Mississippi State University

Scholars Junction

Theses and Dissertations Theses and Dissertations

1-1-2008

Evaluation of automated, manual and constant aeration practices in managing of dissolved oxygen for channel catfish farming in earthen ponds

Shelby E. Fortune

Follow this and additional works at: https://scholarsjunction.msstate.edu/td

Recommended Citation

Fortune, Shelby E., "Evaluation of automated, manual and constant aeration practices in managing of dissolved oxygen for channel catfish farming in earthen ponds" (2008). *Theses and Dissertations*. 2000.
https://scholarsjunction.msstate.edu/td/2000

This Graduate Thesis - Open Access is brought to you for free and open access by the Theses and Dissertations at Scholars Junction. It has been accepted for inclusion in Theses and Dissertations by an authorized administrator of Scholars Junction. For more information, please contact scholcomm@msstate.libanswers.com.

EVALUATION OF AUTOMATED, MANUAL AND CONSTANT AERATION PRACTICES IN MANAGING OF DISSOLVED OXYGEN FOR CHANNEL CATFISH FARMING IN EARTHEN PONDS

By

Shelby E. Fortune

A Thesis
Submitted to the Faculty of
Mississippi State University
in Partial Fulfillment of the Requirements
for the Degree of Masters of Science
in Wildlife and Fisheries Science
in the Department of Wildlife and Fisheries

Mississippi State, Mississippi

May 2008

EVALUATION OF AUTOMATED, MANUAL AND CONSTANT AERATION PRACTICES IN MANAGING OF DISSOLVED OXYGEN FOR CHANNEL CATFISH FARMING IN EARTHEN PONDS

By

Shelby E. Fortune

Approved:

Todd Tietjen Assistant Professor of Wildlife and Fisheries (Director of Thesis)	Louis D'Abramo Professor of Wildlife and Fisheries (Committee Member)
Terrill Hanson Associate Professor of Agricultural Economics (Committee Member)	Bruce D. Leopold Professor and Head of Wildlife and Fisheries (Graduate Coordinator)
George M. Hopper College of Forest Resources Dean	

Name: Shelby E. Fortune

Date of Degree: August 9, 2008

Institution: Mississippi State University

Major Field: Wildlife and Fisheries Science

Major Professor: Dr. Todd Tietjen

Title of Study: EVALUATION OF AUTOMATED, MANUAL AND CONSTANT AERATION PRACTICES IN MANAGING DISSOLVED OXYGEN FOR CHANNEL CATFISH FARMING IN EARTHEN PONDS

Pages in Study:

Candidate for Degree of Master of Science

Maintaining dissolved oxygen concentrations under different operating schemes (constant, manual or automated aeration control) was evaluated in 20 earthen catfish ponds ranging from 0.04 to 0.07 hectares in size. Ponds were assigned to treatments based on achieving equal distribution of biomass among treatments. Catfish weighing approximately 0.11 kg each were stocked at a rate of 14,820 catfish/hectare and were fed, to satiation, a 36% crude protein floating feed for the first week and switched to a 32% crude protein floating feed for the remainder of the study. Percentage weight gain, FCR and survival were calculated but did not differ among treatments. A partial enterprise budget analysis was generated to determine comparative value of different aeration techniques relative to production costs. Mean partial net returns did not differ among treatments. Complete comparison was not possible due to failure of automated monitors to record DO and to operate aerators under designed protocols.

ACKNOWLEDGMENTS

I would like to thank Dr. Todd Tietjen for his guidance throughout my time in graduate school. Dr. Tietjen provided me with invaluable assistance in organizing and completing my master's research and provided me with a better understanding of water quality processes. I would also like to thank my committee members, Dr. Louis D'Abramo and Dr. Terry Hanson, for their commitment and enormous assistance throughout my graduate program. Without their expertise and knowledge in aquaculture production practices, nutrition and economics my master's thesis would not be what it is, nor would I have received such an in depth understanding of these concepts. Finally, I would like to thank my parents and the rest of my family for always supporting me in all of my endeavors. They deserve more thanks than I can ever give.

TABLE OF CONTENTS

Page

CHAPTER

LIST OF FIGURES

LIST OF TABLES

CHAPTER I

INTRODUCTION

Catfish farming has developed into one of the most important aquaculture industries in the United States (Southworth, et. al. 2006). Growth of the industry over the last 30 years has occurred because of consumer demand for a high quality product and effective marketing. This economic success has principally resulted from maintaining competitive production costs, year-round product availability and improved management of water quality. Hargreaves and Tucker (2003) found that oxygen requirements, temperature effects, water quality tolerance limits of fish, organic matter decomposition and nutrient removal are the primary biological and physical factors that need to be evaluated to ensure successful pond aquaculture operations. Maintenance of adequate concentrations of dissolved oxygen (DO) is critical in maintaining a functional aquaculture system and is a primary component of water quality (Colt 2006). Fish require oxygen, supplied by photosynthetic production and gas exchange with the atmosphere, to produce energy for body maintenance, movement, and biosynthetic processes (Buentello, et. al. 2000).

National vs. Global Aquaculture Supply

The rise of aquaculture production has impacted many global markets, by supplementing or replacing capture fishery products and/or by developing new market opportunities through improved availability (Young, et. al. 1999). About 86% of the total global aquaculture volume is produced in Asia. The U.S. contribution to the total global volume is 5% (Simco 2000). Channel catfish is the primary cultured freshwater fish in the United States accounting for over 60% of all food fish production (Simco 2000). As farming of aquatic organisms continues to increase significantly worldwide, domestic aquaculture producers are facing considerable competition from international producers (Borisova 2007). Aquaculture operations across the United States must continue to find more efficient techniques to improve production/growth rates and reduce production costs to remain competitive with foreign markets (Simco 2000).

Rapid development of technology, market rivalries and higher quality standards can influence the type of production strategies used by aquaculture enterprises (Borch 1999). New production techniques and technology have the potential to reduce costs and correspondingly increase net returns; however, catfish producers must determine if implementation of new technology will actually benefit their operations (Hanson 2007). By implementing technologies such as automated DO monitoring systems, production costs of aquaculture operations may decrease, thereby enhancing the ability of the United States production to compete with imports. The benefits of such technology may not be realized if such strategies do not result in a reduction in operational costs and/or an increase in revenue (Simco 2000).

Dissolved Oxygen Effects on Feed Consumption and Growth

Interactions among stocking rates, feeding and water quality can influence growth, yield and feed conversion ratios and are very important to catfish aquaculture. One of the most common water quality problems encountered in aquaculture systems is low concentrations of DO (Boyd and Tucker 1998). Reduced, non-lethal concentrations of DO result most often in reduced growth rates. Oxygen is essential for respiration whereby nutrients are oxidized to release the energy necessary for movement, reproduction, feeding, growth and other vital functions (Boyd 1990). Throughout the culture period, DO concentrations must be monitored and managed to maintain levels sufficient to achieve maximum growth of aquaculture species and to avoid extreme changes in the chemical environment (Buentello, et. al. 2000).

By maintaining necessary concentrations of DO and combining effective feeding strategies, the goal of optimal growth can be realized (Hargreaves and Steeby 1999). Chronically low DO concentrations are likely to reduce appetite, stunt growth and lead to stressful conditions, which can compromise immunocompetence. Substantial losses of fish will occur if the DO concentration is below a critical threshold for an extended period of time (Buentello, et. al. 2000).

Although high concentrations of DO promote increased feed consumption and growth, water temperature also plays an important regulating role. Hargreaves and

Steeby (1999) found that interactions between DO and temperature directly affect physiological patterns of catfish by altering their metabolic rates. Greater temperatures increase metabolic rates and high concentrations of DO are needed to support correspondingly greater respiration demands.

Improvements in catfish farming and other aquaculture enterprises require large-scale implementation of specialized production techniques that focus on increasing production efficiency. Changes designed to overcome growth-limiting factors are constrained by current industry-standard practices including pond size, stocking and feeding rates, water quality management, and stock management schemes. Efficiency-based models that maximize profits from aquaculture production should be designed to optimize resource use, rather than maximize production or yields. Significantly greater net returns can be realized through this eco-friendly approach (Hargreaves and Tucker 2003).

Monitoring Dissolved Oxygen

The common practice is to maintain DO concentrations in aquaculture ponds at 4-5 mg/L to support optimal catfish growth (Tucker 1991). Methods for measuring DO must be accurate and precise because the measured amounts are relatively small (mg L^{-1}), and small changes can be biologically important. One of the earliest methods proposed for measuring DO was the Bunsen method which boils gases out under atmospheric pressure (Wetzel and Likens 1991). Although this method is very accurate, it is too bulky for field work and requires a high level of expertise to obtain accurate measurements. The Winkler method for measuring DO, or a modification of this method, is one of the more commonly used chemical methods. This method requires training and use of strong chemicals, and is not widely used on privately owned aquaculture farms (Washington State Department of Ecology 2005). The most common method used to measure DO concentrations in aquaculture ponds involves some variant of electrode-based DO probes, mainly because these probes are convenient to use in the field (Wetzel and Likens 1991). Use of oxygen probes to monitor DO is very efficient and allows for continuous/frequent measurements (Wetzel and Likens 1991). These probes must be calibrated often, at least before and after each data collection period (Washington State Department of Ecology 2005).

Concentrations of DO in freshwater are influenced by temperature, atmospheric pressure, and concentrations of ions (Wetzel and Likens 1991). Measuring and monitoring DO concentrations, combined with measurement of other water quality variables in an aquaculture setting can become a laborious task due to the high number of ponds or sampling locations, weather conditions and the potential depletion of oxygen during the evening and early morning. DO concentrations are less at greater water temperatures during summer due to decreased temperature-dependent solubility combined with an increase in metabolism and respiratory demand. Accordingly, sampling frequency generally increases during this critical time of year. An additional confounding factor is overcast days which result in less sunlight reaching the water's surface causing a decrease in the rates of photosynthesis rates by microscopic algae and macrophytic plants in the pond. As rates of oxygen consumption for respiration are not similarly depressed during overcast days and occur throughout the day, dangerously low concentrations of DO can result throughout the day and night. Most aquaculture farms check DO levels throughout the night during the summer to prevent low oxygen concentrations and avoid economic losses that can result from oxygen deficit (Boyd 1990; University of Florida 1992).

Oxygen Introducing Processes

DO concentration is one of the physical variables most commonly used to evaluate condition of aquatic environments because sufficient DO is essential to the health and survival of most aquatic organisms (Wetzel and Likens 1991; Hargreaves and Steeby 1999). Fish production in pond culture systems is often limited by inadequate concentrations of DO (Drapcho and Brune 2000) and the supply of DO, either biologically or mechanically, is an essential management practice for successful pond aquaculture. Oxygen supply must be sufficient to fulfill overall respiratory demand for the naturally occurring pond biota (microbes, algae, insects, etc.) and for cultured fish (Hargreaves and Tucker, 2003).

Atmospheric gas exchange and photosynthesis are the processes whereby oxygen is introduced into aquaculture ponds. Atmospheric gas exchange is enhanced by using mechanical aeration devices. Mechanical aeration improves efficiency of atmospheric gas exchange by insuring mixing and exposure of large portions of the water column to the atmosphere. Through atmospheric gas exchange, oxygen can be introduced into the water layers of a pond. This type of aeration depends on velocity and duration of wind, and the difference between the partial pressure oxygen in the atmosphere and the water. Air bubbles form and rise through the water causing oxygen to dissolve into the water, and thereby replenish levels. The rate of re-aeration that occurs through atmospheric gas exchange is often insufficient to satisfy the overall oxygen requirements of these highly productive systems; therefore, this process is often not as important as photosynthesis in the total supply of oxygen to aquaculture ponds (Hargreaves and Tucker 2003).

Photosynthesis generally provides most of the oxygen produced naturally in aquaculture production ponds (Boyd and Tucker 1998). Maintaining an adequate, but not excessive phytoplankton population is difficult because plant nutrients derived from fish feed and fecal production represent a continuous supply of nutrients for phytoplankton growth. Blooms of phytoplankton and the populations of microbial communities consume much of the available oxygen, potentially leaving insufficient amounts to support the cultured fish population, particularly during periods of low photosynthesis. Mechanical aeration is used to supplement and maintain DO concentrations at levels required for continuous, good quality growth of a fish population (Hargreaves and Tucker 2003).

Active Aeration Techniques

Mechanical aeration equipment is generally used to increase DO concentrations to maintain acceptable levels (Moulick, et. al. 2002). Many different mechanical aeration techniques have been used or tested. They include exchanging oxygen-depleted water with oxygenated water from another pond, inorganic fertilization to encourage oxygen production by photosynthetic organisms, adding compounds that release oxygen via chemical reactions, releasing pure oxygen gas into pond water, and aerating with mechanical devices that either release air bubbles into the water or splash water into the air (Boyd 1998). Mechanical aeration is the most common and considered to be the most efficient management practice to increase DO concentrations throughout the water column of a pond (Boyd 1990).

Vertical pumps, pump sprayers, propeller-aspirator-pumps, paddlewheels, and diffused-air systems have been used to increase DO concentrations in pond-based aquaculture (Moulick, et. al. 2002). Managing these aeration devices also requires additional labor costs as they must be manually turned on and off frequently throughout the day and night (Boyd 1998).

Tractors equipped with paddlewheel aerators are used regularly when rapid increases in DO concentrations are needed to avoid highly stressful conditions possibly leading to mortality (Boyd 1990). Because tractors are portable, they can be moved from pond to pond as needed and placed anywhere along the bank. Paddlewheel aerators are usually operated with paddles submerged approximately 3 to 4 inches in the water. For greater oxygen transfer, paddle depth can be increased to approximately 5 to 6 inches; however, this increases fuel consumption and produces a stronger water current, which forces fish to expend more energy (and consume more oxygen) when swimming near the aerator (Boyd 1990).

The ability and effectiveness of a mechanical aerator to transfer oxygen to water is expressed as its standard oxygen transfer rate (SOTR) and the standard aerator efficiency (SAE), respectively. The SOTR is the amount of oxygen that an aerator will transfer in one hour to clear freshwater at 20°C which contains 0 mg/L DO. SOTR is usually expressed as pounds of oxygen added per hour and converted to kilograms of oxygen added per hour. The SAE is the SOTR divided by power input and is normally expressed as pounds (kilograms) of oxygen per kilowatt-hour or pounds (kilograms) of oxygen per horsepower. These conversion factors allow managers to standardize and evaluate the operation of different aeration devices (Boyd 1990).

Automated Oxygen Monitoring and Aeration

Most fingerling and foodsize catfish aquaculture operations use manual oxygen monitoring techniques. Manual monitoring techniques generally require use of a DO meter that is equipped with an oxygen probe that is manually introduced into each pond to determine DO concentrations. Only 7.7% and 20% of catfish fingerling operations and average foodsize operations, respectively, use automated oxygen monitoring systems (USDA, Part I 2003; USDA, Part II 2003). Automated oxygen monitoring systems are capable of reducing extent of variation in oxygen concentrations that occur throughout the day, increasing efficiency and possibly lowering cost of aeration. Automated monitors provide an immediate response of aerators to any low DO concentrations recorded by the automated monitoring system. In contrast, manual monitoring will only detect decreased DO when the pond is next visited by managers (Hoagland 1998).

Automated monitors offer an efficiency that cannot be achieved by manual operation of aerators because the automated monitors respond quickly to recorded DO data, resulting in less lag time. Automated oxygen monitoring systems have the potential to reduce labor and energy costs, decrease the incidence of disease and mortality cause by DO stress, and increase production yields through constant monitoring combined with aeration management of desired DO concentrations in aquaculture ponds (Daniels and Whitis 2005). Undesirable DO concentrations can occur more frequently between pond checks under a manual monitoring and aerator management practice.

Some aquaculture farms do use constant aeration to minimize as much as possible the incidence of lethal concentrations of DO. Ponds using constant aeration should result in the least variable DO concentrations during each 24 hour period. However, this approach increases overall electricity costs and can decrease the overall efficiency of the operation and net profit that can be realized.

Related Aeration and Dissolved Oxygen Studies

Abdalla and Romaire (1996) conducted a three month study to investigate effects of duration of aeration on water quality and the production of catfish. Ponds were aerated with 0.33 horsepower, time-controlled, floating vertical pump aerators. There were 5 treatments; no aeration, continuous (24 hour) aeration, and aeration from 4am to 7am, 4am to 6am and again from 4pm to 6pm, and 1am to 7am. DO, along with other chemical variables of water quality, were measured at 5 pre-determined days during the study. Relative to initial body weight, mean fish growth in unaerated ponds was significantly less (-54%) than that of fish in ponds aerated continuously (+97%) and those mean weights for either 3, 4, or 6 hours of aeration (+32%, +32% and +23%, respectively). Production for the continuous aeration treatment was significantly greater than that of each of the 0, 3, 4 and 6 hour aeration treatments. There was no significant difference in production among the 3, 4 and 6 hour aeration treatments. Early morning DO concentrations of less than 1 mg/L were recorded in the ponds without aeration, whereas concentrations greater than 4 mg/L were always recorded under continuous aeration. The greatest variability of DO concentrations throughout the day was observed in ponds that were not mechanically aerated, whereas DO in continuously aerated ponds showed the least variation. Variability of DO concentrations in partially aerated ponds fell in between unaerated and constantly aerated ponds.

Lazur (1995) demonstrated that continuous aeration and circulation of water significantly increased mean weight yields of catfish grown in cages attached to floating wooden piers in an 8.25 hectare pond that had a mean depth of 2 meters and a maximum depth of 4 meters. Three cages were equipped with an airlift pump, and three others had no supplemental aeration device. Cages were approximately 30 meters apart, to the deeper sections of the pond. Both treatments contained 500 fish /m^3, and the mean weight of a fish was 21 grams. Fish were fed daily with a commercially available 36% crude protein floating feed. Initially fish were fed at 3-4% of their body weight; however, after approximately 60 days, fish were fed to satiation. After 215 days, the mean individual final weights of fish harvested from cages in the control and airlift treatments were 227 grams and 286 grams, respectively.

Tucker and Steeby (1995) observed that circulation in catfish ponds for several hours during the day did not completely reduce incidence of low overnight DO concentrations; however, it did reduce the total hours of aeration required to replenish and maintain DO concentrations at satisfactory levels overnight. Although overall net fish production and mass did not differ between the two treatments, reduction in aerator use was noticeable and did lower the likelihood of nightly fishkills due to mixing in additional oxygen during the day.

More efficient aeration techniques in aquaculture systems permit greater feeding rates and increased catfish production (Torrans, 2005). Automated devices can continuously monitor DO concentrations and activate a mechanical aerator when DO concentrations decrease to a specified level. Using shrimp ponds at Auburn University, Hoagland (1998) evaluated automated DO sensors, timers, and manual control as techniques for turning aerators on and off, and compared energy use among them. Aeration controlled by automated DO sensors used 62% less electricity than aerators operated by timers, and 80% less electricity than manually operated aerators. His study predicted that automated monitoring systems should be the most common method of monitoring water quality variables in the future. In light of these findings, automated DO sensors should be tested in commercial aquaculture enterprise (i.e. catfish aquaculture), to determine if they can actually reduce overall production costs.

Daniels and Whitis (2005) conducted a survey of approximately 95% of the catfish producers who use automated oxygen monitoring systems in Alabama to determine if these systems actually reduced aeration costs. Of the 51 surveys that were sent to catfish producers, 28 responses (55%) were received and 96% confirmed that the systems were still in use. When farmers were asked why they invested in the automated monitoring system, 68% replied to “prevent catastrophic fishkills”, 57% replied “to save money on electricity” and 57% replied “to save money and time.” Farmers were then asked if they thought the automated monitoring system reduced electricity costs; 50% stated a savings of 10-25% and 29% of 25-50% in electricity costs. Only 11% of the farmers who completed the survey believed they were saving less than 10% in electricity costs. When asked if the automated monitoring system had protected them from unpredictable losses of fish during daylight hours when oxygen is not checked as frequently as nighttime hours, 61% replied affirmatively. Within that 61%, 71% stated that the entire automated monitoring system had paid for itself by saving just one pond of fish. Responses to questions concerning maintenance requirements for a farmer’s particular automated monitoring system ranged from 29% stating the system required very little maintenance to 36% stating maintenance was slightly demanding. Another 29% believed that maintenance was moderately demanding whereas 4% felt that maintenance was too demanding and required an employee to exclusively focus on the successful operation of the system. When farmers were asked if they would use the same automated oxygen monitoring system again, 86% said that they would and believed that the automated oxygen monitoring system increased their profits.

Torrans (2005) conducted a two year study to determine if aeration activated at different concentrations of DO would increase overall pond production of catfish. Six 0.1 hectare ponds were fitted with 3 aerators and one circulator, all of which were under the control of a commercially available automated monitor that controlled aeration. Three ponds each were assigned to high-oxygen and low-oxygen treatments. During both years, aeration in the high-oxygen treatment was initiated when DO concentrations dropped below 5.0 mg/L. Aeration in the low-oxygen treatment was initiated when the DO concentration dropped below 2.5 mg/L in the first year and 1.5 mg/L in the second year. Feed consumption declined in ponds where DO concentrations were allowed to fall below 2.5 mg/L relative to the high-oxygen ponds. There were no significant differences in survival or the feed conversion ratio between treatments, but net production was significantly greater in the high-oxygen ponds. Although results from this study were not extrapolated to commercial scale ponds, increased aeration resulting from a greater threshold concentration of DO for activation has the potential to increase catfish production.

Use of automated aeration techniques for management of DO can prove to be very efficient despite relatively high costs of initial installation and continued operation. The possible realization of lesser expense for labor and electricity coupled with increased net production through use of an automated monitoring system could outweigh initial installation and ongoing maintenance and operating costs and thereby increase profits on aquaculture farms (Lee 1993).

Study Objectives

The study had three objectives: 1) Compare effectiveness of automated oxygen monitors, manual monitoring and constant aeration in the management of DO concentrations in experimental aquaculture ponds, 2) Compare fish production parameters among three treatments and 3) Determine economic value associated with the use of constant, manual and automatic aeration techniques by comparing rates and costs of production.

CHAPTER II

STUDY AREA & METHODS

Research was conducted at the Aquaculture Research Unit of the Mississippi Agricultural and Forestry Experiment Station (MAFES), Mississippi State University. Twenty ponds, ranging from 0.04 to 0.07 hectares in water surface area, were used to conduct the investigation. Ponds were selected based upon the recent past performance of the Integrator Aquasystems™ automated monitoring system at accurately recording DO concentrations (Fondren, personal communication) and assigned to the different treatments. A relatively consistent biomass of fish was stocked into each replicate pond for all treatments.

The comparative performance among treatments (constant, 24 hour aeration, manual aeration based upon a standard manual protocol and automated monitoring and aeration) was evaluated. All test ponds were equipped with an Air-O-Lator Aquarian Residential ½-horsepower floating fountain aerator and an Integrator Aqua Systems™ unit that provided solar-powered, oxygen monitoring and aeration control for each pond; data were wirelessly transmitted to a central computer for storage and software activation/deactivation of individual aerators. For the automated treatment, the Integrator Aquasystems™ system was used to automatically control the aerators which were activated if oxygen concentrations were ≤ 4 ppm and turned off if oxygen concentrations were ≥ 5.5 ppm. The manual monitoring and maintenance protocol entailed turning the aerators off after DO concentrations reached 4 ppm in the morning (at approximately 8 AM). All aerators were turned off by 10 AM unless a pond was experiencing, or expected to experience, low oxygen conditions. If the DO was less than 8 ppm in the afternoon (at approximately 4 PM), aerators were turned on. There were 6 ponds (replicates) for the constant aeration treatment and the manual monitoring and maintenance treatment, and 8 replicates for the automated monitoring and aeration treatment. In the event that oxygen depletion could not be offset by the in-pond aerators, ponds in the constant aeration and manual monitoring and maintenance treatments received supplemental aeration through a tractor-powered paddlewheel. Protocols for paddlewheel aeration called for supplemental paddling at night if oxygen concentrations remained below 4 ppm with aerators activated and paddling during the early evening if oxygen concentrations were in the 4.0 to 4.5 ppm range. The automated monitoring and maintenance treatment received supplemental paddling only when oxygen reached 3.5 ppm during a sunset to sunrise period under the assumption that if DO concentrations fell to this level, demand for oxygen exceeded the ability of the fountain aerator to supply oxygen. The duration for each occurrence of paddlewheel aeration was recorded and included in subsequent analysis.

Catfish were individually counted and bulk weighed prior to stocking into each pond on July 18, 2007. Fish were obtained from other experimental ponds at the Aquaculture Research Unit. The calculated mean individual weights (kg) of fish stocked ranged from 0.09 to 0.13 kg, and the total biomass of fish stocked into each pond ranged from 517 to 712 kg. The stocking density was 14,820 /hectare, a rate that was under evaluation for the third phase (growout) of a modular system for catfish farming under large scale conditions (D'Abramo, personal communication). Catfish were fed daily during morning, to satiation, a 36% crude protein floating fingerling feed (Land O' Lakes Purina Feed, Saint Paul, Minnesota) for the first week and then a 32% crude protein floating feed (Delta Western, Indianola, MS) from the beginning of week 2 until the completion of the experiment on November 4, 2007 when catfish from each pond were seine harvested, counted and bulk weighed.

Dissolved Oxygen Concentrations

The DO data collected for all experimental ponds by the automated oxygen monitors was to be used to compare the diurnal patterns of oxygen concentrations for each treatment. This procedure was designed to identify which ponds would have had unacceptable DO concentrations without automated monitoring and to estimate DO benefits of automation.

Total aeration hours were recorded daily by the automated system for the aerator unit located in each of the replicate ponds. Total aerator hours were then summed over the duration of the study to determine total aeration per replicate pond. Total aeration hours for each of the ½-horsepower floating fountain aerators in each pond and for the tractor paddlewheel were converted to SOTR. Floating fountain aerators using ½-horsepower motors add 1.04 kg of oxygen per hour (Air-O-Lator Corporation 2007). Tractor paddlewheels using a 45-horsepower engine add 63.28 kg of oxygen per hour

(Boyd 1990). These values were multiplied by hours of fountain and paddlewheel aeration and then summed to determine total kilograms of oxygen added per pond throughout the study.

Production Measures

Mean percentage weight gain, feed conversion ratio (FCR) and mean percent survival were the production variables used to compare performance of the different DO monitoring and maintenance treatments. Treatment means and 95% confidence intervals were calculated for these parameters. Percentage weight gain was determined by calculating the difference between the final harvest weight (kg) and initial stocking weight (kg) per pond, divided by the initial stocking weight (kg) and multiplying by 100. FCR was determined by dividing the total weight (kg) of feed (as is) fed by the weight gain (kg) per pond. Survival was determined by dividing number of surviving fish by number of fish stocked initially and multiplying by 100.

Statistical Analysis

Statistical Analyses using T-tests were used to compare data obtained from the constant aeration treatment and the manual monitoring and maintenance treatment to determine if mean pounds of oxygen added to the water through aeration and production data differed. T-tests were conducted using Microsoft Excel with a critical P-value of 0.05.

Partial Enterprise Budget Analysis

With the information collected using the described methodology, a partial enterprise budget analysis was generated to compare costs between the constant, manual and automatic oxygen monitoring treatments. A partial enterprise budget analysis determines whether the changes made to the operation will result in an increase or a decrease in the overall net return due to change in operation practices (Hanson, et. al. 2007). This analysis is very useful in determining whether the long-term profitability of a farm will be improved by implementing one of the oxygen monitoring and aeration practices over another. Only revenues or costs that changed due to the use of one of these treatments were included. The analysis incorporated catfish sales, variable costs and fixed costs of each pond to determine if any overall change in net return occurred by using one of the three different monitoring techniques. Each pond was considered separately, and then a mean and 95% confidence interval of all ponds within a treatment were calculated for each cost. Costs were then extrapolated to a 1-hectare scale pond. Statistical analyses using T-tests were conducted on production costs to identify any possible cost difference between the constant aeration treatment and the manual monitoring and maintenance treatment.

Catfish sales were determined by multiplying the difference in the total final weight harvested and the total initial weight stocked by $ 1.65 per kilogram. Variable costs included those associated with feed, energy, fuel, labor and the additional automatic aerator equipment and maintenance, i.e., DO solution, probe membranes, batteries, etc.

Feed costs were determined by multiplying the total feed fed expressed in tons, by the cost of feed which was $281 per metric ton (actual purchase price).

Electricity costs for aeration were calculated by multiplying the total aeration hours by number of kilowatt-hours per hour for a one-half horsepower unit (1.05 efficiency ratio) and by kilowatt-hour cost ($0.08). To determine number of kilowatt-hours per hour for a one-half horsepower aerator, number of kilowatt-hours per hour for a 10 horsepower aerator (8.47) was multiplied by one-half horsepower and divided by 10 horsepower (Hanson, personal communication). Kilowatt-hour cost was determined by taking a mean of off-peak ($0.05) and peak ($0.11) electricity costs (Hogue, personal communication).

Fuel costs for manual monitoring techniques were calculated based on use of approximately 106 liters of gasoline per week to monitor all 75 ponds (Fondren, personal communication). Weekly gasoline use was extrapolated to a per pond per day basis for the 110 days of the study and then multiplied by the cost of regular grade gasoline. The constant aeration treatment was divided by one-half based on the assumption that ponds with 24 hour aeration would only be checked half as often, and the automated monitoring and maintenance treatment was not manually checked at all (Fondren, personal communication). The diesel gasoline costs for emergency paddlewheel protocol using a 45 horsepower tractor were based on the assumption that for every 12 to 16 hours of emergency paddlewheel time, 45 liters of diesel was used (3.75 to 2.81 liters per hour). Mean liters of diesel used per hour was multiplied by hours of paddlewheel use per pond and then multiplied by cost of diesel per liter to determine total cost. Ponds in all treatments received emergency paddlewheel aeration. Regular grade gasoline and diesel costs during the study were acquired through personal correspondence with Rackley Oil in Starkville, Mississippi (Rackley Oil, personal communication).

Labor costs for manual monitoring were calculated per pond for the 110 day study based on information obtained about frequency of DO measurements needed and collected manually. Under manual operation protocol, employees record DO daily at approximately 0600, 1400, 2200, 0200, and 0400; at each time, measurements require one hour to complete. This information is the foundation for a model sampling schedule representative of the manual process. Under the constant aeration treatment, ponds were checked half as often as the manual monitoring and maintenance treatment and accordingly the required labor is 50% less. DO concentrations for the automated monitoring and maintenance treatment were not checked at all. Labor to manage the automated oxygen monitoring system included calibration and computer time that were not required in the other two treatments. Amount of labor was calculated based on the assumption that calibration of the automated monitor took 0.33 hours per unit, and computer observation of DO concentrations took 0.083 hours for each pond per day for the 110 day study (Fondren, personal communication).

Emergency paddlewheel operation, based on the assumption that moving the tractor from one pond to another, aerating the water and removing the tractor when DO concentrations were adequate, was estimated to require a total of 0.33 hours; therefore amount of labor was determined by multiplying 0.33 hours by number of times throughout the study a pond needed emergency aeration (Fondren, personal communication). All labor hours were multiplied by $5.15 per hour (Fondren, personal communication) to determine labor costs for each treatment. Additional automated monitoring treatment costs included DO solution, probe membranes, batteries, etc for 2 years equaled $11,719; however, the cost of the additional supplies was prorated to a per unit basis, i.e., a per pond basis, for the 110 day study period and multiplied by the unit costs of those supplies. These additional costs were approximately $16.05 per automated unit.

Fixed costs included the depreciation of the computer needed to operate the automatic monitoring system, the automated monitors and the DO meter used for manual monitoring. Cost of the computer was prorated to a per pond basis, depreciated over 5 years and prorated to the portion of a full year that the study was conducted to obtain the specific depreciated value over the time period of the study. Total cost of the automated monitoring system was used to determine cost of each individual unit, which was then depreciated over 5 years and prorated to the portion of a full year the study encompassed. Depreciation of the automated monitoring system was extrapolated to a 4-hectare pond scale because commercial farms would only use one unit per 4-hectare pond. The constant aeration treatment and the manual monitoring and maintenance treatment did not require use of a computer or automated monitor.

The DO meter used for manually monitoring all 75 ponds was prorated to a per pond basis, depreciated over 5 years and applied to the portion of a year the study represented. The treatment using the automated oxygen monitor did not require use of a

DO meter, though in reality a producer would have one on hand for use if the automated DO monitoring system were to malfunction (as was the case in this study).

CHAPTER IV

RESULTS

Dissolved Oxygen Concentrations

Because of ongoing performance issues with the Integrator monitoring equipment in all treatments with the automated monitoring system, accurate measurements and recording of oxygen concentrations was not accomplished. Additionally, the automatically aerated ponds could not be included in statistical comparisons with the other treatments because these ponds relied solely on information collected by the automated monitors to control the operation of the aerators, and the equipment malfunction resulted in unreliable DO measurements. As a result, the data was of indeterminate quality and was not used for the automated monitoring treatment; however, production results for a subset of the ponds in this treatment (2 ponds) representing the best case outcomes given the malfunction is presented to represent the potential outcome of automated monitoring and aeration control. These 2 ponds were used in this non-statistical comparative analysis and may represent the potential of this management approach.

Figure 1 presents a best case diurnal oxygen curve derived from a single pond representing each of the three management treatments on September 21, 2007, day 66 of the study. These data unfortunately are not representative of the recorded DO concentrations diurnally during the entire study period. DO concentrations were greatest and least in the pond where aerators were being operated automatically. During evening and early morning hours, when DO concentrations commonly decrease, the oxygen profile of the pond controlled by automatic aeration was similar to those of the ponds where manual aeration and constant aeration protocols were followed.

The actual DO concentrations recorded throughout the study by the automated monitoring system varied unpredictably throughout this study, further illustrating the effect of the equipment malfunction on the recording DO concentrations. Some automated monitoring units recorded DO concentrations that ranged from 1 mg L^{-1} to 24 mg L^{-1} (the greatest value the instrument is capable of displaying) during a 24 hour period. Other units recorded zero values when actual DO concentrations were adequate to sustain the catfish biomass in the experimental ponds (and where manual DO measurements indicated sufficient oxygen concentrations). The oxygen monitoring malfunction in the automated aeration treatment did not impact aeration in the constant aeration and manually monitored and maintained treatments because operation of the aerators in these ponds were being controlled by personnel or simply remained on. In the automated aeration treatment, while the aerators did operate, they did so in response to erroneous DO concentrations, invalidating the results obtained from the ponds in this treatment.

Total kg of oxygen added via aeration for each pond is presented in Figure 2. One replicate pond (A11) in the constant aeration treatment was excluded from analysis due to comparatively poor overall production performance relative to the other ponds in all treatments. The kg of oxygen added via aeration differed between the constant and manual aeration treatments (P = 0.0235). Data for the automated monitoring treatment were not statistically compared to those of the other monitoring treatments. The constant aeration treatment recorded a mean of 2,673 kg of oxygen added, and the manual monitoring and maintenance treatment recorded a mean of 1,670 kg of oxygen added, a difference representing almost one-half the amount of operational hours for continuous running of aerators. The two best case ponds in the automated monitoring and aeration treatment recorded a mean of 1,234 kg of oxygen added. Overall, these results suggest that it might be more efficient and cost effective to manually activate and deactivate aerators as opposed to running them for 24 hours daily, with some suggestion that automated aeration may be able to further reduce electricity use.

Production Measures

Production data are presented in Tables 1 to 3. Production (kg ha^{-1}) at harvest for each pond is presented in Figure 3. Percentage weight gain for the pond excluded (A11) from the overall comparison of response was 192% and the FCR was 2.3. Survival was 83.5%. Mean percentage weight gain, FCR and survival for all the remaining ponds, regardless of treatment, were 280%, 1.7, and 97.1%, respectively.

Mean percentage weight gain (Table 1) for constantly aerated ponds and manually monitored and maintained ponds were 279% and 284%, respectively. Mean FCR (Table 2) and survival (Table 3) for constantly aerated ponds and manually monitored and maintained ponds were 1.62 and 1.64, and 96.3% and 97.9%, respectively. Mean percentage weight gain, FCR and survival for the constant aeration treatment and the manual monitoring and maintenance treatment did not significantly differ. Production measures for the 2 best case ponds in the automated monitored and aeration treatment were similar to those of the other two management treatments. Notably, for the two replicate ponds where dissolved oxygen concentrations were believed to be more accurately monitored and DO appropriately maintained, the mean percentage weight gain was 352%. Also, mean FCR and survival were 1.70 and 98.4%, respectively. The greater percentage weight gain achieved suggests that this automatic monitoring system could be more effective than the other DO management protocols at promoting increased production parameters.

Partial Enterprise Budget Analysis

Partial net returns for each of the experimental ponds in the study are presented in Figure 4. Results for the partial enterprise budget analysis indicated that the mean partial net return obtained from the two best case automated ponds ($3,551 per hectare) was greater than the mean of the other two treatments; however, these data were not statistically significant compared to the other two management treatments. The constant aeration and manual monitoring treatments had mean partial net returns of $2,737 and $2,688 per hectare, respectively, and did not significantly differ from one another. However, cost of aeration for the constant aeration treatment ($1,600 per hectare) was significantly greater than that of the manual monitoring and maintenance treatment ($887 per hectare).

Mean catfish sales and mean selected (partial) production costs (variable plus fixed costs) of catfish harvested from ponds in the constant aeration and the manual monitoring and maintenance treatments did not differ significantly. Sales of catfish harvested from ponds in the constant aeration treatment and manual monitoring and maintenance treatment were $7,114, and $7,004 per hectare, respectively. Mean selected (partial) costs for the constant aeration treatment and manual monitoring and maintenance treatment were $4,378, and $4,316 per hectare, respectively. The mean selected (partial) variable costs for the constant aeration treatment and manual monitoring and maintenance treatment were $4,369 and $4,309 per hectare, respectively and did not significantly differ. Mean total fixed costs, considering the depreciated value of a handheld oxygen meter for the constant aeration treatment and manual monitoring and maintenance treatment were $7.31 and $7.23 per hectare, respectively, and did significantly differ. The difference in total fixed costs between these treatments can be attributed to the greater use of the DO meter for the manual monitoring and maintenance treatment. Catfish sales, variable costs and fixed costs for the two ponds in the automated monitoring treatment were $8,831, $5,224 and $56.34 per hectare, respectively. Means and 95% Confidence Intervals for all operational and fixed costs are presented in the Partial Budget Analysis (Table 5). Depreciation values are presented in Table 6.

CHAPTER V

CONCLUSIONS

This study suggests that automatically controlling aeration can successfully maintain as high a quality oxygen environment in aquaculture ponds as well as manually monitored and controlled aeration systems, based on the results from the two best case outcome ponds in the automated treatment. The potential to outperform manual or constant aeration methods relative to production is suggested, but could not be statistically evaluated due to the automated equipment malfunction in the automated treatment. The cause of the equipment malfunction in the automated monitoring system is not known. Possible malfunction causes include interference of wireless transmission from automated units to the hub computer, the high influx of DO data that the computer could not record properly, damaged or defective DO probes on the automated unit causing inaccurate DO readings and/or improper calibration techniques. Regardless of the cause, the automated monitoring system did not record accurate DO concentrations; therefore, the automated monitoring and aeration treatment was not included in a statistical analysis. Malfunction of this equipment is a risk that has been revealed by this study and needs to be part of the overall economic analysis and decision to adopt this management practice. Further investigation of the automated monitoring system when the system is operating correctly could demonstrate that while the initial investment is high, the greater net returns realized would compensate for the greater cost of the equipment.

More precise aeration techniques in aquaculture systems have the potential to reduce aeration costs and produce greater catfish yields (Torrans, 2005). Cost of implementing and maintaining an automatic monitoring system can be high, and use of an automated monitoring system, pertaining to this study, did not significantly increase the partial net returns (profit) relative to the constant aeration and manual monitoring and maintenance treatments. Overall cost of aeration was reduced, but labor time to calibrate and perform computer associated work increased. Evidence of the automated monitoring system's potential to increase profits and compensate for the high installation cost is evident in two ponds in the automated oxygen monitoring treatment that operated closest to the experimental protocol; however, further studies should be conducted to test this hypothesis.

Automated DO monitors could be beneficial to commercial pond aquaculture enterprises under circumstances beyond their the potential for increased profitability. For farmers who encounter problems acquiring and retaining employees willing to work late evening and early morning hours, use of an automatic monitoring system could be a solution. Reduced overall staffing caused by the addition of an automated monitor could help to decrease overall management costs. Farmers who may choose to not rely solely on an automated oxygen monitor could use the technology as a back-up mechanism. Also, automated monitoring systems offer an appealing alternative to labor intensive approaches currently used to monitor DO concentrations and perform normal aeration procedures in catfish ponds.

If use of automated oxygen monitors can benefit aquaculture operations through control of aeration throughout the entire farm or as a supplemental monitoring aide, changes must still be made to make them more affordable and reliable. Making software more user-friendly, building automated oxygen units that are more durable to withstand adverse environmental conditions and lowering purchase costs could promote much more interest in the use of an automated oxygen monitoring system (Daniels and Whitis 2005).

The assimilation of new technology and management practices in the catfish industry is motivated by the goal of an increase in net return on investment through an increase in productivity coupled with lesser production costs (Hargreaves and Tucker 2003). As pond-based culture of fish continues to increase globally, aquaculture operations in the United States must continue to evaluate means to achieve more efficient management practices to lessen production costs and thereby remain competitive with foreign imports (Simco 2000). To successfully meet that challenge, implementation of automatic monitoring of dissolved oxygen in concert with effective aeration management may be an important factor.

LITERATURE CITED

Abdalla, A. A. F., Romaire, R. P. (1996). Effects of timing and duration of aeration on water quality and production of channel catfish. *Journal of Applied Aquaculture*, 6 (1), 1-9.

Air-O-Lator Corporation (2007). Aquarian Residential Brochure. Retrieved March 25, 2008 from http://www.airolator.com/AqurianResidentialBrochure.pdf.

Aquatic Eco-Systems, Inc. (2004). *Dissolved oxygen in aquaculture: the first limiting factor of water quality*. Retrieved April 10, 2006, from http://www.aquaticeco.com/index.cfm/fuseaction/popup.techTalkDetail/ttid/1.

Boyd, C. E. (1998). Pond water aeration systems. *Aquacultural Engineering*, 18 (1), 9-40.

Boyd, C. E. (1990). Dissolved Oxygen: Predicting Dissolved Oxygen Concentrations: Aerator Performance Tests. Pages 144-149, 286-295, 313-336 *in Water Quality in Ponds for Aquaculture*. Birmingham Publishing Company: Birmingham, Alabama.

Boyd, C. E., & Tucker, C. S. (1998). Chemical, Physical, & Biological Treatments. Pages 498-512 *in Pond Aquaculture Water Quality Management*. Kluwer Academic Publishers: Norwell, Massachusetts.

Borisova, T. A., D’Sourza, G. E., Miller, D., Labys, W. C. (2007). Remaining competitive at the regional level: Developing a local aquaculture industry. *Aquaculture Economics and Management*, 11 (1), 73-98.

Borch, O. (1999). New organizational forms within the aquaculture industry: the fish-farming enterprise as a ‘virtual’ organization. *Aquaculture Economics & Management*, 3 (2), 105-120.

Buentello, J. A., Gatlin, D. M. III, Neill, W. H. (2000). Effects of water temperature and dissolved oxygen on daily feed consumption, feed utilization and growth of channel catfish (*Ictalurus punctatus)*. *Aquaculture*, 182, 339-352.

Colt, J. (2006). Water quality requirements for reuse systems. *Aquacultural Engineering*, 34, 143-156.

Daniels, W. & Whitis G. N. (2005). Use of oxygen monitoring equipment to reduce energy costs and improve efficiency & A survey on the use of automated oxygen monitoring systems on Alabama's catfish farms. *Alabama Agriculture Energy Conference*. Retrieved February 26, 2008 from http://www.adeca.state.al.us/C0/Agriculture%20Energy%20Efficiency/default.aspx.

Drapcho, C.M., & Brune, D.E. (2000). The partitioned aquaculture system: impact of design & environmental parameters on algal productivity & photosynthetic oxygen production. *Aquacultural Engineering*, 21, 151-168.

Hanson, T., Anderson, J. D., Ibendahl, G., Hogue, C., Avery, J. (2007). Partial budgeting as a decision-making tool for catfish producers: With an example for east Mississippi catfish producers. Mississippi State University Extension Service, Publication 2436, Mississippi State University, MS.

Hargreaves, J. A., & Steeby, J. A. (1999). Factors affecting metabolism of commercial channel catfish ponds as indicated by continuous dissolved oxygen measurement. *Journal of the World Aquaculture Society*, 30 (4), 410-421.

Hargreaves, J. A., & Tucker, C. S. (2003). Defining loading limits of static ponds for catfish aquaculture. *Aquaculture Engineering*, 28, 47-63.

Hoagland, R. H.III (1998). Energy efficiency of an automated aeration control system for shrimp ponds, M.Sc. thesis, Auburn University, Alabama.

Lazur, A. M. (1995). Effects of continual water circulation on channel catfish production in cages. *Journal of Applied Aquaculture*, 5 (3), 1-9.

Lee, P. G. (1993). Computer automation for recirculating aquaculture systems. Pages 61-70 *in Techniques for modern aquaculture. Proceedings of an aquacultural engineering conference, Spokane, Washington, June 21-23, 1993*.

Moulick, S., Mal, B. C., & Bandyopadhyay S. (2002). Prediction of aeration performance of paddle wheel aerators. *Aquacultural Engineering*, 25, 217-237.

Queiroz, J. F., Boyd, C. E., & Amit, G. (1998). Evaluation of a bio-organic catalyst in channel catfish, *Ictalurus punctatus*, ponds. *Journal of Applied Aquaculture*, 8 (2), 49-61.

Simco, Bill A. (2000). Aquaculture Economics. *Business Perspectives*, 13, 44-48.

Southworth, B. E., Stone, N., Engle, C. R. (2006). Production characteristics, water quality, and costs of producing channel catfish *Ictalurus punctatus* at different stocking densities in single-batch production. *Journal of the World Aquaculture Society*, 37 (1), 21-31.

Tucker, C.S. 1991. Water quantity and quality requirements for channel catfish hatcheries. Southern Regional Aquaculture Center Pub. SRAC-461. pp. 8.

Tucker, C. S., & Steeby, J. A. (1995). Daytime mechanical water circulation of channel catfish ponds. *Aquacultural Engineering*, 14 (1), 15-27.

Torrans, E. L. (2005). Effect of oxygen management on culture performance of channel catfish in earthen ponds. *North American Journal of Aquaculture*, 67, 275-288.

University of Florida: IFAS Extension (1992; Reviewed: May 1997, February 2003). *Dissolved oxygen for fish production*. Retrieved April 9, 2006, from http://edis.ifas.ufl.edu/FA002.

USDA. 2003. Part I: Reference of fingerling catfish health and production practices in the United States, 2003 USDA: APHIS: VS, CEAH, National Animal Health Monitoring System. Fort Collins, CO # N406.1103.

USDA. 2003. Part II: Reference of foodsize catfish health and production practices in the United States, 2003 USDA: APHIS: VS, CEAH, National Animal Health Monitoring System. Fort Collins, CO #N407.1103.

Young, J. A., Brugere, C., Muir, J. F. (1999). Green grow the fishes-Oh? Environmental attributes in marketing aquaculture products. *Aquaculture Economics & Management*, 3 (1), 7-17.

Wetzel, R. G. (2001). *Limnology: Lake and River Ecosystems* (3rd ed.). California: San Diego, pp 196.

Wetzel, R. G., & Likens, Gene E. (1991). *Limnological Analyses* (2nd ed.). New York: New York, pp 69.

Washington State Department of Ecology (2005). How to measure dissolved oxygen. Retrieved April 8, 2006, from http://www.ecy.wa.gov/programs/wq/plants/management/joysmanual/4oxygen.html.

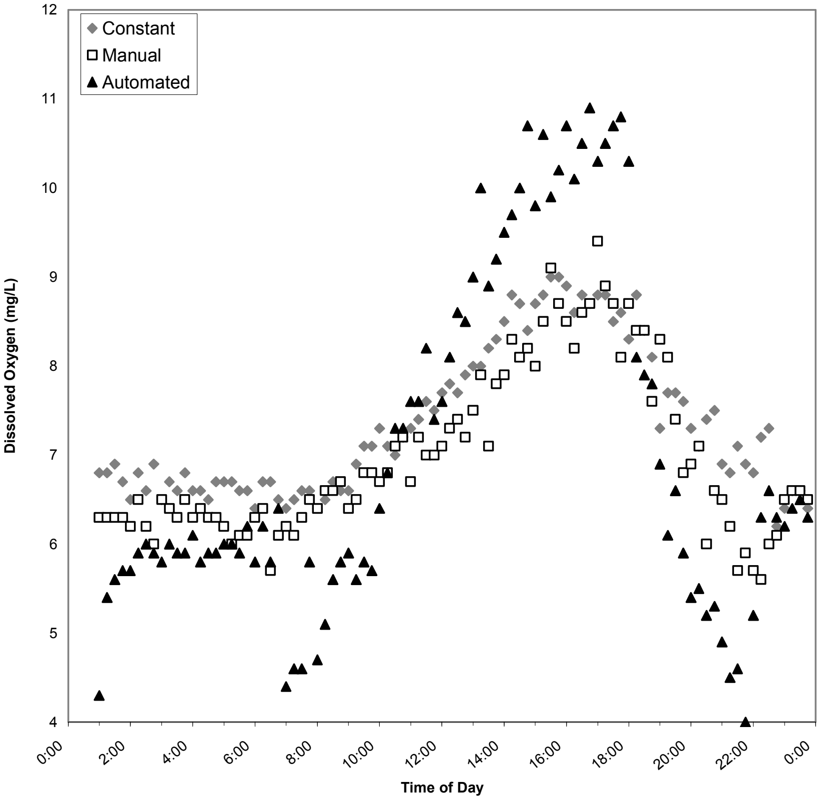

Figure 1. Diurnal dissolved oxygen concentrations in three ponds, one per treatment, for September 21, 2007. DO concentrations were recorded every 15 minutes throughout the day.

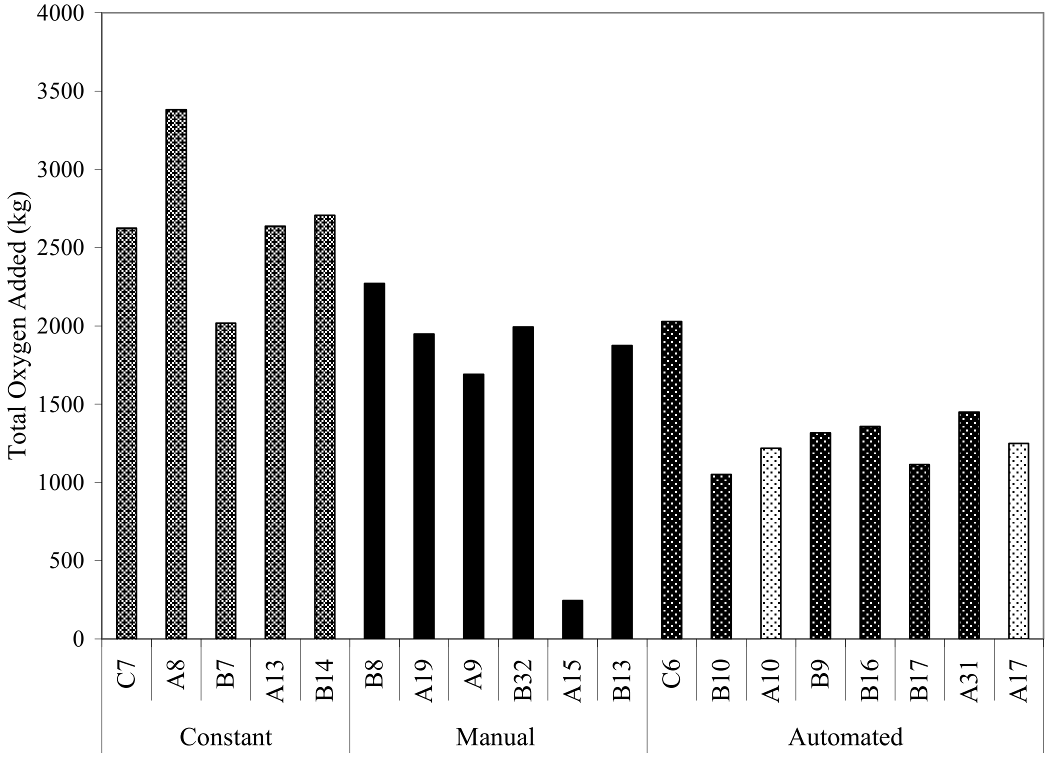

Figure 2. Total kg of oxygen added via aeration for all experimental ponds. Pond A11 (constant aeration treatment) is not included due to production problems. Ponds A10 and A17 (automated monitoring treatment) were used for comparative reference for this treatment.

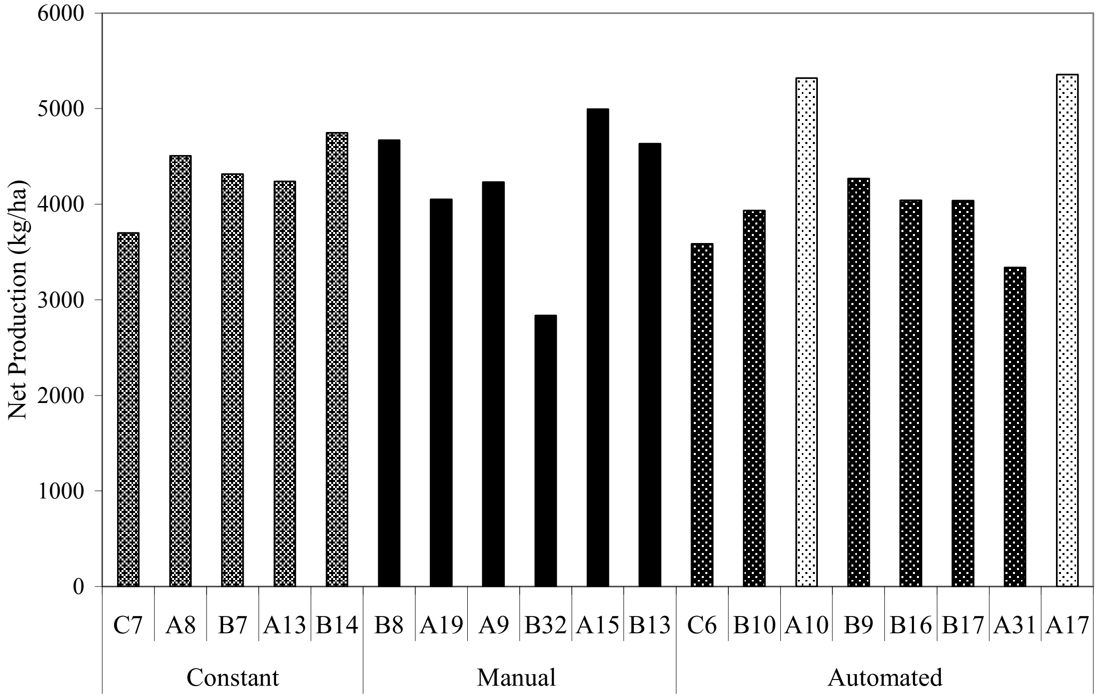

Figure 3. Net production (kg/ha) for all experimental ponds. Pond A11 (constant aeration treatment) is not included due to production problems. Ponds A10 and A17 (automated monitoring treatment) were used for comparative reference for this treatment.

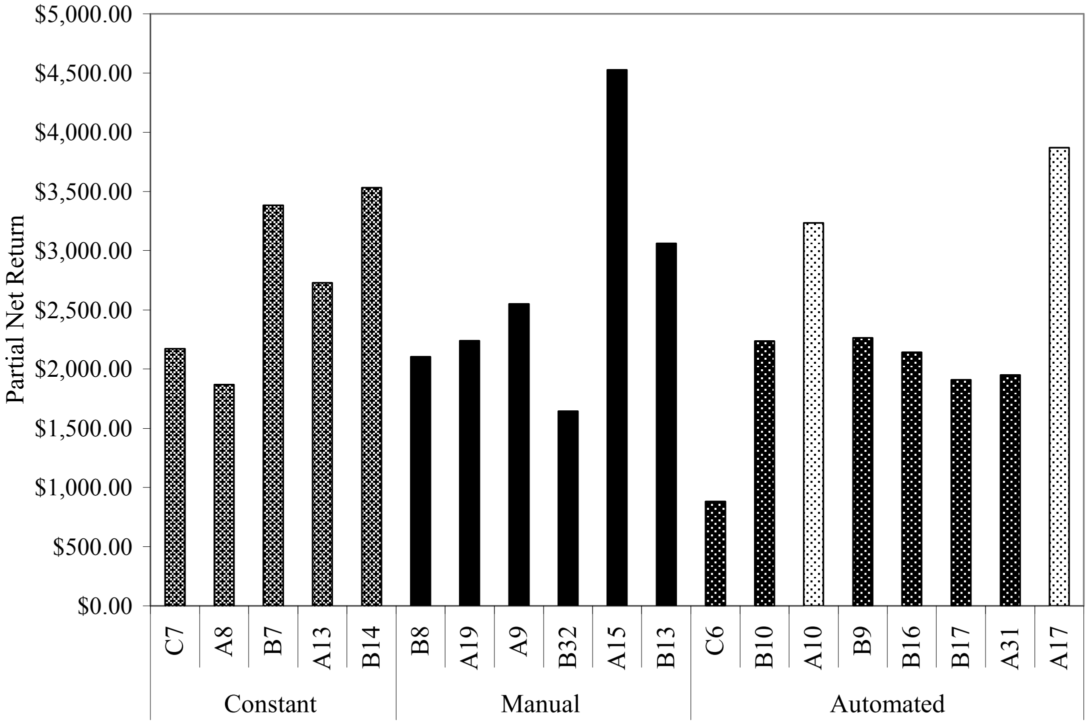

Figure 4. Partial net returns for all experimental ponds. Pond A11 (constant aeration treatment) is not included due to production problems. Ponds A10 and A17 (automated monitoring treatment) were used for comparative reference for this treatment.

Table 1. Mean percent individual weight gain of catfish populations per treatment for the 110 day duration of the experiment. The weight gain for two best case ponds in the automated monitoring treatment was added for comparative reference and was not included in statistical comparisons.

	Mean Percent weight gain	**95% Confidence Interval**	**T-Test P-value: Trts. A & B**
A. Constant (n=5)	279	23	0.837032
B. Manual (n=6)	284	43	
C. Automated (n=2)	352	83	

Table 2. Mean feed conversion ratio (FCR) of catfish populations per treatment for the 110 day duration of the experiment. The mean FCR for two best case ponds in the automated monitoring treatment was added for comparative reference and was not included in statistical comparisons.

	Mean FCR	**95% Confidence Interval**	**T-Test P-value: Trts. A & B**
A. Constant (n=5)	1.62	0.05	0.562624
B. Manual (n=6)	1.64	0.06	
C. Automated (n=2)	1.70	0.01	

Table 3. Mean percent survival of catfish populations for the 110 day duration of the experiment per treatment. The mean percent survival for two best case ponds in the automated monitoring treatment was added for comparative reference and was not included in statistical comparisons.

	Mean % Survival	**95% Confidence Interval**	**T-Test P-value: Trts. A & B**
A. Constant (n=5)	96.3	2.21	0.255289
B. Manual (n=6)	97.9	1.25	
C. Automated (n=2)	98.4	2.55	

Table 4. Total mean costs in partial enterprise budget analysis per treatment. Costs were extrapolated to a per pond basis and the mean values and standard deviation were calculated to determine whether there were any statistical differences between the constant aeration and manually monitored and maintained treatments. The mean costs and standard deviation for two best case ponds in the automated monitoring treatment were added for comparative reference.

	Unit	Cost/Unit	Constant Average	95% CI	Manual Average	95% CI	Automated Average	95% CI
I. Receipts								
Catfish Sales	kg	1.65	7,113.51	516.25	7,004.05	1,011.41	8,830.74	61.75
II. Variable Costs								
Feed	metric ton	281	1,954.93	104.48	1,946.80	239.68	2,553.55	8.93
Electricity								
-Aeration	efficiency ratio for 1/2 hp	1.05	1,600.18	178.26	887.13	371.11	530.17	195.49
	$/kw-hr	0.08						
Fuel								
-Manual Monitoring-regular	liters	0.75	163.05	5.76	322.88	37.23	0.00	0.00
-Paddlewheel-diesel	liters	0.79	198.06	299.57	268.18	275.77	448.30	400.66
Labor	hourly	5.15						
-Manual Monitoring			370.89	13.11	734.47	84.68	0.00	0.00
-Emergency Paddlewheel			82.37	104.64	149.70	154.21	257.08	250.62
-Calibration of Integrator			0.00	0.00	0.00	0.00	33.99	2.66
-Computer Time for Integrator			0.00	0.00	0.00	0.00	934.71	73.28
Integrator supplies	day	16.05	0.00	0.00	0.00	0.00	466.08	36.54
Total Variable Costs			**4,369.48**	571.01	**4,309.17**	695.03	**5,223.89**	559.35

Table 4 Continued.

III. Income Above Variable Costs		**2,744.03**	583.09	**2,694.88**	814.40	**3,606.85**	621.10
Integrator Depreciation	$	0.00	0.00	0.00	0.00	40.50	0.00
Computer Depreciation	$	0.00	0.00	0.00	0.00	15.84	1.24
DO Meter Depreciation	$	7.31	0.13	7.23	0.83	0.00	0.00
Total Fixed Costs		**7.31**	0.13	**7.23**	0.83	**56.34**	1.24
V. Total Costs		**4,376.79**	571.10	**4,316.40**	695.63	**5,280.23**	560.59
VI. Partial Net Return		**2,736.72**	583.16	**2,687.65**	813.98	**3,550.51**	622.34

Table 5. Depreciation values for automated monitoring system, computer needed to run automated monitoring system and DO meter used for manually monitoring ponds. The automated monitor had to be extrapolated down to a per unit basis to determine the depreciation of a single unit. All equipment was depreciated over a 5 year span and was done for each individual pond (unit).

	# of Units	Total Cost of Automated System ($)	Cost/Unit ($)	Economic Life (years)	Depreciation/Year ($)	Depreciation/Unit/Year ($)	Depreciation/3.6 months
Automated Monitor	87	237,652	2,732	5	47,530	546	163.90
Computer	1		1,000	5	200	200	60.00
DO Meter	1		465	5	93	93	27.90