond storage capacity (0, 2, 4, and 6 inches), and intentional flushing to improve water quality (1, 2, 3 exchanges per year). Most water additions from pumping replace losses from evaporation, evapotranspiration, and seepage (usually 60% or higher). Unintentional discharge, largely from precipitation, usually ranged from 13% in an average year to as much as 30% in a high rainfall year, with most of the discharge occurring in winter. Seasonal mass loading (pounds/acre) for single-crop crawfish production systems were as follows: TSS, 848; TP, 1.99; TN, 10.6; and $CBOD_5$, 18.5. Eighty-nine percent of TSS and 70% of TP, TN, and $CBOD_5$ released from experimental crawfish ponds during summer drawdown occur with the first 5% and last 20% of water released.

Waddell Mariculture Center. Settling of the last 20 to 30% of shrimp pond drainage often, but not always, reduces total nitrogen and total phosphorus. Reductions are sometimes as great as 80% of initial levels, and are typically only significant during the first hour of sedimentation. Proportional reductions in total nitrogen and total phosphorus are not as great as proportional reductions in suspended solids, turbidity, and BOD_5. Reductions in turbidity and suspended solids are similar. Reductions in suspended solids during the first hour of settling are greater than reductions that occur during the subsequent 19 hours. In high-density ponds (i.e., stocked with 100 postlarvae/m^2), settling during the first 30 minutes reduces turbidity by 45 to 92%. In lower-density ponds (i.e., stocked with 10 to 50 postlarvae/m^2), settling during the first 30 minutes reduces turbidity by 5 to 49%. Planktonic algae is the primary component of turbidity in effluent and is only modestly affected by sedimentation. Although there is a tendency for high-density ponds to have greater initial levels of suspended solids, turbidity, and BOD_5, and greater reductions (both in magnitude and proportion) in these parameters during relatively short sedimentation periods than lower-density ponds, there is substantial overlap between these groups. The findings preclude firm statements regarding the benefit of sedimentation based solely upon shrimp stocking density.

Initial levels and the effect of sedimentation on suspended solids, turbidity, and BOD_5 vary greatly among ponds, regardless of pond location or stocking density. Factors that contribute to this high variability include those that affect sediment resuspension during harvest, in particular, sludge pile size and location with respect to drainage flow, slope of the pond bottom, operation of aerators during harvest, and shrimp activity. Sedimentation prior to water release may be particularly beneficial when pond harvest strategies that encourage the flushing of sludge are employed.

Objective 2. *Evaluate the impact of aquaculture pond effluent discharge on receiving stream water quality.*

Mississippi State University. Seventeen stream sample locations were selected and geo-referenced within four sub-watersheds with variable development of the landscape to aquaculture ponds. Stream sampling occurred during base flow conditions and during the only significant runoff event that occurred during spring 2000. Despite elevated stream flow during this event, few ponds were observed to be discharging water. No changes in stream water quality could be attributed to aquaculture ponds. In some stream reaches, the magnitude of in-stream variation in water quality over short distances was large.

A study was conducted to evaluate the duration and settling characteristics of initial pond effluent from levee ponds. Settling characteristics of effluent samples collected at the discharge point were determined. In addition, spatial and temporal variation of water quality in channels receiving the effluent was measured. When draining was initiated, shear forces generated by water moving into the drain pipe caused scouring in a zone around the entrance to the drain pipe. The initial flush of discharged water consisted of pond water and a slurry of sediment that had accumulated over the screen inside the pond. The initial discharge was very high in total suspended solids (43,860 mg/L), volatile suspended solids (3,770 mg/L), BOD_5 (118 mg/L), and nutrients. Within 2.5 minutes of the initial discharge, total suspended solids decreased to 1,790 mg/L, volatile suspended solids to 205 mg/L, and BOD_5 to 29 mg/L. By 30 minutes, the poorly consolidated sediment from around the drain structure inside the pond had been discharged, and the effluent quality was identical to the bulk pond water for the remainder of the draining period (approximately 5 days). For the effluent, 15.2% of the total solids were discharged with the first 1.7% of the total volume discharged. The initial solids concentration was 900 times higher than the solids concentration in the bulk pond water. In contrast, the BOD_5 of the initial flush of water discharged was only about nine times higher than the BOD_5 of the bulk pond water and concentrations decreased more rapidly than total suspended solids. Therefore, cumulative discharge of BOD_5 as a function of water volume discharged did not have an initial spike of similar magnitude as for total suspended solids; rather, cumulative discharge of BOD_5 was roughly proportional to the volume of water discharged. These results suggest that the ratio of mineral solids to organic matter of the initial flush of water was relatively higher than that of subsequently discharged water.

The median settling velocity decreased from 0.3 cm/second in the initial effluent to 0.06 cm/second after 30 minutes. Total suspended solids in a ditch 100 meters from a catfish pond outfall increased to a maximum 30 minutes following the initiation of pond discharge, but then decreased to concentrations that were less than or equal to initial ditch concentrations. The duration of poor water quality of initial effluent from catfish ponds with internal drains is brief (less than 30 minutes) and discharged solids settle rapidly within receiving ditches.

University of Arkansas at Pine Bluff. A field study evaluated exiting drainage ditches for solids settling. Surveyed ditches ranged from 1,050 to 2,300 feet in length and from 12 and 39 feet in width. Study ditches included vegetated and non-vegetated types. Volatile suspended solids (VSS) decreased by 14.1% over the first 100 meters (110 yards) of ditch. Total suspended solids (TSS) remained unchanged because of increases in fixed suspended solids (FSS). Current velocity in the ditch explained up to 65% of the variability in change in solids. There was a net increase in TSS when average velocity exceeded 2 feet/second. Fractionation may have affected the character of organic particles by breaking large particles into fine particles.

Additional work was conducted to characterize nutrient concentrations in baitfish pond effluents and receiving streams. Ten baitfish ponds were sampled and characterized from December 2000 through June 2001 in the central Arkansas Delta ecoregion. Effluent samples taken during the first and last 10% of pond drainage volume were analyzed for total nitrogen, total phosphorus, BOD, and TSS concentrations. Pond drainage ditches were sampled along the ditch length to determine overall reduction of TSS, and ditch water quality was sampled and analyzed prior to stream discharge. Upstream samples were collected concurrently with pond and ditch samples and were analyzed for similar nutrient concentration and physical characteristics. There were no significant differences in effluent quality between the first 10% and the last 10% of effluent volume, except the last 10% had significantly higher TSS concentrations than the first 10%. There was no significant difference in nutrient concentrations in effluents sampled at the standpipe and effluents sampled at the end of drainage ditches. Filtering effluents through a 5-micron mesh screen did not significantly reduce nutrient concentrations. There was also no significant difference in standpipe effluent concentrations versus those found upstream of the discharge point. In general, concentrations of measured parameters in commercial baitfish pond effluents were lower than or similar to those reported for commercial catfish ponds during the same seasons.

Louisiana State University. Drainage ditches were evaluated for sedimentation of solids, nutrients, and organic matter discharged during final summer drawdown (maximum mass loading) from experimental crawfish ponds. In an initial study, the TSS were reduced over a distance of 800 feet from 28% in a wide, shallow, non-vegetated ditch to 80% in a narrow, deep heavily vegetated ditch, prior to entering a receiving stream. In contrast, TSS increased 15% over a distance of 800 feet when effluent was discharged into a shallow, narrow, non-vegetated ditch. In a subsequent study, the TSS were reduced 79% over a distance of 800 feet, and 93% at 2,400 feet prior to entering the receiving stream when effluent was discharged through a heavily vegetated drainage canal (filter strip). Concomitant reductions in TP, TN, and $CBOD_5$ ranged from 26% to 77%.

Waddell Mariculture Center. Water quality in pond drainage after passage through a discharge canal indicates that total suspended solids, turbidity, and BOD_5 at the farm discharge are at levels similar to pond effluent after 20 hours of sedimentation. This suggests that significant water quality improvements occur during passage through the drainage canal from the pond to the facility outfall.

Objective 3. *Evaluate a range of water management techniques appropriate for ponds as means of reducing the quantity and improving the quality of discharged water.*

Mississippi State University. A study was conducted over 3 years to evaluate the accuracy of a mathematical model used to predict performance of a management strategy to reduce pond effluent volume and groundwater use requirements. The strategy consisted of increasing the water storage capacity (depth) of one pond by 1 foot in an interconnected 2-pond or 4-pond module. Tested pond system configurations included three conventional production ponds linked to one production-storage pond; one conventional production pond linked to one production-storage pond; and one conventional (control) pond. During the study, effluent release, groundwater use, precipitation, evaporation, and infiltration were monitored to validate the model. Additionally, ponds were stocked at commercial rates and water quality (dissolved oxygen, temperature, total ammonia, nitrate, chlorophyll *a*, conductivity, alkalinity, and hardness) and occurrences of disease (proliferative gill disease, enteric septicemia of catfish) were monitored to determine whether the management strategy had unintended consequences.

> ## *Results at a glance...*
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> ✰ *Effluent volume can be reduced by increasing pond depth to increase rainwater storage capacity and linking the combined production-storage pond to one or three adjacent conventional ponds. Effluent volume was reduced by more than 50% and groundwater consumption was reduced by more than 40% compared to conventionally managed ponds. Linking ponds and reusing stored water has not affected fish growth, occurrence of diseases, or water quality.*

The study period encompassed years that were both drier and wetter than normal. There was good agreement between the model and actual pond performance, indicating that the model has utility for a broad range of precipitation/evaporation regimes. Significant reductions in effluent release and groundwater use can be achieved using this approach. Harvest size, water quality, and occurrence of disease indicate no negative consequences of linking ponds.

During 2000, groundwater use in the 1:1 system was about 26% less than in the control pond. In the 3:1 system, groundwater use was about 29% less than in the control pond. This represented a water savings of approximately 24 cm and 27 cm, respectively. During 2001, groundwater use in the 1:1 system was about 58% less than in the control pond. In the 3:1 system, groundwater use was about 45% less than in the control pond. This represented a water savings of approximately 34 cm and 27 cm, respectively.

The groundwater use data appear consistent with site precipitation. Although both 2000 and 2001 had total precipitation values somewhat greater than the 30-year site average, the critical period (May-October) showed marked differences in the 2 years. The 30-year average precipitation for May through October in Stoneville, MS is approximately 55 cm. Values for 2000 and 2001 were 42.8 and 70.6 cm, respectively. The differences were more marked in the critical months of July-August, during which only 1.5 cm of precipitation fell in 2000. This value is only 10% of the 30-year July-August mean for Stoneville (15 cm). During 2001, July-August precipitation was nearly 30 cm, which is about twice the 30-year mean. Although 2000 and 2001 were both somewhat wetter years than normal over 12 months, the warm months of 2001 were much wetter than those of 2000. This difference appeared to largely account for the ground water use differences observed in these years.

During 2000, groundwater use was roughly equivalent in the six treatment ponds. The decreased groundwater requirement of the treatment ponds was probably due to the storage capacity of the production-storage ponds. Once stored water was exhausted (as it was during the dry summer of 2000), groundwater requirements of the six ponds were similar.

During the wetter summer of 2001, the production-storage ponds required no groundwater. In the four treatment production ponds, use of stored rain water accounted for a substantial decrease in groundwater requirements relative to the control pond. In the production-storage ponds, residual stored water, perhaps coupled with other as yet unexplained effects, eliminated groundwater requirements entirely for the year.

The largest task remaining in this project is analysis of the continuous measurements of pond depth and discharge. This task is continuing.

North Carolina State University

Water budgets. A water budget describing water use on a commercial hybrid striped bass farm in North Carolina had been calculated from data collected over a two-year period. The farm has 78 water acres and consists of 18 ponds of approximately 4.5 acres each. All water on the farm is groundwater and no surface water is used. Water is used to fill ponds after draining, to add water to make up for evaporation and seepage, and to flush ponds as needed for water quality reasons. Ponds are usually drained and dried after all fish are harvested, although sometimes scheduling demands require that ponds are immediately restocked after harvest, in which case ponds are not drained between crops. Discharge volume was calculated with a basic water budget equation.

Much of the discharge from the farm occurs during the summer and fall. Twenty-four major discharge events (not due to rainfall) were measured during 2001. There were no large discharges of water during winter (December-March) and most water was discharged between April and August.

On average, the farm discharges 48 inches of water annually.

Fixed-film Filter Media. Two synthetic filter materials were evaluated for their ability to remove suspended solids and nutrients from hybrid striped bass pond effluents. BioStrata is made of black corrugated PVC sheets layered and glued into a honeycomb block form and has a surface area to volume ratio of 110 ft^2/ft^3. A total of 7 ft^3 was used in a tank. Koi brushes are cylindrical brushes 24 inches in length by 4 inches wide. Twelve rows of six brushes each were suspended vertically in the center compartment of a tank. A tank with no baffles and no filter media served as a control. Tanks were rectangular fiberglass (96 inches by 24 inches by 24 inches) and fitted with baffles to contain the filter material and prevent laminar flow. Water was pumped into the tanks at one end, flowed over/through the filter media, and drained from the other end. Standpipes at the drain end of each tank maintained water depth at 24 inches. Three tanks were used in each trial: one containing BioStrata media, one with Pond (or Koi) brushes, and one control tank.

Water was pumped from a 0.25-acre hybrid striped bass grow-out pond stocked at 6,000 fish/acre. Total suspended solids concentration in the pond water during these trials ranged from 63 to 170 mg/L. Most of this turbidity was from suspended clay particles; the pond had very little phytoplankton and chlorophyll *a* concentrations were very low. Water quality was measured at the inflow and outflow of each tank approximately every 3 days during each trial, which lasted between 15 and 22 days. Four hydraulic loading rates ranging from 1.4 to 16.6 gallons per minute were tested during the study, resulting in hydraulic retention times in the filter units between 2.5 hours and 12 minutes, respectively.

Neither filter media was consistently effective in removing solids and nutrients from pond water. The honeycomb BioStrata media reduced concentrations of chlorophyll *a* by 20-40% but usually resulted in increased concentrations of nitrogen, phosphorus, and suspended solids. The brush media removed between 10-30% of nitrogen and less than 5% of solids, but was ineffective in removing phosphorus and chlorophyll *a* from pond water. Because of the very low abundance of phytoplankton in the pond water being filtered, changes in chlorophyll *a* concentrations as result of filtration through media were very small, although they appear large expressed as a proportion of influent concentration. Nutrient and solid removal among sampling dates and within and among trials varied widely. Many times there were no consistent differences in water quality between inflowing and outflowing water. Thus, mean removal rates should be interpreted cautiously.

Solids that accumulated in the tanks during filter-media trials were collected, dried and weighed. The solids were primarily inorganic and were approximately 15% volatile solids. In two trials, brush media removed 3-4 times the weight of solids removed in the control tank, and the honeycomb BioStrata media removed the most solids, 9 to 15 times the amount removed by the control tank. In another trial, the effectiveness of the two media was reversed and the honeycomb BioStrata media removed 4 times the solids as the control, and the brush media removed 15 times the amount removed by the control. The most efficient removal of solids required the filtration of 115 L of pond water to remove 1 g of dried solids (this was using the honeycomb BioStrata media at flow rates of 1.4 gallons per minute); the least efficient required 20 times that volume (brush media at 8.4 gallons per minute).

Water quality. Fish production and water quality in annually drained hybrid striped bass ponds was compared to that in ponds managed with no discharge. Twelve, 0.25-acre ponds were managed according to common commercial practices for hybrid striped bass production. After 3 years, fish production was not significantly different between the two treatments. Although total suspended solids concentration was greater in undrained ponds, there were no other differences in water quality between the two water management regimes.

Turbidity and total suspended solids concentration in pond water were greater and feed consumption and mean weight of fish were lower in ponds that were not dried between crops compared to ponds that were dried and received soil or water amendments. The relative effectiveness of different amendments suggest that applications of anionic polyacrylamide are more effective in reducing turbidity and improving water quality than alum or gypsum when applied to pond water in soil-water mesocosms.

University of Arkansas at Pine Bluff. As a water conservation technique in response to declining aquifer levels, re-use of pond water is growing popular in the Arkansas baitfish industry. Predation of fry by cyclopoid copepods present in re-used water is the greatest challenge to widespread adoption of this practice. A study was conducted to evaluate treatments affecting zooplankton populations so that water can be re-used and the volume of effluent reduced. The aim of this study was to evaluate methods of restarting the zooplankton bloom in pond water held from previous production operations. The abundance and evolution of rotifer and copepod populations in ponds containing old water, old water treated with 0.25 ppm Dylox, and mechanically filtered old water were compared to ponds filled with ground water. Zooplankton were sampled and water quality was monitored daily for 6 weeks. Rotifer abundance increased in ponds in all treatments during the first 8 days. Average rotifer density over 8 days did not differ between treatments. However, average copepod abundance was affected by treatments. New water had significantly fewer copepods than Dylox-treated or old water, but did not have fewer copepods than mechanically filtered water. Mechanical filtration compared more favorably to ponds filled with ground water than to ponds treated with Dylox or not treated. Filtration minimized adult copepods, while maintaining sufficient rotifer density for baitfish culture. Mechanically filtered old water has good potential of providing sufficient food (rotifers and nauplii) for newly stocked fry while minimizing the risk of copepod predation on fry.

Cyclopoid copepod predation has been established as an important factor causing low and variable survival rates during sunshine bass fingerling production. A concentration of 500 copepods/L can result in no survival of 5-day-old fry stocked at 20/L for 24 hours. Concentrations of 50 copepods/L and below resulted in survival rates not significantly different from controls with no copepods. Farmers will encounter cyclopoid copepod concentrations between 50 and 500 copepods/L in pond water fertilized to enhance rotifer blooms or in water held from previous operations. This study investigated the effect of cyclopoid copepod concentration on survival rates of sunshine bass, golden shiner, fathead minnow, and goldfish fry. Survival of golden shiner, fathead minnow, and goldfish was 95-100% at all copepod concentrations (0, 100, 200, 300, 400, and 500/L). Survival rates of sunshine bass (75.0-93.1%) were not significantly different among copepod concentrations ranging from 0 to 300/L. Sunshine bass fry survival at 400 copepods/L (62.5%) was significantly higher than at 500 copepods/L (39.4%), and significantly lower than at 0 and 100 copepods/L. On the basis of these results, stocking sunshine bass fry into ponds with fewer than 300 cyclopoid copepods/L probably represents a low risk of predation. Concentrations of cyclopoids between 300 and 500/L represent a higher risk of predation. Concentrations of cyclopoids exceeding 500/L will probably result in extremely low survival and poor yields. Five-day-old golden shiner, fathead minnow, and goldfish stocked in old pond water with 500 cyclopoid copepods/L or less could have acceptable survival rates.

Louisiana State University. Several water management techniques were evaluated alone and in combination in empirical field trials to reduce mass loading of solids and nutrients in crawfish ponds during the production season and final summer drawdown. The BMPs included cessation of crawfish harvesting activities 2 weeks prior to draining, rapid draining versus slow draining, draining from the surface as opposed to the bottom; retaining the last 20% of pond water followed by slow draining, and allowing the last 20% of pond volume to evaporate. The most effective means for reducing quantity and improving the quality of discharged water was the addition of 6 inches of water storage capacity and eliminating the last 20% of the pond volume when possible.

Objective 4. *Develop and evaluate models for predicting risks to the environment and the costs and benefits of implementing Best Management Practices (BMPs).*

University of Arkansas at Pine Bluff. Partial enterprise budgets are being developed for the various effluent management strategies evaluated in this project. Budget analyses were completed for sedimentation basin management options for commercial catfish ponds. In all, 108 different scenarios were analyzed for sedimentation basins on catfish farms. Budgeting work on the integrated production-storage pond strategies for catfish culture was also completed. Seventy-two different scenarios were analyzed for production-storage ponds. Preliminary cost data have been collected on the fixed-film filter options under study in this project.

Sedimentation Basins. Costs associated with settling basins are dependent on the size and number of basins, and whether sufficient land is available for basin construction or if existing production ponds must be retrofitted and taken out of production. Sizing of settling basins is controlled by factors such as the type of effluent to be treated (draining or storm overflow), layout of ponds, size of the largest foodfish pond, the number of drainage canals, and the scope of regulations governing the release of aquacultural effluents. The number of settling basins is affected by the hydraulic residence time (HRT) which is calculated from Stoke's Law. The HRT, in turn, is affected by the size distribution of suspended particles.

The number of settling basins is also affected by the number of drainage outlets on a farm. Some farms may drain in four to five different directions. Furthermore, farms that have ponds that are not contiguous would need a greater number of basins. Three farm size scenarios were considered in an analysis of settling basin costs: a 160-acre farm with approximately 140 acres of water, a 320-acre farm with 280 acres of water and a 640-acre farm with 560 acres of water. Average sizes of foodfish ponds in this analysis were assumed to be 10 and 15 acres, while fingerling ponds were 5 acres each.

Larger farm sizes result in higher and more variable costs. Investment costs included excavation of settling basins and the installation of stationary re-lift pumps to drain effluents from excavated basins. Annual operating costs consisted of copper sulfate applications (to promote sedimentation of phytoplankton cells), the annual cost of pumping, and levee mowing and maintenance, whereas annual fixed costs refer to depreciation of basins and pumps, interest on investment, and the opportunity costs associated with land taken out of production for the settling basin. Estimates of lost revenue due to production foregone from retrofitted production ponds were $300, $346, and $480/acre for the 160-, 320-, and 640-acre farms, respectively. Larger farm sizes will result in higher and more variable costs. Investment costs included excavation of settling basins and the installation of stationary re-lift pumps to drain effluents from excavated basins.

Large investments are needed for the construction of settling basins. This investment cost depends heavily on the drainage layout of the farm and the scope of regulations governing the release of effluents. Regulations that require settling basins on catfish farms would increase total investment cost on catfish farms by $126 to $2,990/ha and total annual costs by $19 to $367/ha.

Utilization of existing foodfish ponds for settling basins represents a more economical approach for the treatment of harvest/draining effluents than construction of settling basins. This is particularly true for those scenarios where all effluent volume must be treated. This difference was a consequence of the extremely high cost associated with excavating a sedimentation basin sufficiently deep to collect all farm effluents by gravity flow. Finally, compliance costs for the treatment of overflow effluents were moderate to high and strongly influenced by farm size.

For farms on which existing fish ponds would have to be converted to settling basins, over half of the cost was due to the production foregone and annual fixed costs of the pond. Requiring catfish farmers to construct settling basins would impose a disproportionately greater financial burden on smaller farms. The magnitude of the increased costs associated with settling basins was too high relative to market prices of catfish for this technology to be economically feasible.

Production-Storage Ponds. Two configurations (1:1 and 1:3), based on the number of production ponds served by each production-storage pond, were assumed. Increased depth of the combined production-storage pond increases the storage capacity of the system but incurs higher earthmoving costs. Three additional depths were considered: 12, 24, and 36 cm and seepage values of 0.0 and 1.0 mm/d were assumed. Cost estimates were developed for farms with average foodfish pond sizes of 10 and 15 acres. Fingerling ponds were not linked.

In total, 24 scenarios were defined for each of three farm sizes (total = 72 scenarios). Depth of storage pond and pond configuration were the two most important factors affecting implementation costs of this technology. For instance, estimated total investment costs for a 160-acre farm with 10-acre foodfish ponds, 1:1 configuration, and 0 mm/d infiltration rate, ranged from $76,123 to $215,088 as the additional depth of storage ponds was increased from 12 to 36 cm. However, if the configuration is 3:1, investment costs decreased (ranging from $44,782 to $115,947).

Fixed-film Filtering Systems. Investment and operating costs were estimated for the fixed-film honeycomb and brush filtering systems. Based on the assumptions used and on the experimental data available, costs of this filtering system ranged from $0.03 to $0.07/kg of fish produced with this treatment option.

Farm-Level Economic Effects of Imposing Effluent Treatments on Hybrid Striped Bass Farms. A Mixed-Integer Programming (MIP) model was developed to evaluate the farm-level effect of imposing effluent treatment options on hybrid striped bass farms. Settling basins and constructed wetlands entail high cost for farmers with high reduction in effluents. Filtering treatments incur high cost without much reduction in nutrient concentration in effluents. Not flushing water from the pond or not draining the pond annually reduces effluent volume. Reduction in the amount of water flushed or drained from the pond also decreases operating costs without any additional investment cost associated with adoption of the treatments. It is estimated that various effluent treatment options would increase production costs on average by $0.001 to 6.79/kg. Based on the MIP model, no annual draining and not flushing pond water are the best operational treatments. When discharge standards are imposed, the model selected the no-draining treatment. By not draining ponds, farms would minimize treatment cost by reducing effluent volume. Additional work is needed on the long-term risks associated with not flushing or not draining hybrid striped bass production ponds.

Objective 5. *Based upon existing information, supplemented by project findings, develop a comprehensive set of BMPs that can be implemented to reduce the environmental impacts of pond aquaculture in general. Develop supplemental BMPs particular to the various pond cultured species in the region that will complement the generic, pond-system BMPs. These BMPs would include best culture practices, waste handling and management, and water quality management and reuse.*

Auburn University. Funding from this SRAC effort was used to supplement additional funds from the Alabama Catfish Producers in developing BMPs for Alabama catfish farming. An environmental audit form for assessing the status of environmental management on catfish farms was developed. This instrument was used to identify potential problems that can possibly be solved with BMPs. The audit form was used by project participants to conduct environmental audits of aquaculture production facilities. A document containing best management practices to reduce the volume and improve the quality of channel catfish farm effluents was prepared through the cooperation of Auburn University, Alabama Catfish Producers Association, Natural Resources Conservation Service (NRCS), and the Alabama Department of Environmental Management. These BMPs were reviewed by all agencies involved and were presented to the farmers for comment. Farmer meetings were held to assure that farmers were aware of the BMPs and had opportunity for input. The BMPs are maintained by NRCS at <http://www.al.nrcs.usda.gov/about/so_sect/eng/ aq_bmp.html> in the form of Guide Sheets, and they also have been published by Auburn University. Guide sheets were developed for the following topics:

- Reducing Storm Runoff into Ponds
- Managing Ponds to Reduce Effluent Volume
- Erosion Control on Watersheds and Embankments
- Pond Management to Minimize Erosion
- Control of Erosion by Effluents
- Settling Basins and Wetlands
- Feed Management
- Fertilization of Catfish Ponds
- Water Quality Protection to Improve Effluents
- Water Quality Enhancers
- Therapeutic Agents
- Fish Carcasses
- General Operations and Worker Safety
- Emergency Response and Management

These BMPs will be referred to in the Alabama Department of Environmental Management regulations that will be made for aquaculture effluents.

Louisiana State University. Current NRCS Conservation Practices were reviewed to assess their applicability to development of a set of BMP effluent and watershed management guidelines for the crawfish aquaculture industry. Specific attributes evaluated for each conservation practice included applicability, need for clarification or modification, economic feasibility, environmental effectiveness, need for additional research, and need for educational programs for users. A set of BMPs for aquaculture production in Louisiana was drafted and reviewed by various commodity, state, and federal agencies. The revised document "Louisiana Aquaculture Best Management Practices" was completed and published in spring 2003, and includes individual reviews of BMPs for crawfish pond production, catfish pond production and recirculating system production (for alligators, finfish, or shedding crustaceans). Crawfish pond production BMPs focus on reducing pumping costs, improving flushing efficiency, and minimizing sediment loading during draining.

Objective 6. *Convene a series of workshops to educate and inform producers and regulators on the characteristics and management of aquaculture effluents from ponds, including BMPs, based on the best available information and that minimize environmental impact and satisfy regulatory compliance requirements.*

A workshop was convened on 6-7 November 2000 in Roanoke, VA. The objectives of the workshop were to (1) develop a prioritized list of practices that will minimize environmental impacts of aquaculture and be economically acceptable to producers; and (2) familiarize state regulators and consultants with the aquaculture effluents issue and provide the information necessary to develop effective and reasonable regulations.

In Arkansas, information on effluents and BMPs for pond aquaculture has been extended to producers. Two Extension newsletter articles were published. Results of the water re-use zooplankton study were presented to baitfish producers at the UAPB Aquaculture Field Day (attendance was approximately 300 people). A poster presentation on effluents and BMPs was exhibited at the Aquaculture Field Day and a presentation was made on the same topic at the annual convention of catfish and baitfish producers (150 people). Extension faculty assisted the Arkansas Bait and Ornamental Fish Growers Association in adapting proposed BMPs for catfish production to baitfish, and in developing the association's BMP document.

Most scientists in this SRAC project are active participants in activities coordinated by the Joint Subcommittee on Aquaculture's Aquaculture Effluent Task Force, including the various subgroups representing the species and areas of specialization of project scientists.

WORK PLANNED

The research supported by this project has been completed. A Final Project Report of findings will be prepared and published.

IMPACTS

The technical guidelines for several straightforward options for effluent treatment or volume reduction have been evaluated and are now available for consideration and implementation by producers of fish in ponds. Project personnel have been involved with the development and dissemination of information on best management practices to fish producers and to federal regulatory authorities considering regulation of aquaculture pond effluents. The comprehensive cost estimates and the best management practices developed in this study could potentially provide valuable information for both the Environmental Protection Agency (EPA) and the aquaculture industry as EPA proceeds with their rule-making effort to develop Effluent Limitation Guidelines.

Generalized results of the comprehensive cost estimates related to sedimentation basins have been discussed by members of the Economics Subgroup of the JSA Aquaculture Effluents Task Force with officials of the Environmental Protection Agency and the aquaculture industry. It is likely that the results of these studies will play a role in decisions made as EPA proceeds with their rule-making effort to develop Effluent Limitation Guidelines.

Best Management Practices developed as part of this project are being implemented in Alabama, Arkansas, and Louisiana. In Alabama, BMPs are the basis for regulation by the Alabama Department of Environmental Management (ADEM). The Arkansas Bait and Ornamental Fish Growers Association used SRAC information in developing a set of Best Management Practices for bait and ornamental fish farms. Association members have committed to following these recommended practices in order to minimize any possible environmental impacts from their farms. In Louisiana, BMPs appropriate for the state's diverse aquaculture industries have been collated in a manual for distribution to fish farmers.

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