Comparing Economic Returns of Dissolved Oxygen Management in Commercial Catfish Production

by

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Abstract

Catfish culture is one of the largest forms of aquaculture in the US. Catfish production systems have been able to achieve production up to almost 12,000 kg ha^{-1} $year^{-1}$ (Bott, 2015) since the increase in availability of hybrid catfish fingerlings in 2008. The goal of this research is to evaluate the production and economic returns of two commercial catfish operations under traditional and experimental systems of oxygen management. A west Alabama farm agreed to install two floating in-pond raceways cells in each of two commercial ponds (0.8 cells/ha), called raceway ponds. One cell was stocked with channel catfish the other with hybrid catfish. A Mississippi Delta farm agreed to an increased range of paddlewheel aeration rates from 6.8 to 18 kW/ha and grew hybrid catfish in open ponds. Diffused air hoods (2.3 kW/ha) were added to 13.7 kW/ha of paddlewheel aeration as an alternative treatment. Mechanical mixing equipment (2.3 kW/ha) was added to 13.7 kW/ha of paddlewheel aeration as a second alternative treatment. The open ponds were equipped with commercially available remote dissolved oxygen (DO) probe and aeration controls. Aerator run time and amperage readings were used to estimate power usage. Change in nightly DO readings near saturation was used to estimate whole pond respiration. Whole pond respiration was used in an attempt to compare waste loads between ponds.

All cells exhibited mean daily minimum dissolved oxygen levels at or above 3.5 mg/L. Raceway cells were harvested (before market size) after four months of growth (July 2014-October 2014). Production was 1,236 and 2,734 kg/ha when channel and hybrid catfish were raised, respectively. Feed conversion ratio (FCR) was 1.75 and 1.46 for channel and hybrid catfish, respectively. The raceways exhibited higher feed efficiency than the industry average like previous versions of in-pond raceways

Since fish in raceway cells did not reach market size a sale price of $2.75 /kg was projected. The resulting cost of production in the raceways was $3.61/kg and $2.83/kg when channels and hybrid catfish were raised, respectively. The number of cells was projected to 2.43 cells/ha and recalculated costs of production were $2.98/kg and $2.52/kg for channels and hybrid catfish, respectively. So the experimental (0.8 cells/ha) raceways were not profitable when channel catfish or hybrid catfish were grown. However, in a sensitivity analysis, the projected commercial analysis was profitable when hybrid catfish were grown.

Open ponds were harvested after approximately one year. The average mean daily minimum DO was 3 mg/L for the open ponds. A feed problem caused five of the ten open ponds to experience fish losses due to anemia. The average cost of production ($/kg) ranged from 1.94 to 2.31 for open pond treatments. Open pond production (kg/ha) increased with oxygen management (kW/ha) up to 18.75 kW/ha. Although increased production (kg/ha) usually relates to increased profits ($/ha), lower survival in open ponds affected feed efficiency which decreased profitability. Average production ranged from 9,539 to 24,509 kg ha^{-1} $year^{-1}$ across the range of open pond treatments with FCR from 2.4 to 2.9.

Ponds with paddlewheel aeration and a mechanical mixer exhibited similar production in ponds that used paddlewheel aeration alone. Ponds that used diffused air hoods and paddlewheel aeration achieved (15%) higher production than paddlewheel aeration alone. Six open ponds contained oxygen management equipment over 13.7 kW/ha. Five of these six ponds produced over 20,000 kg/ha versus the average production in the Alabama catfish industry of less than 7,000 kg/ha (Courtwright, 2013). Whole pond respiration was moderately correlated to feed input (R> 0.5) in open ponds. Ponds with mixing equipment (diffused air or mechanical) indicated that the equipment may manage waste loads better than paddlewheel aeration alone. In conclusion, open pond results confirm that production increases with oxygen management up to at least 18 kW/ha of aeration.

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List of Terms

Aeration- The process by which oxygen is circulated through a liquid usually by increasing natural atmosphere water diffusion rate.

Air Lift Pump- A system that injects air bubbles into the bottom of a cavity such as a submerged pipe. The air water mixture rises and can be directed to pump, circulate or aerate the water depending on the use.

Bioload-The biological load of living or organic matter in the pond water usually referring to feed and plankton in the pond water.

Biomass-In catfish culture usually referrers to the mass of fish cultured unless another organism is mentioned such as plankton biomass.

BOD- Biological Oxygen Demand, the amount of oxygen need to for aerobic organisms to breakdown organic matter within a set time period.

Catfish- The accepted market name for Channel Catfish (*Ictalurus punctatus*) (National Marine Fisheries Service, 2011). (For simplicity accepted market names will be used although Pangasius is the scientific genus name for certain types of catfish found in Vietnam and Cambodia.)

Correlation-A single number from -1 to 1 that shows how strongly pairs of variables are related.

Crowder-A movable obstacle that allows fish to be crowded into a corn to be harvested, usually in raceways or tanks.

Diffused Air Hood- Similar to air lift pump, a submerged grid of diffuser tubing that produces raising bubbles that glances off an oblique baffle to aerate water and provide water flow in the horizontal direction.

Dissolved oxygen (DO) - The concentration of oxygen dissolved in water; measured in mg/L.

Enterprise Budget- "A projection or estimate of the costs and returns of producing a product" (AGMRC, 2014). Also known as cost per unit or normalized profit.

Fingerling- Small fish used as seedlings for Foodfish, usually 5 cm to 22cm.

Food Conversion Ratio (FCR) - The number of food units needed to raise one unit of fish.

Foodfish- Fish in a size range suitable for consumption by the general market (0.6 kg), or fish raised for consumption.

Fry- Infant recently hatched fish typically stocked in ponds to be grown into fingerlings.

Income-Monetary payment for goods or services.

In-pond Raceways System (IPRS) - Fish confinement system used in larger pond culture.

Multibatch-The practice of growing multiple size classes of fish in the same system and regularly harvesting the largest foodfish in such a way as to always have fish that are near harvest and just been stocked.

Mechanical horizontal circulators-Applies to a variety of water moving and mixing devices that typical operate on a fan or auger principal to move water in a horizontal direction for mixing or water circulation.

Open Pond-Traditional pond culture where fish are not confined to a sub-section of the pond.

Oxygen Management-A range of techniques or equipment that manages dissolved oxygen content in ponds. Usually by aeration or mixing oxygen throughout the pond volume.

Pangasius- Genus of medium-large shark catfish native to south and Southeast Asia; Common market name for Tra (*Pangasius hypophthalmus)* and Basa *(Pangasius bocourti)* (National Marine Fisheries Service, 2011).

Production-The amount of fish biomass produced or grown. Usually normalized by area and time required to grow the crop of fish.

Profit-The amount of money a farm retains after accounting for expenses.

Singlebatch-The practice of stocking one size fish and waiting until they are of foodfish size then completely cleaning out the system.

Sock- Mesh netting used to hold fish after they have been collected from their growing system.

Soil Oxygen Demand (SOD) - The portion of the BOD (see above that is at the soil water interface.

Standard Aerator Efficiency (SAE) – Unit that measures how efficiently an aerator transfers oxygen into water for a given power; measured in kg O_2/kWh.

Standing Biomass (**Standing Crop) -** The maximum mass of fish a pond holds in a production cycle.

TAN-Total Ammonia Nitrogen, combination of both unionized and ionized ammonia.

Waste-Pond bioload that entered pond as food and not absorbed by the fish, can be in the form of uneaten feed, fish excrement, or any number of plankton whose growth is dependent on fish excrement.

Whole Pond Respiration WPR- estimated oxygen consumption rate of all organisms in a pond that affect the change in dissolved oxygen.

Chapter 1 Introduction

Total seafood production has steadily increased with time due to either an increase in per capita demand or population as shown in Figure 1.1 (FAO, 2012). The amount of seafood caught from wild stock in oceans is not likely to increase significantly, based on the relative leveling off in capture fisheries production over the past two decades. As the demand for seafood increases, aquaculture production must increase (FAO, 2012). Since the mid 1980's, a rising trend in aquaculture production continues (Figure 1.1).

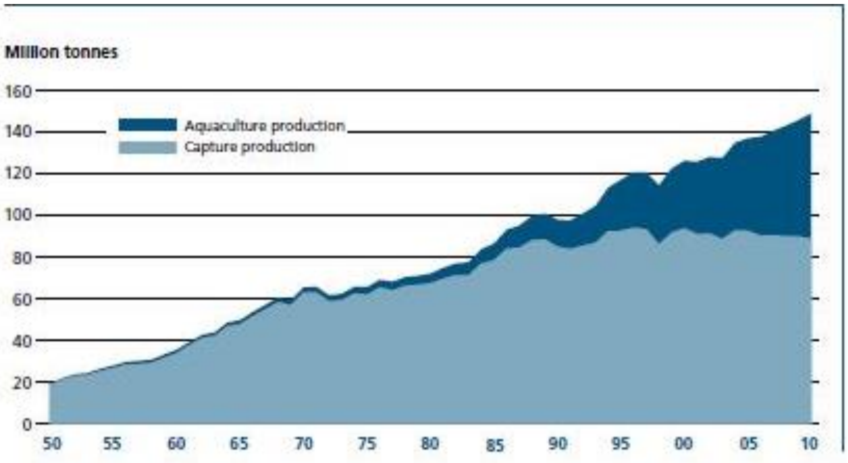


Figure 1.1 Levels of world capture and aquaculture production, 1950-2010 (FAO, 2012).

1.1 Aquaculture in Asia

Several places compete with the US in aquaculture production including China, Vietnam, and other tropical regions that raise Tilapia. Vietnam, especially the Mekong Delta, has many unique production components. In Vietnam, producers are able to divert large volumes of river water through pumps and canals to flow into fishponds. The Vietnamese also house their fish in confined environments with respect to size and density such as cages or small ponds, whereas the ponds used in the Southeastern United States are much larger and less confined. Many of the species in South East Asia are exotic, tropical species that are air breathers, meaning they are extremely resistant to poor water quality and low dissolved oxygen. Typical pangasius (a catfish genus native to Southeast Asia) production may range from 150,000-300,000 kg/ha with ponds producing two crops per year.

The frequency of production creates an advantage to farmers as it allows them to more accurately scale production to market demands. For example, in a low demand season where feed prices are high and sale prices are low, farmers are able reduce production to just meet market obligations. With the short production cycle, if the market improves, farmers are able to increase production and harvest fish within six months. Pangasius ponds are set up in small, deep units typically ranging from 0.2 to 1.25 ha in area with a depth of 2.5 m to 5 m. Smaller, deeper ponds result in more manageable and controllable units and a large volume per land ratio. The key to Vietnamese success is water exchange, using the local river system since aeration is not standard in Vietnamese finfish production. On the contrary, in shrimp culture or other species where water exchange is less frequent, high levels of aeration are standard.

1.2 Market of Catfish Aquaculture in Southeast US

Farm raised catfish is the most significant area of aquaculture in the United States with sales of approximately 500 M US dollars (USDA, 2013). Mississippi, Alabama, Arkansas, and Texas produce 95% of all farmed catfish in the US (USDA 2013). Despite the success of previous years, since the 2000's catfish market sales have declined due to competing imports and increased feed prices as a result of ethanol production (Figure 1.2).

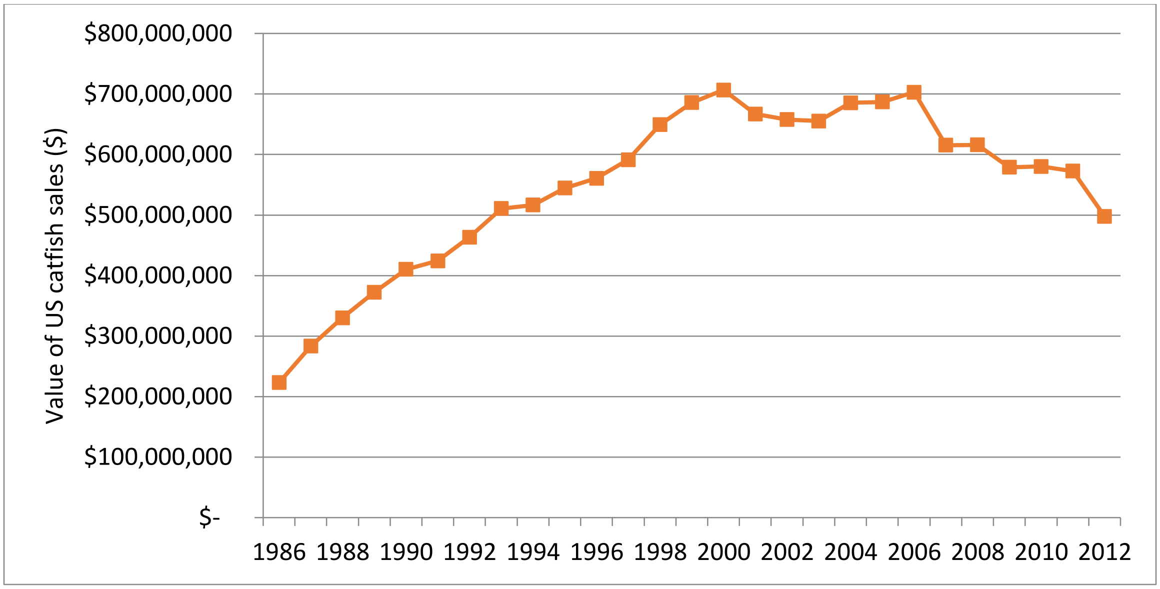


Figure 1.2 Value of catfish sales from US processors (USDA, 2013).

Since 2003, 50% of the catfish market value has been lost (USDA, 2013). Many catfish farmers fail to gauge production in order to meet market demands in terms of both quantity and quality. As a result, the industry often produces either an excess or shortage of product. In the case of an oversupply, the market price often drops below the cost of production (Courtwright, 2013). During periods of price volatility, many farmers often question restocking and make short-term decision, abandoning long-term improvements. If there is not enough fish to meet market demand, the shortage may appear beneficial for the farmers as the price increases, but there is a negative result for the industry and overall market. Customer satisfaction can significantly decline during a shortage, because prices rise and demand is not being met. The 2013 industry summary clearly shows the volatility in price where the price ranged from $1.80 per kg to $2.45 per kg for live fish (Hanson, 2014). This level of volatility in the market results in uncertainty for many US producers as they are unsure of the quantity of foodfish biomass to produce. If farms were able to consistently shorten production cycle, the farmer could better adjust production to meet market demand.

1.2.1 Stocking

In the catfish industry, there are two distinct production phases: fingerling production and foodfish production. The term fingerling refers to very small fish, usually up to one year of age. Fingerlings are usually hatched at a commercial hatchery (nursery) then, within a few days, transferred into an open pond. The small fish are carefully managed and given specific feeding regimens in terms of nutrition and feeding portions. While hatching and raising fingerlings occurs in many places across the US, there is a regional concentration of commercial hatcheries and fingerling producers in the Mississippi Delta. The Mississippi Delta allows farmers to remain relatively close to customers for easy transportation of fingerlings while having ample access to fresh well water. Fingerlings grow 12.7 to 20.3 cm in length before being sold to a foodfish producer. The size of the fingerlings is important, because size significantly affects how long it will take the foodfish producer to raise the fish to foodfish or market size, 0.68 kg. Once the fish reaches market size, it will be sold to a catfish processer.

Larger fingerlings are often considered favorable, because they require a shorter production cycle, which over several years will allow the farmer to produce more crops. However, larger fingerlings also come at a higher price. Many farmers therefore buy smaller fingerlings, in hopes of reducing the overall cost by cutting down on the percentage of the final crop that will be paid to fingerling producers. The condition of the fingerlings can be critical, because fish in poor condition will likely get sick during transportation or while being acclimated to their new environment. If fish are sick, the foodfish farmer will experience loss, through either fish mortalities or reduced growth.

1.2.2 Aeration

Fish metabolism is significantly affected by temperature. Generally, fish's metabolism increases with an increase in temperature. The increased metabolism causes fish to consume more feed in the warm summer months, in contrast to cold winter months when fish become relatively dormant as their metabolism slows. Consequently, during colder months fish are less sensitive to being handled, therefore, colder months are the ideal time to handle (i.e., move and transport) fish.

During summer months, the fish are fed heavily due to their increased metabolism, yet they retain only a portion of the feed (approximately 40%). The remains are either left uneaten or are excreted by the fish into the water. In the presence of sunlight during the daytime, soluble nutrients stimulate photosynthesis production and algae growth. The growth of algae and increased photosynthesis leads to daytime oxygen levels above saturation in pond waters. During the daytime oxygen levels can rise above the saturation point of water (approximately 8 mg/L for warm fresh water) reaching as high as 20 mg/L, at which time large amounts of oxygen diffuse into the atmosphere. During the night, there is no oxygen production from the algae because there is no sunlight to stimulate photosynthesis. Nevertheless, at night the organisms are still respiring and using oxygen which results in low levels of dissolved oxygen (DO) in the water. If the low nighttime DO levels are not treated with aeration, oxygen levels could easily decrease to below 1 mg/L causing the fish to stress, become sick, or even die. The cycle of day to nighttime oxygen levels is known as the diel cycle, or daily cycle, similar to a sine function with daytime maximum and late-night minimum DO levels (Figure 1.3). The daily DO range increases with increased feed. This nighttime respiration includes fish, plankton in the water column, and bacteria at the soil water interface. The majority of this respiration comes from the water column (Steeby, 2003).

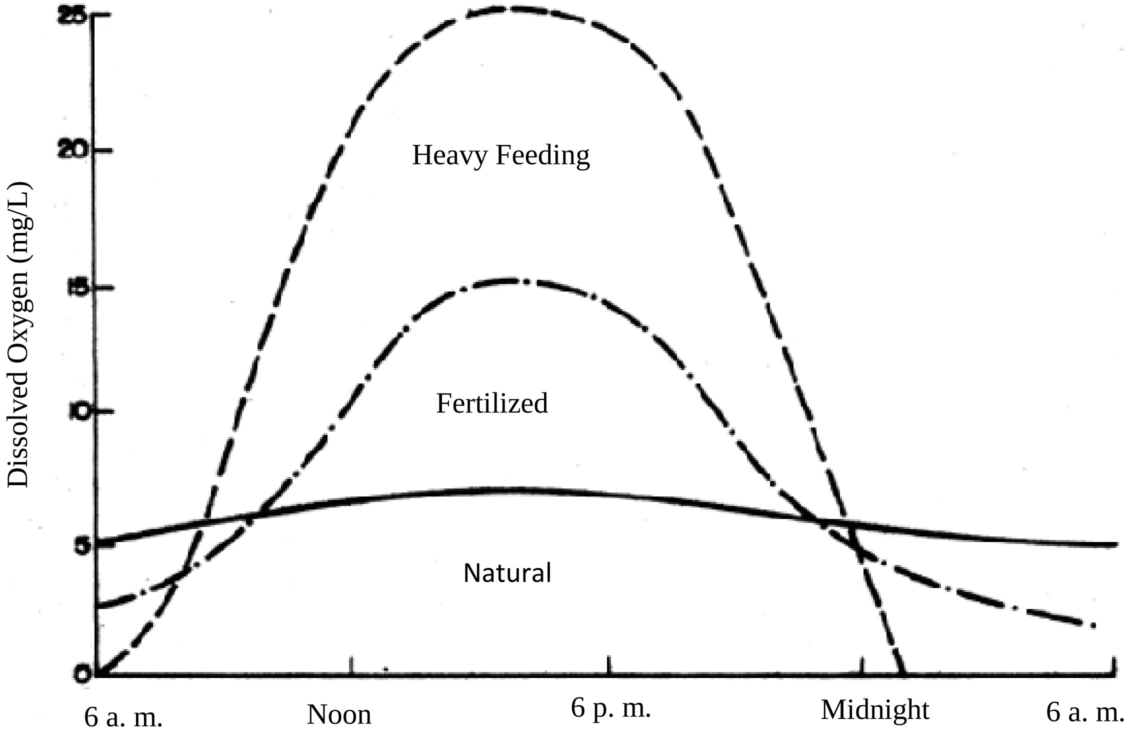


Figure 1.3 Daily oxygen cycle (modified from FAO, 2015).

During colder weather, feeding is required less frequently and because the oxygen saturation point rises in colder water maintaining adequate oxygen levels are much less of a concern during winter months.

1.2.3 Pond Development

The US catfish industry rose in the 1970s and 80s in the Southeast with catfish being raised in large 9 ha earthen levee ponds first with fertilizers then eventually with small amounts of feed added. Over the years, feeding has increased greatly. Since the 1990's more emergency aeration has been needed due to the diel cycle. By the 2000s, paddlewheel aeration at night became standard during warmer production months. Today, many catfish famers in Southeastern US use the same large ponds from the 1970s and 80s or adaptations of these large ponds divided into several smaller ponds. With increased global competition and increasing feed prices, several additional large-scale changes are needed by the foodfish farmer to become more competitive globally.

1. Consistent product aimed at market needs
2. Decrease time to produce a crop of foodfish
3. Reduce cost either by increasing feed efficiency or decreasing overhead per unit

1.2.4 Experimental Systems

Channel catfish (*Ictalurus punctatus*) have historically been the primary culture species in the US catfish industry. By the 1970s, hybrid catfish demonstrated significantly faster growth than channel catfish (Yant et al., 1975, Chappell, 1979). Even with recent improvements in hatching hybrid fry, less than 5% of west Alabama farmers have switched to hybrid only production (Courtwright, 2013). Traditionally catfish are raised in open ponds where the fish are not confined. On the other hand, catfish can be raising in in-pond raceways systems which confine fish to a small area partition of the pond and move the pond water through the raceway.

In addition to species improvements, new in-pond raceway technology provides the potential to improve the catfish industry. In-pond raceways provide a means to contain the fish, and therefore allow the farmer to more easily manage the crop. In-pond raceways also offer the benefits of tank culture including recirculating flow and treatment, precise application of inputs such as feed, chemicals, and aeration, improved record keeping, and increased visual confirmation of inventory. In-pond raceway technology also utilizes much of the existing pond infrastructure making it easy for farmers to implement.

For over 20 years, paddlewheel aeration has been the standard practice for aeration in aquaculture. In the present study floating in-pond raceway technology, newly developed diffused air hoods and mixing equipment from SN airflow (Greenville, MS) used in wastewater lagoons will be evaluated as commercial methods to manage dissolved oxygen. The diffused air hood evaluated in this study is an adaptation of Auburn University's current floating in-pond raceway water exchange and aeration system. The SN airflow equipment operates theoretically by moving supersaturated top water into the oxygen deficient bottom layer of the water column.

Over the past ten years, rebuilt ponds have tended to be deeper. Deeper ponds are expected to benefit most from mixing since they have a lower surface area to volume ratio, and the oxygen from photosynthesis stratifies in the first meter of the water column. Hybrid catfish have higher feeding rates with subsequently higher waste loading and plankton production than channel catfish used previously by the industry. Consequently, the trend is towards deeper ponds, hybrid catfish, and higher nutrient loading all of which combined requires a re-evaluation of current aeration/mixing methods in catfish pond culture.

1.2.5 Thesis organization

This thesis is divided into five main sections. The first chapter introduces US catfish farming and some of its challenges. The second chapter reviews literature on oxygen dynamics, effects of various DO levels on production, intensive fish farming in Southeast Asia, US catfish farming, and alternative intensive pond systems. The third chapter describes the commercial farms of this study and the research setup on each farm. The third chapter also details how fish production is accomplished and what data was collected. In addition, the third chapter describes how results were calculated. Chapter four presents results of fish production and water quality at each farm. Calculated analysis of production, DO dynamics, and enterprise budgets for each farm setup are also presented in chapter four. Chapter five provides the summary of results from these two intensive farm case studies and recommendations for future research.

1.2.6 Research Goals and Objectives

The overall goal of this research is to evaluate the economic returns and production of two commercial catfish operations under traditional paddlewheel and experimental systems of oxygen management, as follows.

- Compare and contrast the profitability of three oxygen management systems in ten conventional open ponds growing hybrids in a Mississippi Delta farm.

- Evaluate the profitability of four prototype floating in-pond raceway cells stocked with channel and hybrid catfish in two ponds in a west Alabama farm.

Research objectives are presented below as a function of the two culture systems studied, in-pond raceways and open pond systems.

In-pond Raceways

1. Determine if daily minimum DO levels averaged above 3 mg/L.
2. Show whether an experimental 0.8 cells/ha in-pond raceway setup was profitable.
3. Show whether a projected 2.43 cells/ha in-pond raceway setup was profitable.

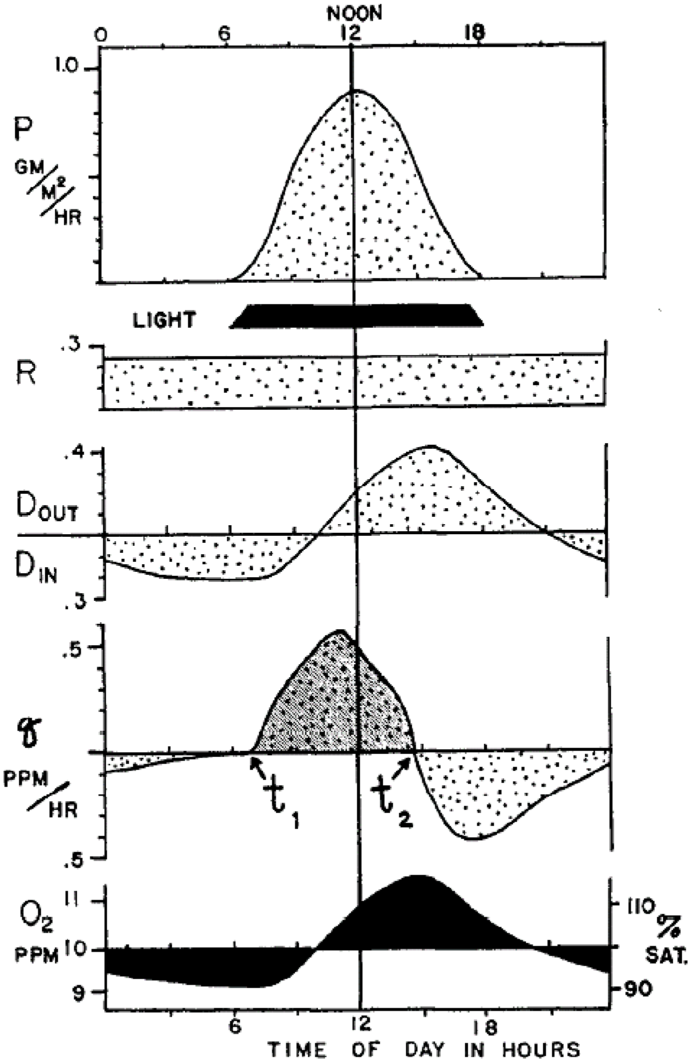
Open Ponds

1. Determine if daily minimum DO levels averaged above 3 mg/L.
2. Evaluate whether higher levels of oxygen management (kW/ha) increased fish production (kg/ha).
3. Evaluate whether higher oxygen management (kW/ha) raised net profits ($/ha).
4. Evaluate whether the observed pond respiration rate increased with increased feeding.

Chapter 2 Literature Review

2.1 Oxygen Cycle

Odum (1956) studied oxygen cycle changes in streams. He accomplished this by placing two DO probes in a stream a known distance apart while monitoring the flow rate of the stream. He was able to calculate the changes in oxygen. Changes in oxygen are dependent on oxygen production, diffusion (natural, forced, and aeration), and respiration rate (Odum, 1956). Oxygen production (P) is dependent on sunlight and therefore increases in the early morning and later in the afternoon and decreases at night as sunlight decreases and shown at the top of Figure 2.1. Respiration rate (R) is considered relatively constant throughout the day and shown second on Figure 2.1. Natural diffusion (D) mirrors dissolved oxygen content and approaches zero near dissolved oxygen saturation as shown on the third item on Figure 2.1. The overall rate of change (q) is sum of oxygen production (P), respiration (R), and oxygen diffusion (D) as shown below (Figure 2.1). The actual dissolved oxygen concentration (O_2) could be calculated as the area under the curve of the rate of change in DO but is usually measured experimentally and can be used to solve the rates of change (Figure 2.1). Oxygen production is not a factor during the night. This fact makes the rate of overall change approach the respiration rate when diffusion is small at night. The magnitudes of the DO curves would be expected to be different for aquaculture ponds that are more heavily loaded with organic matter than the streams studied by Odum (1956), however the concept is similar.



P=Production of Oxygen
R=Respiration
D=Diffusion
q=Net Rate of Change in Oxygen
O_2=Oxygen Concentration
Figure 2.1 Functions controlling oxygen levels (Odum, 1956).

2.2 Circulation and Stratification

Typically, on a warm summer day maximum stratification occurs around 3 pm (Szyper, 1990). Oxygen stratification has been shown to correlate with temperature stratification on a day-to-day basis (Losordo, 1991). This is positive for pond management because if temperature is used to indicate stratification, the water column can be more easily managed for oxygen stratification. The timing of oxygen and temperature stratification is not always regular, however. Sometimes oxygen stratification occurs simultaneously with temperature stratification, and at other times, oxygen stratification occurs after temperature stratification (Losordo, 1991). The typical distribution of water temperatures with pond depths are seen in Figure 2.2 below.

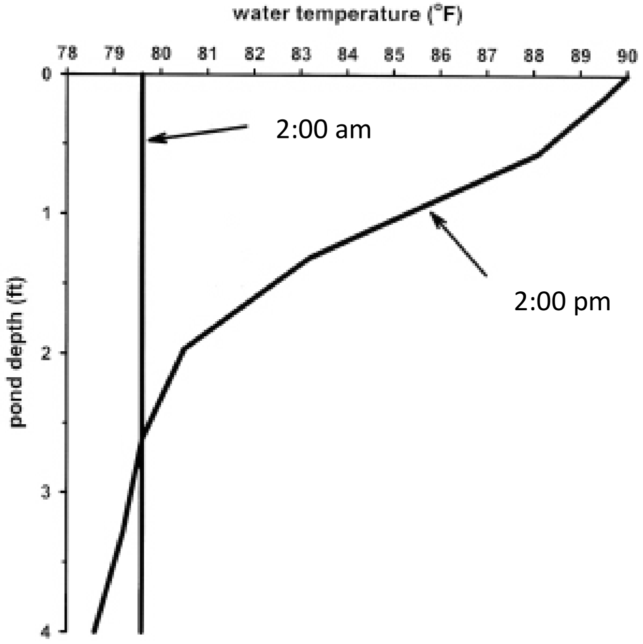


Figure 2.2 Temperature differences during day and night (Hargreaves, 2003).

As early as the 1950's circulation was shown to restore favorable oxygen profiles in stratified lakes with effects observable in less than 5 hours (Schmitz et al, 1958). Lake remediation attempts have shown mixing to increase the DO in intermediate and bottom water levels, while also reducing ammonia and BOD (Toetz, 1979). Even in wastewater lagoons that do not have enough mixing equipment for complete mixing to keep solids suspended, hydrodynamics is one of the most important parameters in controlling lagoon effectiveness (Nameche et al, 1998). In aquaculture plankton are only productive near the top of the water column where light penetrates. This can cause daytime stratified oxygen layers in the upper levels of the water column with above saturation oxygen content and bottom levels of the water column at low levels of oxygen (less than 3 mg/L). Under the stratified conditions, the soil water interface is at near anaerobic conditions (Steeby et al., 2004). For

US catfish ponds, the standard paddlewheel aerator (7.5 kW) is capable of moving approximately 0.6 m^3/s of water (Tucker, 2009). Most aquaculture ponds experience daily stratification and destratification during nighttime aeration (Hargreaves, 2003). Mixing in catfish ponds has potential benefits to reduce stratification during the day.

The degree of stratification (both temperature and oxygen) in a pond is dependent on sunlight, turbidity, and wind speed. In summer months, increased solar energy can increase the amount of stratification, while wind mixes and helps destratify the ponds. Szyper (1990) showed that the mixing equipment does not have to be capable of turning over the entire pond in one day, nor is constant running during photosynthesis production required to see water quality improvements.

Water mixing can occur by moving the water vertically, horizontally, or any angle in between. Super-saturation of top waters has been shown to occur over more than half of observed days during testing by Tucker et al. (1995) where daytime horizontal mixing has been shown to reduce nighttime aeration needs by nearly half (Tucker et al., 1995). Daytime mixing theoretically allows supersaturated upper levels of the water column to be mixed with oxygen deficient bottom of the water column for use later in the night. Increasing DO and waste load homogony in the water column theoretically may allow waste to be managed throughout the day to reduce waste accumulation and risk of oxygen stress. Mixing stratified lakes has been shown to decrease the BOD (Toez, 1979). Increasing contact with oxygen and waste is expected to increase the waste load capacity of the pond and lead to higher levels of production (Chappell personal conversation). Fish have a tendency to occupy the areas of the pond with the best water quality, so distributing the oxygen through deeper water levels theoretically increases the habitable volume of the pond if all other conditions were equal (Szyper et al., 1990). Mixing has been shown to increase DO concentration from less than 1 to greater than 4 mg/L at bottom levels of the water column. This increase helps reduce stress if fish are occupying this area of the water column.

A single 2 hour mixing treatment was compared with two 1 hour mixing treatments in tropical tilapia ponds (Syzper et al, 1990). The two 1 hour mixing treatments were shown to better reduce stratification and improve DO levels. However previous testing has shown mixing equipment to be economically neutral or uneconomical

(Tucker, 1995). Tucker (1995) believed that increasing the depth of the pond would increase the viability of commercial pond mixing because mixing would increase habitable volume for the fish and increase the volume that could “store” oxygen. Boyd (2006) suggested that two types of mixing equipment showed the most promise, air-lift pumps and mechanical horizontal circulators. He went on to say that despite lack of “convincing evidence of the benefits of water circulators… [they] appear worthy of a second round of scientific investigation and farm trials (Boyd, 2006).”

2.3 Pond Aeration and DO

Pond aquaculture is the dominant form of warm water fish production and DO is the most common limiting factor in pond production (Egna and Boyd, 1997). This means that aeration equipment sizing can be one of the most important factors affecting production. Before nightly aeration became standard practice beyond emergency situations, Boyd (1978) published a function that predicted hourly DO based on information about conditions at dusk, plankton population, and fish biomass (Equation 2.1).

$$DO_T = DO_{dusk} \pm DO_{diffusion} - DO_{Fish} - DO_{water\ column} - DO_{mud} \qquad \text{(Equation 2.1)}$$

Boyd (1978) found that the oxygen consumption of the water column was predictable based on measured Secchi disk turbidity and temperature. Meaning that oxygen consumption of the water column was related to plankton concentrations and temperature. Oxygen consumption by the water column was found to be the controlling factor accounting for 70 to 85% of the total pond respiration depending on sunlight conditions and time of year. The formula was tested against experimental pond oxygen levels and determined to be reliable and able to predict dawn DO levels within 10% using the dusk DO. (Boyd et al., 1978).

Boyd hypothesized through calculated respiration rates of fish and oxygen plus aeration that adding one kW of aeration should increase the carrying capacity of a pond by 500 kg of foodfish (assumed SAE of 1.5 kg O_2/kwh and DO of 4 mg/L). Increasing nightly minimum DO has been shown to positively affect fish growth, FCR, pond turbidity, and nitrification (Torrans, 2008). Overall growth rate has been shown to increase with increased

DO minimum of up to 5 mg/L for channel catfish, however that does not mean it is the most economical (Torrans, 2008).

Catfish have been shown to be affected by not just nighttime low DO levels but also by the length of exposure. Green (2012) studied length of exposure to hybrid catfish and derived the unit DO-minutes to best illustrate this variable. Green (2012) advised that high DO (48% of oxygen saturation) be maintained during the summer months and a slightly lower DO (36% of oxygen saturation) be maintained during the rest of the season. The reason for this recommendation is that a linear relationship between minimum DO and feed consumption (normalized to percent of body weight) was observed above 25C (Figure 2.13 A). This relationship change at 25C was also observed by change in feeding habits at 25C (Arguello, 2011). Below the 25C threshold, diminished returns on aeration were observed in terms of feed consumption (Green, 2012). Feeding rate during the hottest summer months was linearly related to DO percent of saturation for the range of oxygen concentrations observed (Figure 2.3). However, when the entire season was studied the same relationship was exponential with decreases in slope between 36% and 48% of oxygen saturation (Figure 2.3 B). Figure 2.3 indicates that it is of additional importance to manage DO during hot weather and high feeding. These graphs also show that for the tested setups (minimum DO@12%, 24%, 36%, and 48% saturation) increasing DO corresponded to increased daily feeding (% biomass) (Figure 2.3).

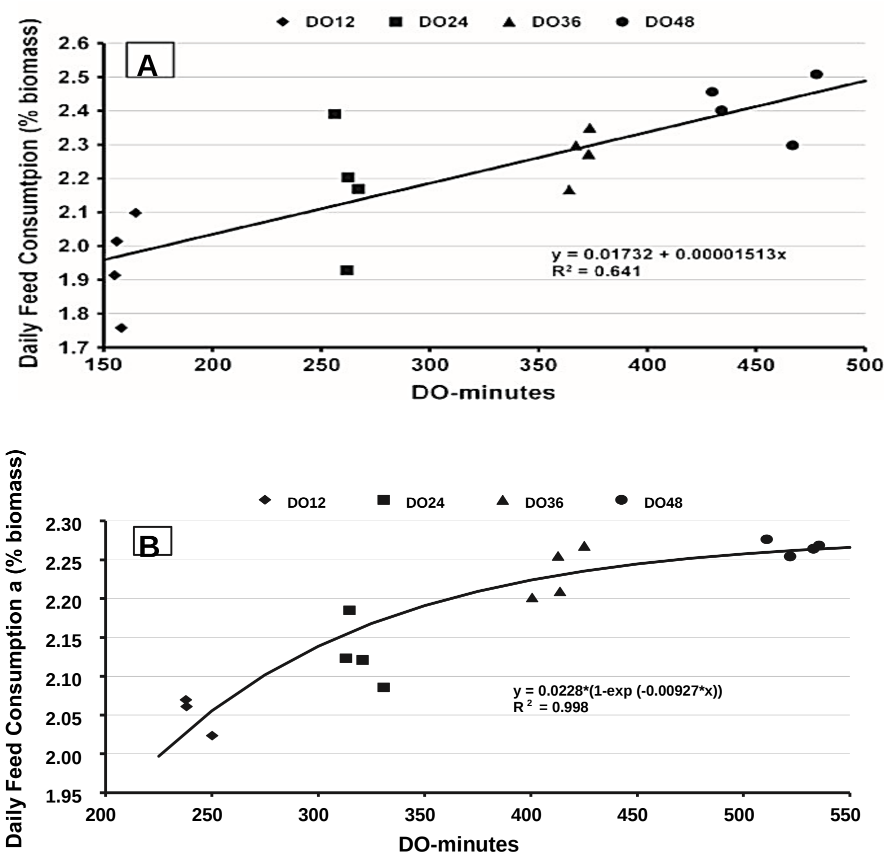


Figure 2.3 DO-minutes versus feed consumption (Green, 2012). Note: Mean daily feed consumption (% biomass/d) for the period 16 June–16 August (A) and 1 May–10 October (B) in relation to the mean DO-minutes from 0400 to 0600 h nightly (Green, 2012).

Previous studies with catfish have not shown any increase in pond culture production using continuous aeration versus nightly aeration (Boyd, 1991). Results could change if biomass and the waste load increases drastically in which case continuous aeration is expected to be beneficial for maintaining additional bacterial concentrations above what the pond can naturally support (plankton production). This method of increasing aerator run times is standard practice for increasing the waste capacity of wastewater lagoons when bacteria load necessary to process waste is higher than supportable by plankton production (Metcalf and Eddy, 1991). In wastewater lagoons if the oxygen produced by algae and transferred by diffusion is not enough to sustain a bacteria population to manage a given waste load, aeration is added (Metcalf and Eddy, 1991). However, if a large percentage of oxygen is lost to diffusion during plankton production and super saturation, then homogenous mixing of the water column theoretically could supply oxygen-to-oxygen deficient layers of the water column.

Tests on the level of waste accumulation in catfish aquaculture primarily focus on the soil and water interface at the pond bottom. It is believed that the sediment oxygen demand (SOD) is not met during the production season when biomass loading is the highest and oxygen availability is lowest (Steeby et al, 2004). This deficiency in oxygen leads to a latent oxygen demand, which can be dangerous to the fish (Steeby et al, 2004). The steady increase in waste accumulation indicates that current commercial aeration practices are not sufficient to manage the long-term waste load applied by fish feed to catfish ponds (Steeby et al, 2004). Boyd (2004) suggested that the easiest way to determine if the waste assimilation capacity of a commercial pond is sufficient is to determine the feeding rate at which aeration is able to keep the early morning minimum above 3 to 4 mg/L.

Another method to estimate waste management in photosynthesis-dominated systems was proposed in 1956 by Odum. He proposed looking at the oxygen curves in streams to calculate rates of production, respiration, and diffusion and suggested a theoretical model to better understand the oxygen dynamics of streams. In his model, photosynthesis production is visualized as a bell shaped curve that is always positive and peaks around the middle of the sunlight period. Respiration is seen as a relatively constant consumption rate. The rate of natural diffusion between air and water is strongly related to percent oxygen saturation. If the oxygen concentration is above supersaturation, then oxygen is leaving the water column into the air and rate increases the further the concentration is from saturation. Likewise, natural diffusion is into the water below saturation and increases the further the concentration is from saturation. The total oxygen transfer rate is calculated as the sum of production, respiration, and diffusion. One of the reasons for developing this method was the focus on light-dark bottle experiments in the water column of planktonic communities that did not include bottom level interactions. Odum noted that near saturation diffusion is negligible (1953). To account for water flow in Odom's (1953) tests, two probes were used and the distance between locations and the flow rate of the river were used to determine water quality changes over time. Kelly (1975) used this method and considered bodies of water with respiration rates higher than production rates to be eutrophic. Whole pond respiration has been calculated using nightly DO monitoring system data and calculating the linear regression of the slope (Hargreaves et al. 1999). This method estimated respiration during the night including the extremes (far from saturation) and did not account for diffusion (Hargreaves et al. 1999). Hargreaves (1999) confirmed that respiration was shown to be related to feeding rate.

2.4 Southeast Asia Intensive Aquaculture

International aquaculture typically is able to achieve higher levels of production than US catfish culture. Due to regulations, temperature, and different comparative advantages it is not possible to duplicate all international culture methods. However, it is important to note how other countries raise fish, how high loads are sustained, and what is their cost structure. Answers to these questions could leverage local comparative advantages to help make US catfish culture more competitive. In Southeast Asian shrimp ponds, it was determined that feeding rate per aeration was inversely related to the dissolved oxygen concentration at dawn (Figure 2.4) (Hopkins et al., 1991). A similar relationship could be developed for catfish but may be specific to the species of fish cultured and the type of feed fed.

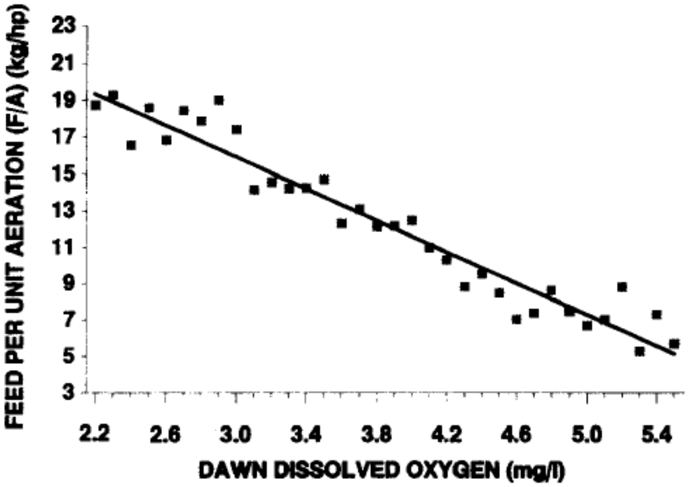


Figure 2.4 Feed per unit of aeration versus DO for shrimp in Southeast Asia (Hopkins et al., 1991).

If minimum DO is assumed to be 3 mg/L, then the relationship below applies (Equation 2.2) (Hopkins et al., 1991).

$$Average\ daily\ feed\ for\ shrimp(kg) \Big/ Aeration\ (kW) = 21 \qquad \text{Equation 2.2}$$

For these trials by Hopkins et al. (1991) 40% protein feed was used, which is well above the catfish industry standard of 28% or 32% protein feed (Courtwright, 2013). Since the US catfish industry uses a lower protein feed than shrimp, it is likely the catfish feed to aeration ratio is higher for shrimp. It is important to note that Southeast Asian shrimp culture is different from catfish in that intensive aeration is run continuously for shrimp, which are restricted to the bottom of the water column and cannot freely swim to the water level that contains the best water quality. Running paddlewheel aeration during the daytime may not provide aeration depending on phytoplankton and bacteria concentrations.

Vietnam currently stands as one of the largest aquaculture countries in the world producing over three million metric tons of seafood in 2012 (VASEP, 2013). As early as 1997, cage culture of pangasius was reported at levels near 80 kg/m^3 per crop with the ability to produce a crop in less than a year (Lazard, 1997). Almost twenty years later many US catfish farms had not yet reached even 1 kg/m^3 (Courtwright, 2013). In the 2000s, pangasius farms in Vietnam had switched to deeper ponds with a smaller area (Phan, 2009). This setup is very different from US culture, which traditionally uses a much higher surface area to volume ratio. Production in Vietnam averaged 400,000 kg/ha per crop (Phan, 2009). This level is several orders of magnitude greater than traditional US catfish culture, which averages at 7,000 kg/ha in its current state (Courtwright, 2013). Production in Vietnam is achieved by extremely high levels of water exchange up to twice a day, with feeding twice a day up to as much as six times a day. Feeding in Vietnam likely has an impact on feed conversion ratio (FCR) which averages 1.7 US catfish culture could benefit from additional feedings per day, but increased number of feedings would incur a significant cost as the surface area of ponds in the US are may be 10 to 20 times higher than pangasius ponds. In order to sustain pangasius' high level of production in Vietnam, pond bottoms are limed, sludge is removed, and fingerlings are tested for uniformity and disease. Most importantly, the cost of production for pangasius in Vietnam averaged $0.89/kg compared to $2.40/kg for US catfish. Reducing the cost of production ($/kg) is necessary if US producers are to become competitive in global markets.

Summary of major differences between domestic catfish farming:

- Use higher protein feed (especially shrimp culture)
- Continuous aeration (especially shrimp culture)
- Regular Water Exchange (especially pangasius)
- Multiple feedings per day (Up to 6 a day for pangasius)
- Small area, larger depths (especially pangasius)

2.5 Domestic Aquaculture

Courtwright (2013) sent surveys to all of the know catfish farms in Alabama for the years 2010 and 2011. Results indicated that only 59% of catfish farms in west Alabama were profitable (Courtwright, 2013). Long term this low profitability will change by farms either becoming more economic efficient or going out of business. After surveying 70% of Alabama farmers, Courtwright made four suggestions for the industry. The first was switching to single batch or a type of intensive production system that allows different size classes to be kept separate. Multibatch ponds showed increased problems with off-flavor, higher FCR, and less uniform size. The second recommendation was to switch to a 32% protein feed versus a 28% protein feed. This recommendation showed a high correlation to profit (Courtwright, 2013). Thirdly, alkalinity was shown by Courtwright (2013) to be an important water quality and was recommended to be above 115 mg/L for production. Lastly Courtwright (2013) recommended increasing aeration from the industry average of 6 kW/ha to 11 kW/ha and above. Aeration was observed to have a strong diminishing effect on off-flavor, yellow fillet, and a strong positive effect on production, and most importantly profit. This survey indicated the need to determine the level of aeration at which farm economic returns begin to diminish.

The trend in aeration versus production for US catfish has an unknown diminishing return and increases up to at least 11 kW/ha (Torrans, 2005). This shows the need for testing aeration levels well above this level to better understand at what level diminished returns are observed. Tests of channel catfish production at different oxygen levels showed a production of 23,000 kg/ha, when minimum DO was above 4 mg/L test versus 10,000 kg/ha when a minimum DO was maintained above 1.5 mg/L (Torrans, 2005). Torrans's test shows the large effect that aeration can play on pond production as well as the need for further studies at the commercial scale. The current industry production average is approximately 6,000 kg/ha (Courtwright, 2013). Torrans did not expect this level of production to translate to the directly into the same 24,000 kg/ha in commercial ponds (Torrans, 2005) because the study took place in 0.1 ha research ponds that were relatively easy to manage. This study also showed that it required 160% more energy to maintain above 4 mg/L versus above 2 mg/L.

Hybrid catfish culture in the Southeast consequently benefits greatly from higher aeration. In an on farm evaluation of hybrid catfish conducted over three years, one farmer was able to consistently produce 14,000 kg/ha in ponds with aeration rates near 18 kW/ha (Hanson et al., 2015). One pond was managed according to farmer stocking and feeding preference while the other two were managed according to Alabama Extension recommendations. The extension recommendations were a stocking rate of no more than 16,000 fish/ha. The recommendations also had fish feed 90% of saturation with a maximum feeding rate of 360 kg/ha/day. The pond managed according to farmer preference (no daily feeding cap) surprisingly yielded the best results with a cost of production of $1.50 per kg of fish. This indicates that extension recommendations may need to be updated for hybrids under intensive aeration. It should be noted that the farmer in this study was using hybrids and provided aeration near 17 kW/ha, which was well above the industry average. Feed conversion was also likely important as it was 1.8, well below the US catfish industry average of 2.3 (Courtwright, 2013).

In testing hybrid catfish at two widely different stocking densities (12,000 head/ha and 48,000 head/ha), Torrans (2015) was able to show that survival and FCR was not affected by stocking density as long as adequate aeration was provided. Aeration equipment in his study was sized at 18kW/ha. The difference in production was 11,000 and 30,000 kg/ha, respectively, while the difference in aeration cost was less than two cents per kg of fish.

2.6 Intensification Systems

There are several reasons to intensify aquaculture production (Avnimelech, 2006):

- Water Constraints (environmental regulations, biosecurity concerns, or water scarcity)
- Better Quality Control
- Higher Feed Conversion
- Better Temperature Control
- Land and Labor savings

Higher capital and operating costs for intensive systems result in systems that are not always profitable (Avnimelech, 2006). In a traditional pond with ample nightly aeration, production level of nearly 20,000 kg/ha (depending on the species) is achievable (Avnimelech, 2006). At this production nitrogen based water quality parameters become limiting. Although aeration and mixing 24 hours a day can raise production levels above supplemental aerating for fish and shrimp raised at or above 20,000 kg/ha, ammonia and nitrite can still become a problem (Avnimelech, 2006). The main options for dealing with water quality problems associated with high loads are to replace existing water with fresh water (Avnimelech, 2006). Examples of such exchange are pangasius culture in Vietnam, trout flow systems in the US, external biofilter unit water recycling systems, or within-pond treatment such as algal systems or bacteria suspension. Bio filters in particular have been used for many years in nurseries, hatcheries, ornamental fish, and sometimes commodity fish, but can be extremely costly (Avnimelech, 2006).

The Partition Aquaculture System (PAS) developed at Clemson University was designed without a traditional pond structure in order to maximize the treatment potential of algae (Brune, 2003). Small 0.14 ha ponds were designed to separate fish from the pond to maximize use of the water as waste treatment (Figure 2.5). The shallow depth of the treatment area, mixing rate, and baffles in the PAS system were designed to increase algal productivity. Algae remove soluble nutrients in the water column from fish waste and allow tilapia to be grown without supplemental feed by grazing on natural food in the water column. Catfish in the PAS system are confined so that nightly aeration can be applied directly and solid waste can be removed by settling at the end of fish confinement area.

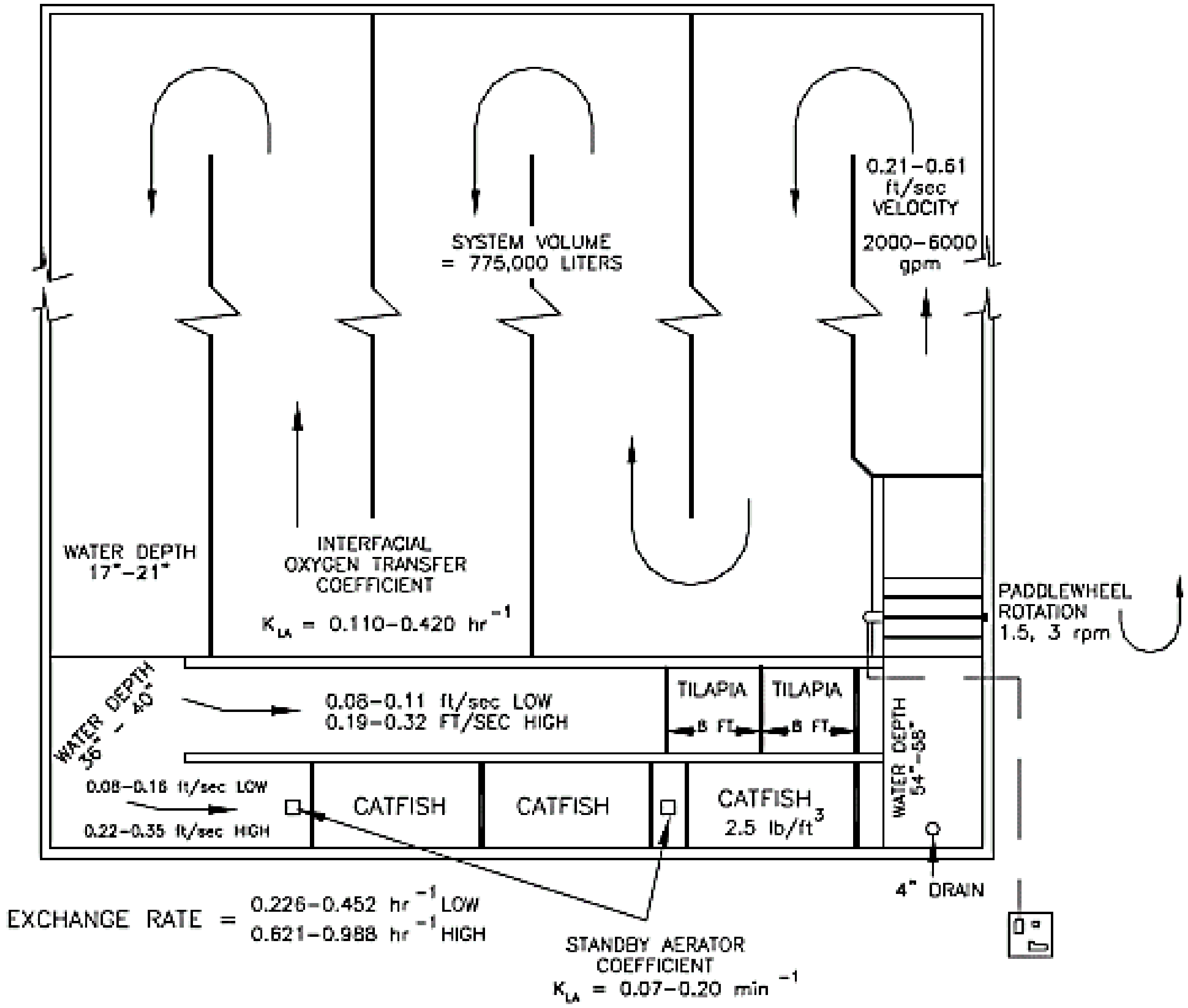


Figure 2.5 Flow diagram of partitioned aquaculture system (PAS) (Brune, 2003).

The PAS system demonstrated that increased water movement through a shallow racetrack increased photosynthesis production (Brune et al., 2003) (Figure 2.5). The system demonstrated nearly 18,000 kg per ha net production of channel catfish. The more commonly used in-pond raceways (Figure 2.6) developed by Auburn University and the split pond systems (Figure 2.7) developed by Mississippi State University incorporate several aspects of the PAS system in an existing pond structure design.

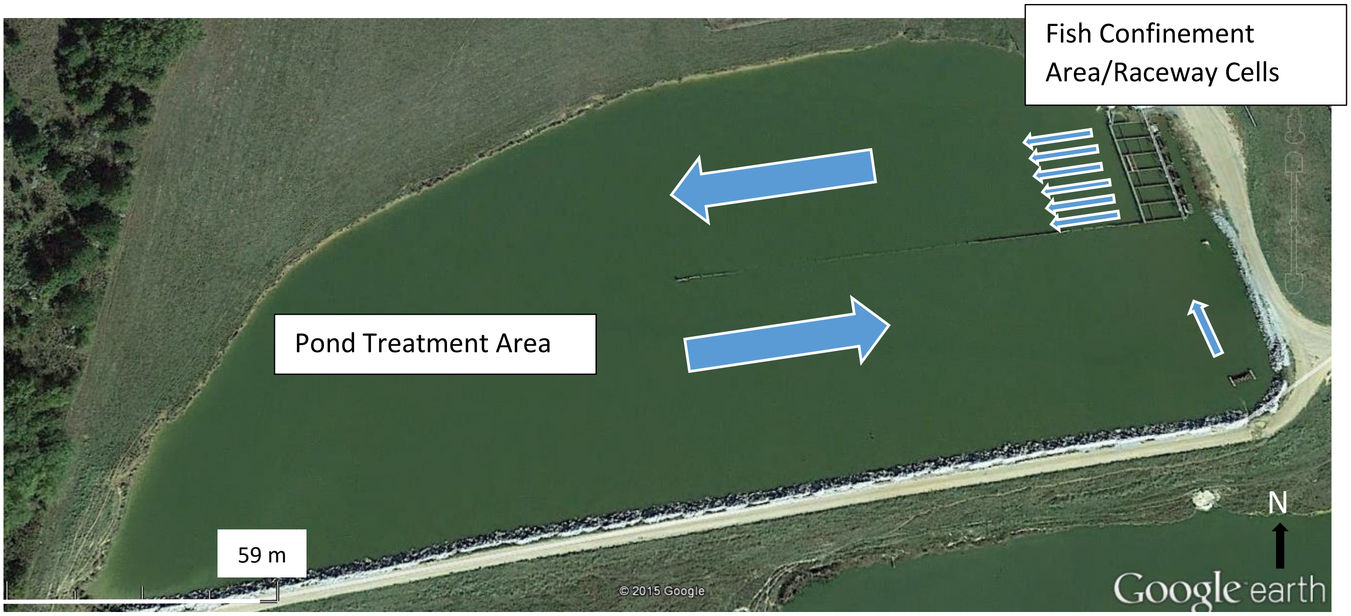


Figure 2.6 Concrete in-pond raceway setup and flow (Dean Wilson Farms, Dallas County Alabama).

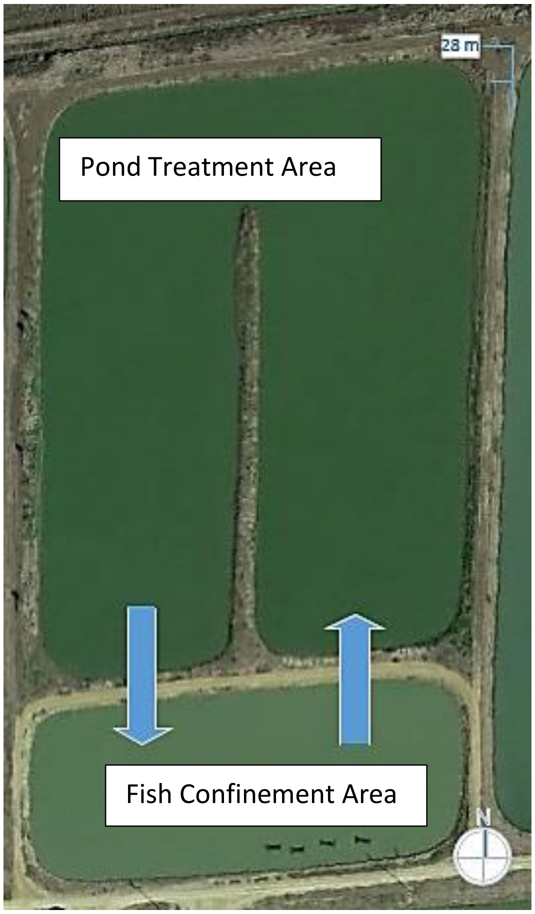


Figure 2.7 Split ponds water flow pattern (Mississippi Delta).

The basic elements of each system are water movement, fish confinement, partial waste separation, settling or extraction, and co-culturing tilapia (Brune et al. 2012). The purpose of these elements is to design the system beforehand to treat water rather than reacting to problems as they occur. The tilapia in the PAS also provides water quality management by reducing the mean age of algal populations from 20 days to 3 days. Reduced algal age lead to high photosynthetic production and waste treatment. The advantage of properly designed poly-culture is that it may increase the waste assimilation capacity of the system with a fish byproduct that can be valuable. The confinement of the cultured species in a PAS type system makes aeration, disease treatment, harvesting, and inventorying more effective (Brown, 2011). These intensification techniques show long-term promise for improving aquaculture.

The four main aspects of Brune's partitioned aquaculture system can be partially seen in the pond adaptions of Auburn University's In-pond raceways and Stoneville's (Mississippi) split pond (Brune et al. 2012):

- Slow rotating paddlewheel
- Fish confinement area
- Settling sump
- Tilapia species

While not all of these four elements from PAS are visible in the Auburn and Mississippi systems, the functionality of these systems is apparent in the following:

- Pond circulation and water quality management
- Precise application of DO and treatments
- Preventative waste management
- Plankton management

Mixing or circulation of pond waters requires management as an important part of the PAS and is believed by numerous researchers as the best way to maximize daytime photosynthesis and enhance water quality (oxygen and nitrogen based water quality parameters) (Hargreaves 2003). Although raceways and split ponds are different systems, many of the functional components are similar, and therefore are useful to compare performance and design considerations. In split-pond systems, it is important to use hybrid catfish (Tucker et al., 2015) because hybrids have superior growth and survival and if the producer is going to spend the time and money to construct an intensive system it makes sense to use the best available fish. According to Brune et al. (2015), maximum production appears to be equal to that of the most productive PAS systems or approximately 22,000 kg/ha. In these intensive systems, photosynthesis provides approximately half of the fish's oxygen demand. According to Brown et al. (2015), when intensively aerated traditional open ponds were compared to split ponds, the production, survival, and FCR were similar but less consistent for the traditional open ponds. Brown et al. (2015) could not make any recommendation between the two systems until there was a better economic understanding of each.

The raceway system has shown production of around 20,000 kg/ha. However, the ability to sell the co-cultured fish is important to the economic viability of the system (Brown, 2011). Since then, several upgrades to the in-pond raceway system have been made. For example, the water moving system and aeration system have been combined into one system. Current models use diffused air to move the water and to aerate. In addition, the system has shifted from expensive fixed concrete systems to floating systems made of various forms of plastic.

2.7 Economic Status of US Catfish

Industry volatility can be seen in sale prices of foodfish and feed. Sale prices in 2013 had a low of $1.80 and a high of $2.49 per kg of fish (Hanson et al., 2013). This fluctuation in sale price is not abnormal in the US catfish industry and makes it difficult to assume a single sale price for enterprise budgets.

Since 2008 catfish feed prices have been relatively high but unstable, adding to uncertainty in the catfish industry (Hanson et al., 2013). In a survey of 70% of west Alabama catfish farms, Courtwright (2013) found the average breakeven price to be $2.40 per kg, ranging from $1.39 to $24.86. Feed was the highest cost and accounted for over half of the total cost of production. Over 40% of farmers surveyed were not profitable for the two year average (2011-2012) (Courtwright et al., 2013). Survey data revealed that breakeven prices were significantly higher than median breakeven prices indicating that there were more farms doing better than doing worse. Farms in the survey were classified into low, medium, and high intensity operations. The high intensity operations included only two out of the sixty farms surveyed. While high intensity farms were few in number, they were significantly more profitable and had lower breakeven prices due to economies of scale.

DO is the most common limiting factor in pond production (Egna and Boyd, 1997). Raising nightly low DO can affect fish growth and FCR for channel catfish (Torrans et al., 2008). Similar results have been observed with hybrid catfish (Green et al., 2012). Increases in aeration are closely tied to not only production but also profit (Courtwright et al., 2013). In farm trials over three years, a west Alabama farmer was able to raise over 14,000 kg/ha year by raising hybrid catfish and aerating near 16kw/ha (Hanson et al., 2015). For this study, the breakeven point was found to be $.31/kg over the three years. In intensively aerated (16kW/ha) research ponds in the Mississippi Delta the effect of additional aeration in terms of cost per kg was $.0036 even though nearly three times as much electricity was used in intensive ponds (Torrans et al., 2015). This research showed that additional aeration energy can be an insignificant cost if the energy used increases the fish produced. Testing of the economic returns to higher levels of oxygen management is needed to better understand the threshold at which aeration energy is increased and profits do not increase.

Chapter 3 Materials and Methods

Two ponds of floating in-pond raceways were installed by seafood wholesaler Harvest Select Catfish, Inc. in Uniontown, Alabama. This west Alabama catfish processor and farm operates more than 1,800 ha in Alabama and Mississippi. The west Alabama branch receives channel catfish fingerlings from their integrated supplier in Inverness, MS. The farm uses a multi-batch system where fish are stocked in a rhythmic pattern so that there always are fish almost ready to harvest. Various sizes of smaller fish are growing with them. With the increases in losses to Columnaris and Aeromonas and other diseases for Alabama catfish over the last five years, Harvest Select was interested in looking at floating in-pond raceways particularly for some of their lower production ponds to see if they could achieve higher profitability and production. Harvest Select has many years of experience raising channel catfish in a multi-batch system, but the version of floating in-pond raceways used in the present study, has never been tested on a commercial site. For uniformity, the studied setup containing floating in-pond raceways will be called in-pond raceway systems (IPRS). Harvest Select and farm management will be referred to as the west Alabama farmer.

In-pond raceways cells in west Alabama were stocked in July of 2014 and harvested in November 2014 when the farm decided to discontinue the project. Harvested fish were restocked into the same pond. Most of the raceway results will be compared to the most recent commercial version of in-pond raceways reported by Brown (2011). Brown (2011) showed high production and improved FCR compared to traditional ponds, but economics were dependent on tilapia that fed on waste and plankton produced by catfish waste.

Intensive hybrid catfish ponds were studied by Jubilee Farms which has been operating in Indianola, MS since 1981. This Mississippi Delta producer developed their business as a fingerling provider for other foodfish farms. Hybrid catfish fingerlings and foodfish has become the cornerstone of Jubilee Farms since they discontinued channel catfish foodfish production in 2006. This Mississippi Delta farmer operates around 100 ha (250 acres) of foodfish ponds. The farm chose as a part of the study to test oxygen management systems with their existing systems of operation. For uniformity, the group of studied ponds growing hybrid catfish in open ponds over the range of oxygen management techniques will be referred to as open ponds (OP). Jubilee farms will be referenced to as the Mississippi Delta farm. This chapter will be divided into three sections experimental setup, graphical and statistical analysis, and economic analysis.

The open pond results are from the ten hybrid open ponds in the Mississippi Delta. Open ponds were stocked in July of 2014 and harvested in the summer of 2015 when fish were believed to be the appropriate size (0.68-0.91 kg). Open pond results are compared to the most recent commercial survey of west Alabama catfish farms (Courtwright, 2013). For each factor (production, profit, and pond respiration) a linear regression of open ponds with paddlewheel aeration (XLP, LP, SP, and XSP) was graphed. The open ponds with paddlewheel aeration plus other oxygen management equipment (SPDA and SPSN) were not included in the paddlewheel aeration regressions. These open ponds' data (SPDA and SPSN) are evaluated to determine if they fall above or below the regression of paddlewheel aeration alone.

3.1 Experimental Setup

This section is sub-divided into two parts, in-pond raceways in West Alabama (IPRS) and open ponds in the Mississippi Delta (OP). The experimental setup details how the catfish were raised and broadly how it relates to the commercial farm that the ponds are on. Lastly, this section details how data was collected at each farm site.

3.1.1 In-pond Raceway System Experimental Setup

Two west Alabama ponds (out of 100) near Uniontown, AL were selected to install floating in-pond raceways as shown below (Figure 3.1).

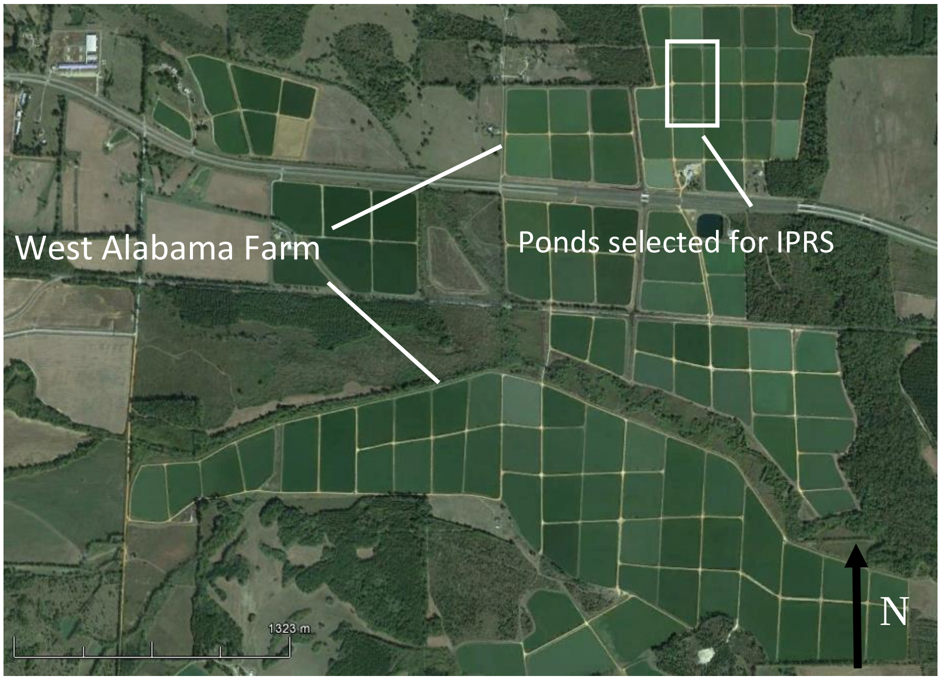


Figure 3.1 West Alabama (near Uniontown, AL) farm selected two ponds for In-pond Raceway System research.

Two 3.05 m x 12.2 m x 1.5 m floating in-pond raceways cells were installed in each 2.47 ha pond (2) on the west Alabama commercial catfish farm (Figure 3.2).

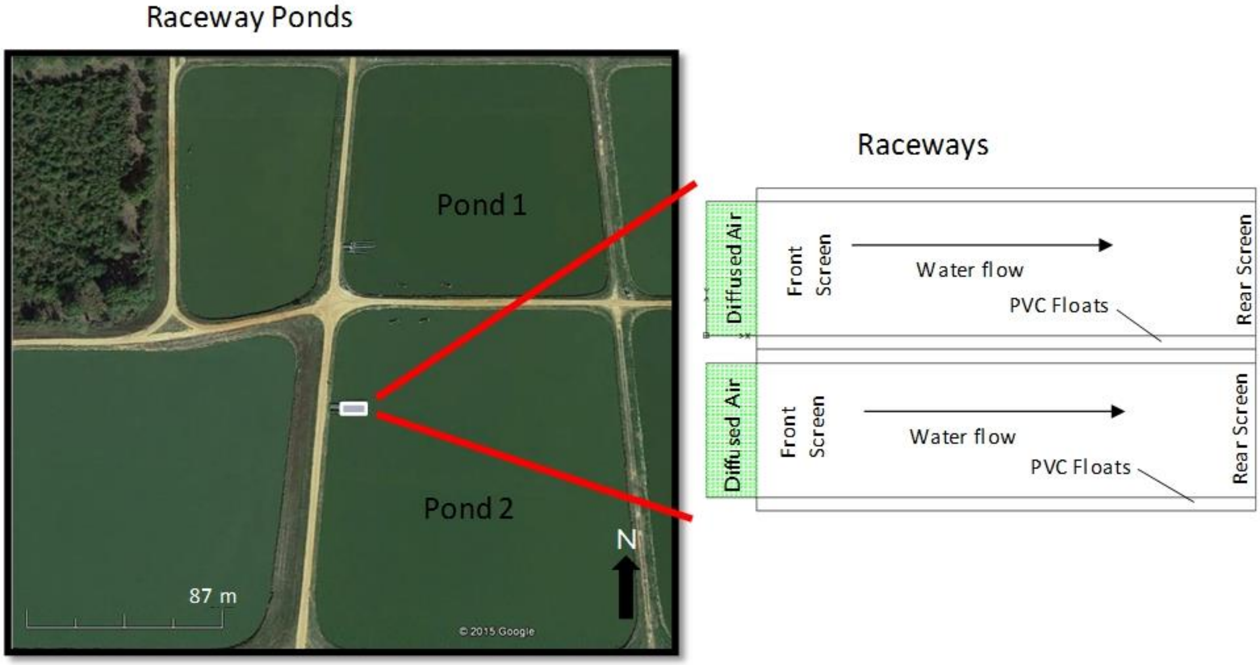


Figure 3.2 Raceway setup at West Alabama farm.

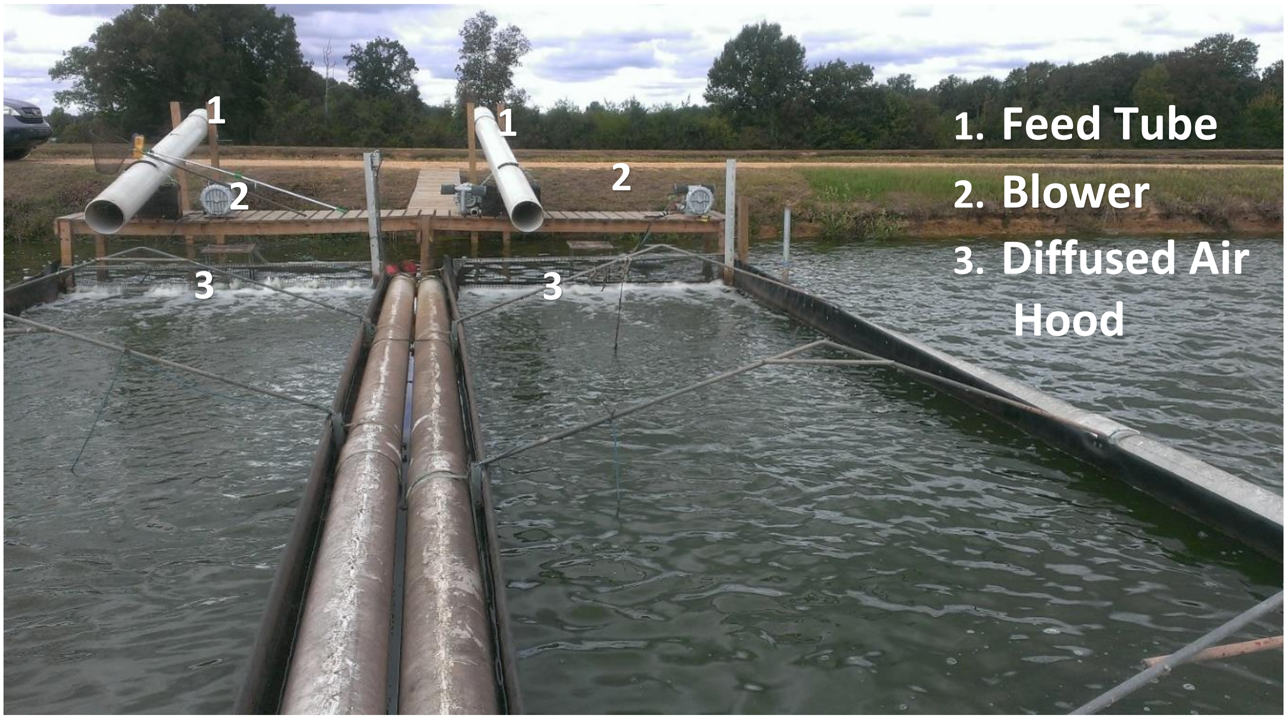


Figure 3.3 Two floating in-ponds raceway cells (West Alabama).

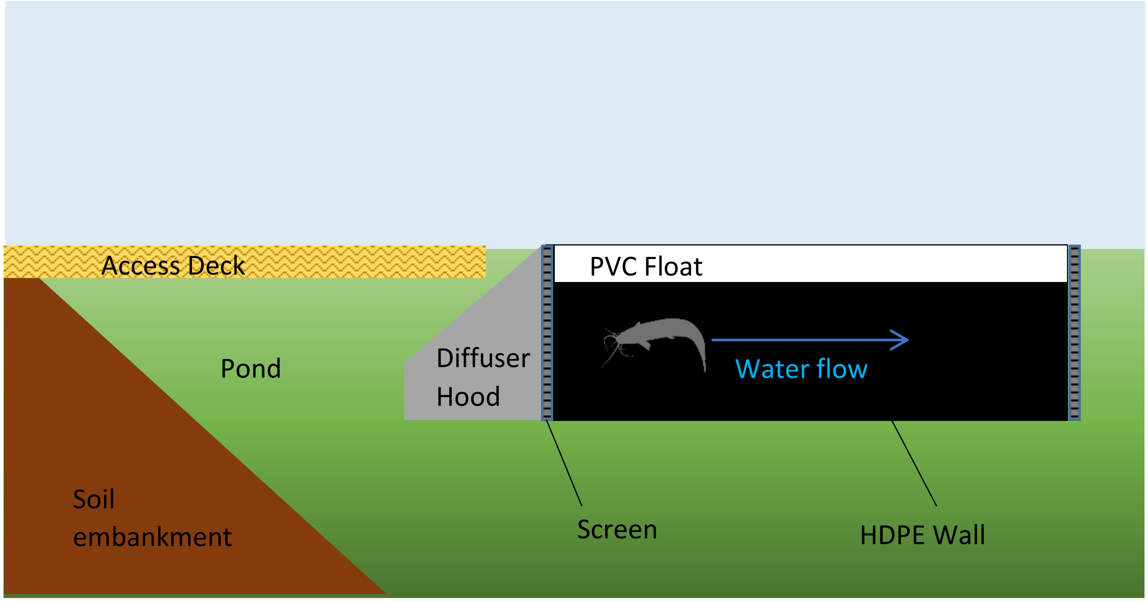


Figure 3.4 Side view: In-pond raceway cell.

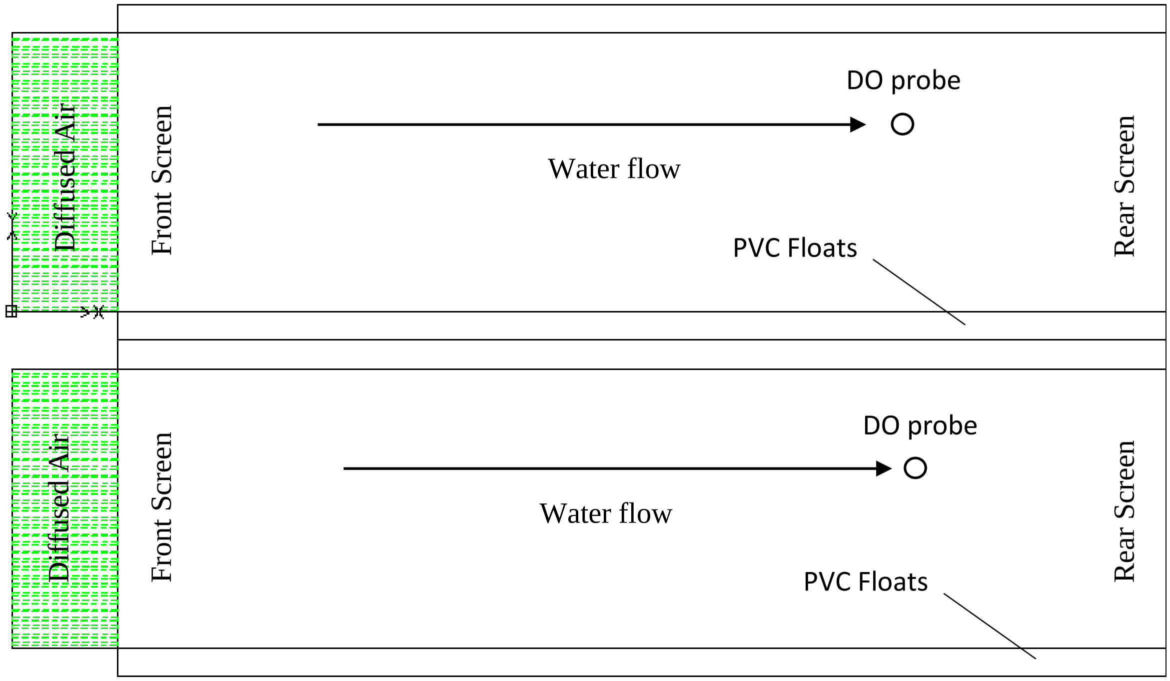


Figure 3.5 Plan view: In-pond raceway cell.

Capped PVC pipe was used as floats and to walk around the floating raceways (Figure 3.3, Figure 3.4, and Figure 3.5). The sides of each raceway are constructed with high density polyethylene (HDPE) membrane. Each raceway cell features a 1.125kW Sweetwater blower from Pentair (Schaffhausen, Switzerland) which aerates and moves water across each raceway via a diffuser hood at the opening of the raceway (Figure 3.6). Each Pentair blower is capable of supplying 125 m^3 of air per hour through the diffuser tubing (at 12.5 kPa of head pressure).

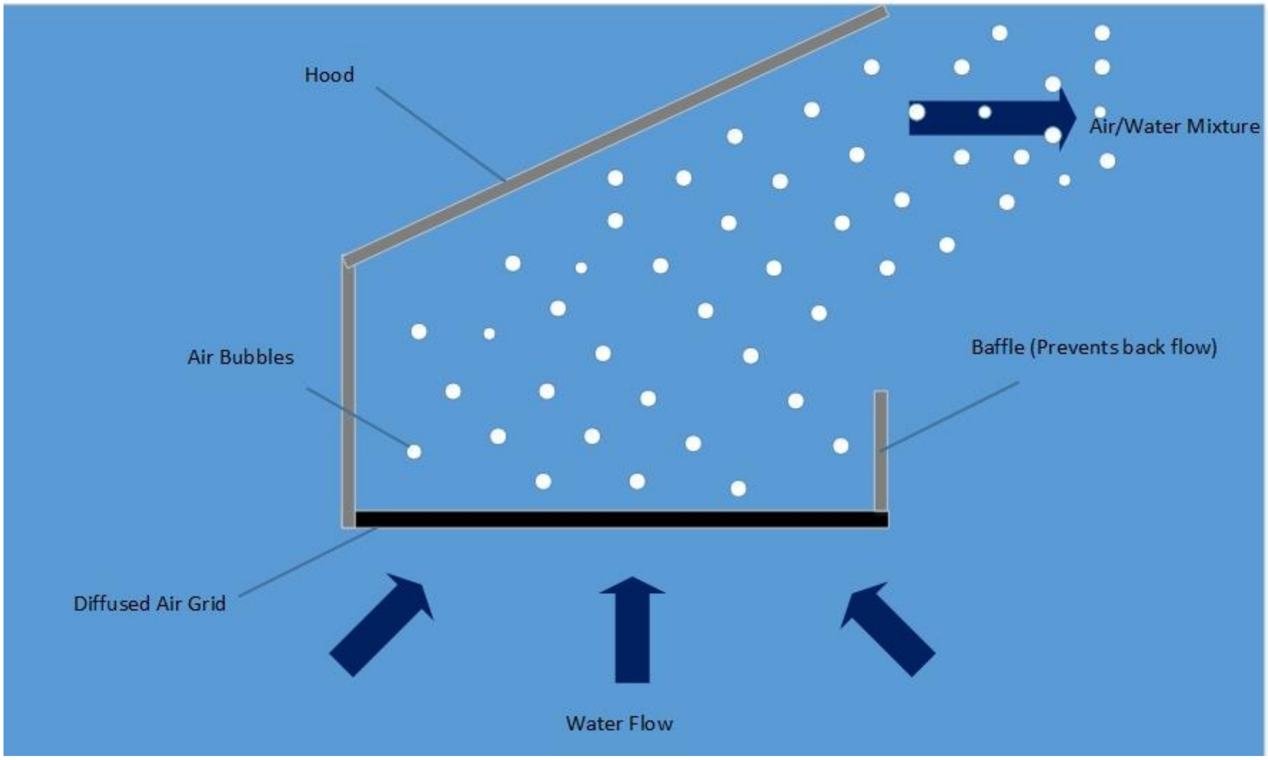


Figure 3.6 Diffused Air Hood water and air flow diagram.

Cells 1 and 3 were stocked with channel catfish (*Ictalurus punctatus*) while cells 3 and 4 were stocked with hybrid catfish (*Ictalurus furcatus x Ictalurus punctatus*) (Table 3.1). The hybrid catfish (Jubilee Channel Strain x DB Blue Strain) were obtained from the Auburn University Experimental Station research raceways in July 2014. Hybrid catfish were approximately 91 g at stocking and stocked at 12,350 fish/cell (Table 3.1). The channel catfish were obtained from the Harvest Select fingerling producer in the Mississippi Delta and stocked according to Table 3.1. Channel catfish were approximately 35 g at stocking and stocked at 12,400 fish cell (Table 3.1).

Table 3.1 In-pond raceway catfish stocking rate, west Alabama.

Date Stocked	Pond (Cell #) *	Species	Total Fish	Size (g/fish)	Total mass (kg)
7/3/2014	1 (1)	Channels	12,980	33	430
7/10/2014	1 (2)	Hybrids	12,196	91	1111
7/3/2014	2 (3)	Channels	11,824	37	435
7/10/2014	2 (4)	Hybrids	12,469	90	1122
*Figure 3.2 for reference on pond and cell layout.					

Fish were fed daily from July to October of 2014 (14 weeks) by feed truck through a PVC pipe (Figure 3.3 see above). Farm management decided to switch to twice a week feeding from October to November harvest of 2014 (5 weeks) across the entire farm. The farm did this reduced feeding as a possible disease prevention technique across the farm. The farm decided to discontinue the project in November because the increased labor requirements to manage raceways and participate in commercial research. Fish were harvested on November 12, 2014 using a 3 m x 1.5 m crowder and boom truck and restocked into the open pond.

Rear screens in the raceways were cleaned twice a week to ensure that water flow was unimpeded by feed and organic wastes. Front screens were cleaned whenever the pond grass was observed clogging the front screen. Each raceway was equipped with DO probes to continuously measure dissolved oxygen levels (mg/L). Fish were treated twice a week with an alternating regimen of formaldehyde (415 mg/L) and potassium permanganate (25 mg/L) for ten minutes whenever fish mortalities were observed.

Feed was summed weekly, collected from the west Alabama farmer, and entered into an Excel spreadsheet. Energy use for air blowers were determined by a power meter (kWh) for both ponds. Water samples were analyzed by the Alabama fish farming center (Greensboro, AL) and myself weekly for nitrite, ammonia, pH, and Secchi disk depth and monthly for alkalinity and chlorides. Additional testing was done for alkalinity if lime was added.

DO levels were continuously monitored by remote DO probe because if any of the blowers for the in-pond raceway failed for more than a few minutes the fish could die. The risk is high because the fish are confined and cannot move to a higher DO level as would be the case in traditional pond culture. The DO probe was positioned six meters from the front of the raceway. Probes were cleaned three times a week and recalibrated weekly. Probe readings during weekends were found to be unreliable due to organic growth on the probe surface. So this data was omitted.

The water touching the surface of the raceway walls and floor does not move due to the non-slip condition of fluids. This effect creates a slower moving boundary layer of fluid next to the raceway walls and floor with maximum flow at the center of the raceway. The longitudinal velocity was measured with a flow-meter at six points (dividing the width by three and 25% and 75% depths) at 3 m from the front of the raceway (Figure 3.7). The flow meter calculated the sixty second average longitudinal velocity for each test point. Velocity was measured for all four raceways and averaged. These 24 sixty second averages were averaged and used as average longitudinal velocity. Volumetric flow (m^3/s) was calculated by multipling longitudinal velocity (m/s) by cross sectional area (m^2). The raceway cell turnover rate (minutes) was calculated by dividing the cell volume (m^3) by the volumetric flow rate (m^3/s) and converting to minutes.

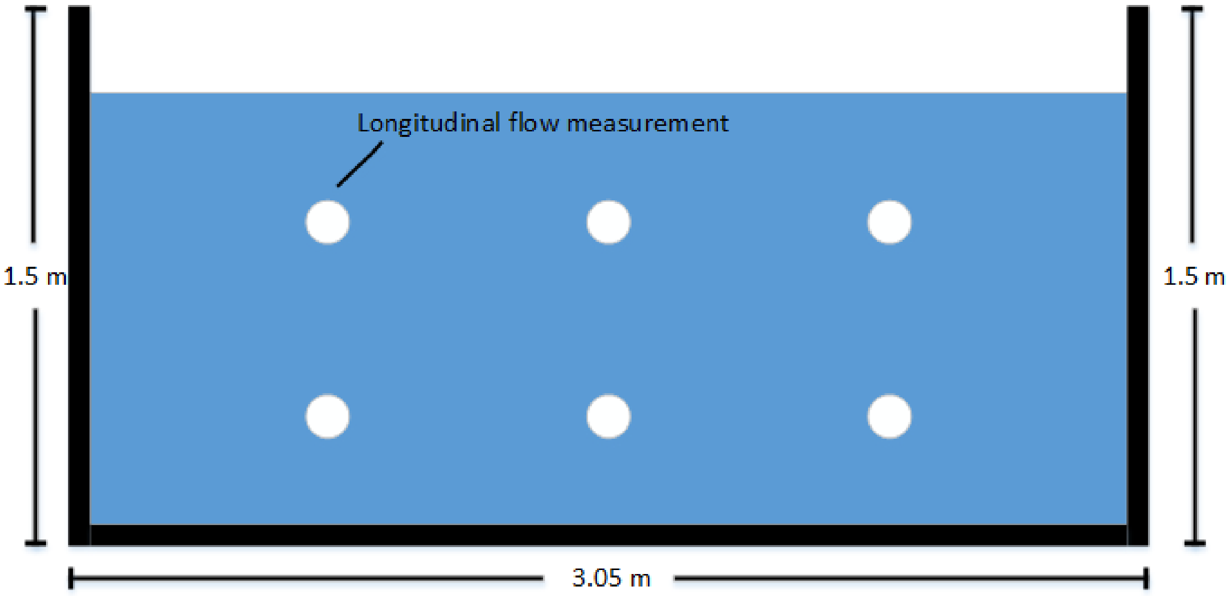


Figure 3.7 Longitudinal flow velocity measurements for each raceway cell (3 m from front of raceway).

Air was run from blowers to the diffused air hoods at the beginning of the raceway cells. The rising air caused the surrounding water to flow with the air. This movement of water started below the diffused air hood and flowed through the raceway providing fresh water. The calculated linear water flow in the in-pond raceways was 0.08 m/s. The volumetric flow rate of water for each cell was calculated to be 288 L/s. The volume of water contained by each raceway cell was 45.3 m^3. At normal flow the raceway cells turned over the water approximately once every 2.7 minutes or 22 times per hour. This is an improvement over previous in-pond raceway versions that had a water exchange rate every 4.9 minutes (Brown, 2011). The total volume of each pond containing the raceway cells was 57,600 m^3. With two cells in each pond, the pond water was turned over approximately every 27.8 hours. If the number of raceway cells were increased to 2.43 cells/ha the pond would turn over approximately once every 9 hours. The estimated water exchange time for the fixed in-pond raceways observed by Brown was 12.7 hours. A split pond at National Warmwater Aquaculture Center in Stoneville Mississippi flows water at 833 L/s and has an approximate water exchange of 10 hours of operation (Tucker 2010). As a design principal raceways are expected to have a higher exchange rate than split-ponds because the fish culture volume is smaller in raceways. Flow rate is important because it allows fresh pond water to come into the raceway cells. The water flow also carries out the water that the fish are living in (respiring and excreting waste) out the back of the raceway were water can be treated by the pond water. Water movement in the raceway cells helps the cells maintain a good DO level (Objective #1 In-pond Raceway System).

At final harvest in November, individual weights and lengths of harvested fish were measured using 150 hybrids per raceway cell and 200 channels per raceway cell. Samples were taken out of at least three different harvest pulls from each raceway cell to maximize sampling diversity.

3.1.2 Open Ponds Experimental Setup

Ten of Jubilee Farm’s ponds near Indianola, MS were selected for studying varying rates of oxygen management (Figure 3.8). The six smaller ponds (1.2 to 1.6 ha) were equipped with a base 22.5 kW of paddlewheel aeration for each pond (Figure 3.8 and Figure 3.9).

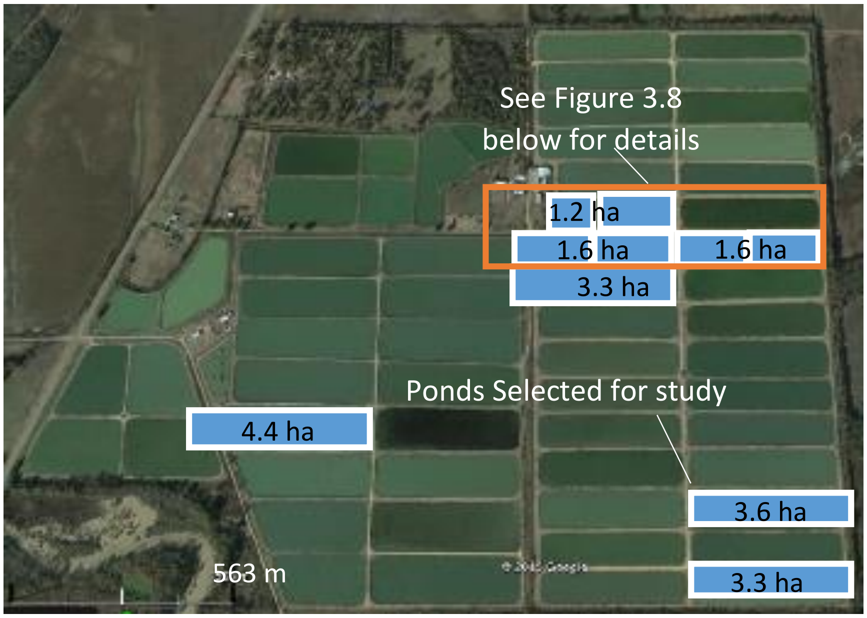


Figure 3.8 Mississippi Delta ponds selected for observation in open pond culture.

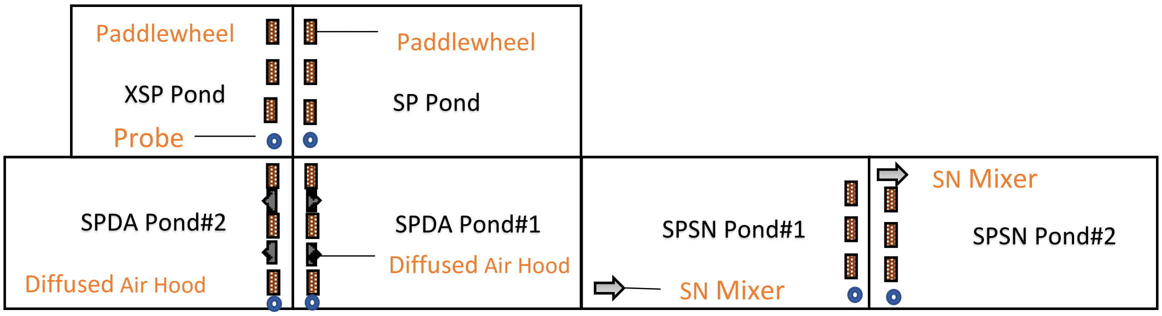


Figure 3.9 Small open pond equipment layout, Mississippi Delta, Note: (Not to scale equipment appears larger than reality).

Four of the six small ponds (1.6 ha) were setup with additional oxygen management equipment in addition to conventional paddlewheel aeration (Figure 3.8 and Figure 3.9). The four large ponds (3.3 to 4.8 ha) were equipped with 30 kW of paddlewheel aeration. The large ponds were used to get a wider range of paddlewheel aeration treatments. A shorthand method was developed to help in denoting the pond type (Table 3.2).

Table 3.2 Open pond type in shorthand.

Number of Ponds	Pond Size (Descriptive Abbreviation)	Equipment (Descriptive Abbreviation)	Shorthand
1	(4.3 ha+) Extra Large (XL)	Paddle-wheel (P)	XLP
3	(3.3 to 3.6 ha) Large (L)	Paddle-wheel (P)	LP
1	(1.6 ha) Small (S)	Paddle-wheel (P)	SP
2	(1.6 ha) Small (S)	Paddle-wheel+Diffused Air Hood (PDA)	SPDA
2	(1.6 ha) Small (S)	Paddle-wheel+S&N Mixer (PSN)	SPSN
1	(1.2 ha) Extra Small (XS)	Paddlewheel (P)	XSP

One of the devices used to provide additional oxygen management was a diffused air hood used in SPDA ponds (Figure 3.10).

Figure 3.10 Five meter long diffused air hood out of water (shown without floats).

The diffused air hood is five meters wide and is powered by a 1.9 kW Sweetwater (Minneapolis, Minnesota) blower for water movement and aeration. This equipment is essentially a larger version of the diffused air hood developed by Auburn University (Fern, 2014) and already used in the floating in-pond raceways at Harvest Select. The diffused air hood pumps air to a coarse bubble diffuser array (3 mm to 5 mm is the finest bubble without additional maintenance for aquaculture). The air bubbles rise in the water and are deflected horizontally from the hood (Figure 3.6 and Figure 3.10). This causes the air and water to flow away from the hood in a horizontal direction. The diffuser tubing was selected for aquaculture because it provides a small bubble size without the need for excessive maintenance. Two diffused air hoods are used in two of the ponds (Figure 3.10). The main benefit of the diffusor hood equipment is aeration however, the hood also provides mixing, water flow, and pond circulation. In an attempt to proactively manage the waste load of the system, management operated the diffused air hoods continuously. Commercially available versions similar to the diffused air hoods used in this study have been independently tested to have a standard aerator efficiency (SAE) of 3.0 kg O_2/kWh (GSEE Inc., 2015).

Table 3.3 Experimental open pond setup Mississippi Delta farm.

Area(ha)	Number of ponds	Paddlewheel Aeration(kW)	Special Equipment (kW)	kW/ha	Shorthand
4.4	1	30	NA	6.8	XLP
3.3	3	30	NA	12.3	LP
1.6	2	22.5	Diffused air (3.75)* Operated continuously	14	SPDA
1.6	2	22.5	SN mixer (3.75)** Operated continuously	14	SPSN
1.6	1	22.5	NA	14	SP
1.2	1	22.5	NA	18.75	XSP

NA=Not Applicable
*Figure 3.10
**Figure 3.11

A 3.75 kW mixing device developed by S&N Airflo (Greenwood, MS) in the 1990s was used in two of the other small ponds (SPSN) (Figure 3.11). The SN mixer primarily was used for mixing the pond water and was used continously throught the project.

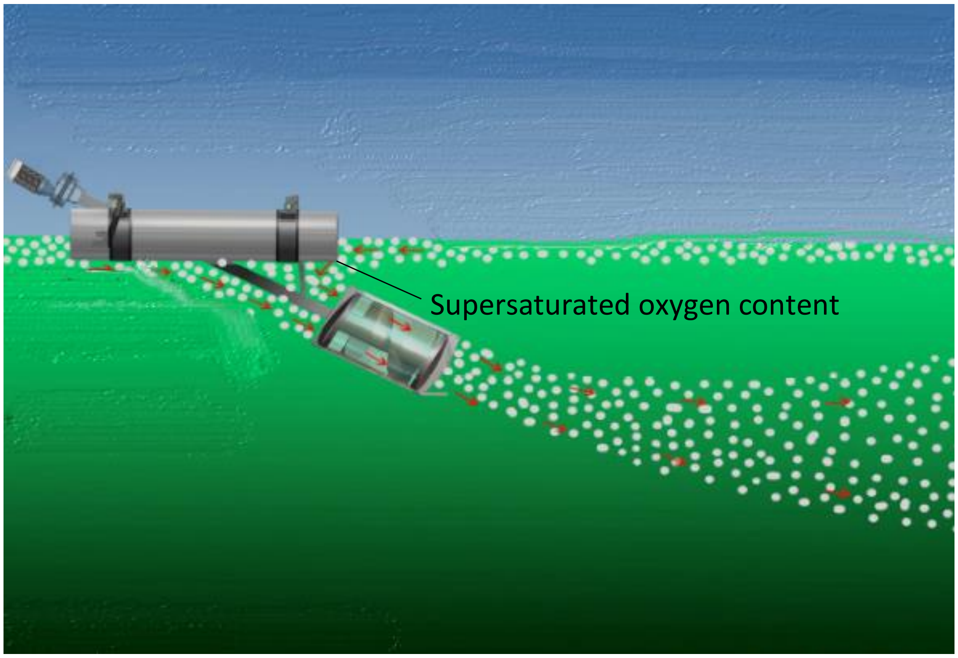


Figure 3.11 SN mixer (Source SN Airflo).

This type of equipment is primarily used for municipal wastewater treatment lagoons. The manufacturer indicates the benefit of this mixing equipment over other water moving machines available in aquaculture is that it operates at a downward angle rather than horizontal. The downward angle of operation is designed to allow supersaturated top water that would otherwise release oxygen to the atmosphere to mix with oxygen deficient bottom waters. In addition to “storing” oxygen for later use the equipment allows pond waste to be more uniformly in contact with the oxygen used for degrading the waste. This waste comes from uneaten feed or nutrients that are not retained by the fish. Thus, the equipment’s primary benefit is designed to occur during the day by moving supersaturated water downward. During nighttime, continued mixing facilitates increased waste/oxygen contact and is expected to aid aeration to some extent. The mixing equipment is run continuously as recommended by industry expert (Chappell, personal conversation).

Mixing and homogenization of water is impacted by the amount of water moved. Theoretically mixing increases waste oxygen contact that would enhance waste assimilation. This theoretically could improve DO levels (Objective #1 Open Pond) or proactively manage waste (Objective #4 Open Pond). Mixing equipment (in SPDA and

SPSN ponds) was operated 24-hours a day. Water flow generated by each diffused air hood (SPDA) was measured to be 17 m^3/min. The approximate turnover rate for the ponds with diffused air hoods (SPDA) was 14 hours (pond volume/flow rate). The SN mixer (SPSN) generated a flow of almost 18.5 m^3/min. Therefore, the turnover rate for the ponds with the SN mixer (SPSN) was approximately 13 hours (pond volume/flow rate). Both of these equipment setups are capable of mixing pond water in 14 hours or less. Mixing equipment is not typically operated in commercial catfish ponds so there is limited information on adequate sizing of mixing equipment. However, the turnover rate is within 25% of the turnover rates of split ponds (10 hours) (Tucker, 2015) and previous in-pond raceways (13 hours) (Brown, 2011).

The open ponds were stocked in July of 2014 (Table 3.4). A total of ten ponds were operated as part of the Mississippi Delta commercial farm case study to improve best aquaculture management practices for oxygen and waste management. Ponds were completely harvested before stocking and at harvest. This allows the farmer to know with a degree of certainty the number of fish in the pond and the mass of fish grown. This method called a single batch system because each pond is only growing one crop at a time. Results of this study could differ if channel catfish or a multi-batch system was used. Channels catfish have a lower feeding rate and likely would not see as large as increase in production as hybrid catfish. The range of oxygen management treatments (6.8-18.75 kWh/ha) is given in Table 3.3. All ten ponds were stocked with hybrid catfish and grown to the desired foodfish size (0.68-0.91 kg). The stocking rate for each pond is given in Table 3.4. Fish were fed daily to satiation until November and resumed in March once weather improved. Fish were fed weekly from November to March when the water temperature decreased. This Mississippi Delta farm treated weekly with copper sulfate from April to September.

Emergency supplemental tractor aeration was added to any pond at the discretion of the night-men in charge of the condition of the fish, largely based on observed stressed fish or behavior of the pond in a pattern of critically low DO for several days. Estimated tractor aeration is based on talking to the night-men about average frequency and duration of tractor aeration in the studied ponds.

Fish fed was mistakenly switched (March 2015) due to a miscommunication with the feed mill. Feed unknowingly did not contain the extra iron and vitamins of the usual diet and fish developed anemia. Ponds with chronic mortalities had the paddlewheel aerators turned on throughout the day (April 2015). In severe cases, the increased mortalities led to an increase in ammonia water quality problems.

Table 3.4 Pond Stocking.

Date Stocked	Pond Number	Pond Type*	Fish/ha	Fish Size(g)	Total Fish Weight Stocked (kg/ha)
7/25	1	SP	5700	50	285
7/17	2	XSP	9000	55	495
7/5	3	SPDA	6100	54	329
7/29	4	SPDA	6000	60	360
7/17	5	SPSN	5500	60	330
7/17	6	SPSN	5700	58	330
7/8	7	LP	3400	57	194
7/5	8	LP	3200	59	189
7/17	9	LP	4400	53	233

*Refer to Table 3.2 for Pond type shorthand

Feed was summed on a weekly basis from the farmer. Dissolved oxygen (DO) data in mg/L was collected by an oxygen monitoring system manufactured by In-situ, (Ft. Collins, CO) mounted on a buoy with a self-cleaning DO probe (Figure 3.12).

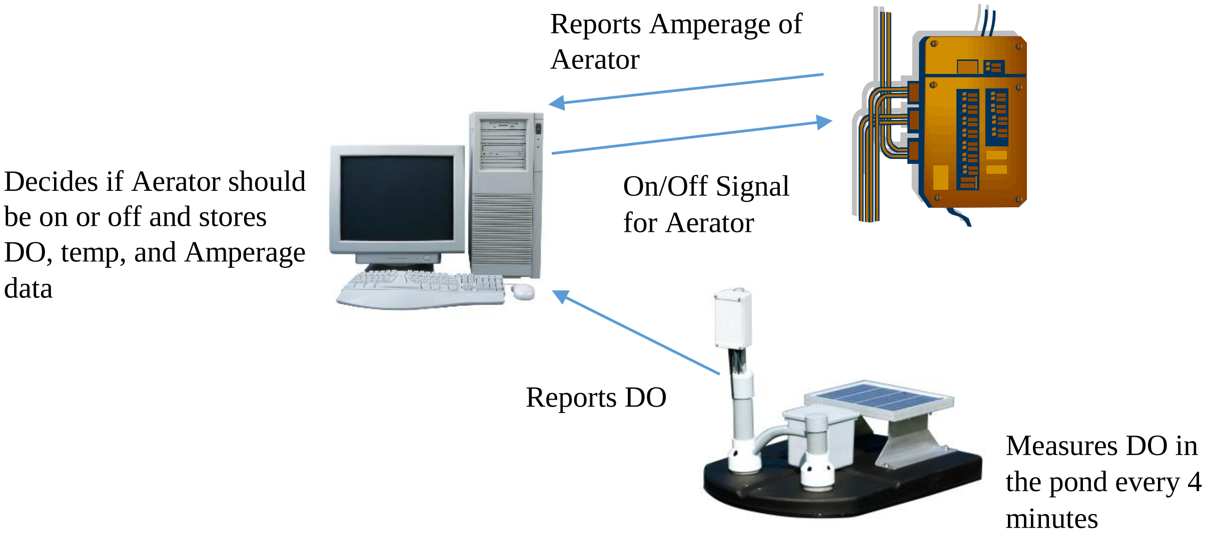


Figure 3.12 DO monitoring and aeration control process (Adapted from: In Situ, Fort Collins, CO).

The buoy is located to the side of the aerators with the probe recording temperature and DO from a depth of 36 cm (Figure 3.9 and Figure 3.12). Each DO probe provides a single point representation of oxygen concentration at the sampling location. As the pond contains 18 to 36 million liters of water the probe cannot accurately represent DO distribution with a single point. The probe location was selected to the side of the aerators because it allowed the nighttime oxygen monitoring crew to determine if there was a problem with probe readings by comparing monitored DO to hand held manual probe readings. Because a single probe failure could lead to a catastrophic loss of 40,000 kg of fish if it failed to turn on the paddlewheel aerator, the DO probe communicated its reading every four minutes to a host computer that would signal the aerators to turn on when needed.

The host computer in the local office temporarily stored the 4-minute DO value and used it to calculate an average every twenty minutes which was then read into a comma delimited data file stored on the office host computer. The monitoring system used 20-minute DO concentrations to control the pond aerators based on the farmer's set points for DO. The aerator set points were staggered from 5 to 3.5 DO mg/L during the night (1900 to 0700). The farm workers in charge of keeping the fish alive could manually turn on aerators if DO levels read by hand held probe indicated low levels. Aerators were setup so that once the controls turned the aerator on the aerator would not be turned off during the night. Daytime (0700 to 1900) set points were staggered from 4 to 2.5 mg/L. Aerators were turned off during the daytime (0700 to 1900) when DO is 0.5 mg/L above the set point.

The system also monitored the amperage of the aeration devices to aid in system maintenance and trouble-shooting. The average amperage was reported to the same comma delimited file as DO levels every twenty minutes. The 7.5 kW aerators are expected to draw 15 to 10 amps from the 480-volt power source. The twenty minute average omits any break in communication between the host and the probe. If a probe fails to communicate for over twenty minutes or there is a computer write error, then data is omitted. This occurred for around five data points for dissolved oxygen per week (out of 6,720). Between July and October of 2014 there were four instances where the monitoring systems program was accidently shut down each time for around three hours (4 readings per hour) and all data collected during that time was lost. Loses of amperage readings were proportionally the same as dissolved oxygen.

Water samples were taken every week from August to the end of November 2014 and monthly from November to beginning of March 2015 when fish feeding was minimal. The frequency at which water quality parameters was tested is shown below (Table 3.5). Samples were taken and tested by farm personnel. If mortalities were observed fish and water samples were taken to Stoneville, MS for additional testing.

Table 3.5 Open Pond Water Quality Testing.

Parameter	Frequency of Testing (Above 25C)	Conditions for additional Testing	Method/Chemistry
Ammonia	Weekly*		Nessler Reagent
Nitrite	Weekly*		Color Disc/ Ferrous Sulfate
Chloride	Monthly	High Nitrite, Water Exchange, or Addition of Salt	Drop Count Titration/ Silver Nitrate
pH	Grab Sample	High Ammonia or Observed Mortalities	Probe
Alkalinity	Stocking		Digital Titrator/ Sulfuric Acid

*Below 25C test monthly

3.2 Graphical and Statistical Analysis

This section starts with common harvest and production analysis similar to both the in-pond raceway system and open ponds, followed by the statistical and graphical criteria used. Lastly, this section is subdivided into an in-pond raceway section and an open pond section that contains additional information on the water quality/DO analysis and the production analysis specific to that setup.

Stocked fish numbers and harvest fish numbers were calculated by the standard practice of dividing the total weight by the average weight. Fish survival was calculated by dividing the total harvest numbers by the total stocking numbers. Growth rate per fish was calculated by dividing grown biomass of fish (harvest mass minus stocking mass) by the crop duration (days) and stocked fish numbers. Production provides a metric of how much fish biomass was grown in the system. Production per area was calculated by dividing grown biomass of fish by pond surface area (ha).

Feed conversion ratio (FCR) was used to quantify the growth of the fish per unit of feed (Equation 3.1).

$$FCR = (Feed\ fed\ (kg))/(Harvest\ mass\ (kg) - Stock\ mass\ (kg)) \quad \text{Equation 3.1}$$

Rstudio (open source) was used for boxplots and statistical analysis. Boxplots were used to graphically displaying the DO distribution of data. QQ plots and shapiro-wilk test were used to test dissolved oxygen data for normality. For both in-pond raceway system and open ponds, DO did not follow a normal distribution. Level of significance was set at 0.05. Pairwise the wilcox test was used to test for statistical differences between the non-normal dissolved oxygen data sets.

A static sensitivity analysis was performed for the economic analysis. The seven largest economic factors (Income, Feed Cost, Fingerlings Cost, Labor Cost, Chemical Cost, Electrical Cost, and Fixed Cost) effecting profitability($/ha) were independently varied from -50% to +50%. The profit after each change is graphed. Factors with the steepest slope (+ and -) have the largest effect on profitability. The graphic is called a spider plot because lines meet at one point (0% change) and diverge to the left and right of this point. The graph allows for the factors influencing profitability to be easily seen and how changes affect profits.

3.2.1 In-pond Raceway System Graphical and Statistical Analysis

The DO probes in the raceways did not have a self-cleaning probe like the open pond systems studied in the Mississippi Delta. Initially DO probes were cleaned twice a week for the first four weeks of the study. After this to increase accuracy the DO probes were cleaned three times a week. Probes were cleaned on Mondays, Wednesdays, and Fridays. However additional investigation revealed that measured DO values for weekends (Saturday-Monday morning) were significantly different ($p<0.01$) from the rest of the week. Additional analysis counted the number of times that the raceway cell had a DO reading of less than 2 mg/L, and less than the DO measured in the pond source. This reading is unusual because the diffused air hood at the start of the raceway aerates and should increase the raceway cell DO as the pond source DO falls below oxygen saturation. Of the thirty-eight instances where this happened all but three occurred on Saturdays, Sundays, or Mondays. Of the three instances where this occurred, two occurred on the Tuesday after Labor Day. For this reason, only the daily minimum during the weekdays was calculated. Boxplots are shown for each of the DO values for each raceway cell and external pond source.

3.2.2 Open Pond Graphical and Statistical Analysis

Minimum dissolved oxygen levels during the winter did not represent dissolved oxygen levels during the growing season as minimums were many times above 8 mg/L during the winter. Dissolved oxygen levels in open ponds were reanalyzed when temperature was above 25C, as dissolve oxygen has been shown to be different by Buentello et al (2000). Matlab (Natick, MA) was used to search the open pond data because each day the monitoring system reported around 10,000 dissolved oxygen data points and 30,000 amperage data points for the Mississippi Delta farm. A Matlab script was developed to find the range for each pond each day of production. The script read the daily dissolved oxygen comma delimited file (csv) for all of the farm ponds and saved the dissolved oxygen data for the selected pond to a temporary matrix. The Matlab script then analyzed the matrix for maximum, minimum, and range for each pond. The daily DO ranges, minimums, and maximums of each of the studied ponds were then output to a separate Excel spreadsheet file.

Daily DO in catfish ponds cycles sinusoidally (Figure 1.3) with super-saturation during the daytime and a low just before dusk (0400 to 0600). However, variations in algal populations, waste load, wind, sun light, and oxygen management equipment setup result in different extremes (max and low) at different times. The functions controlling DO are broken down in Figure 2.1.

The nightly respiration rate is a combination of three components: water column, fish, and soil (Tucker, 1998 and Steeby et al., 2004). The nightly respiration that was recorded by the DO probe will be called whole pond respiration (WPR) similar to Hargreaves (1999). During the night and near saturation, the rate of change in DO should be approximately the measured respiration because natural re-aeration should be negligible compared to whole pond respiration (Odum, 1956).

This whole pond respiration rate calculation will not be performed for times when paddlewheel aeration is on because aeration will have a significant impact on DO values observed. Continuous aeration near the DO probe is the main reason WPR was not calculated for the floating in-pond raceways. Likewise, calculation of whole pond respiration rate will not be performed during the day because oxygen production can only be estimated if sunlight and plankton levels are known. However, near saturation, diffusion is relatively small and aerators are usually not on. Thus, respiration is more easily estimated given the rate of change in dissolved oxygen.

This calculation of total pond respiration should be related to the biomass load. Odum (1956) described an alternate method of determining waste load and assimilation that compared production and respiration values, below Equation 3.2.

$$Rate\ of\ DO\ change = Photosynthesis - Respiration \pm Aeration \text{ and } Diffusion \qquad \text{(Equation 3.2)}$$

Which can be simplified to Equation 3.3 at night at saturation because photosynthesis and diffusion become small compared to respiration. This assumption is not true at different times and as respiration rate becomes smaller the accuracy of this assumption decreases.

$$Rate\ of\ DO\ change \sim Measured\ Respiration \qquad \text{(Equation 3.3)}$$

For the purpose of this study, the calculation will start when the DO falls below 10 mg/L and stop when it falls below 6 mg/L. The respiration rate of the water column has been shown to be related to the amount of feed provided to the fish (Hargreaves, 1999). In this study, the measured respiration rates and feeding rates will be graphed to see if any treatments fall below the trend of open ponds with paddlewheel aeration only. A lower respiration rate for a given feeding rate could be an indicator of proactive waste management. Whole pond respiration was found to not follow a normal distribution. Rstudio was used to analyze WPR for statistical differences and plotted on a boxplot. WPR was graphed with mean daily oxygen range because both are related to plankton levels and correlation was calculated. Total feed was graphed with WPR because feed is the source of additional external organic matter for the pond system.

Power consumption for three phase delta wiring is three times average voltage times the amperage pulled by the motor. Energy used for all open ponds was approximated by the power equation multiplied by the amount of time the equipment is run (Equation 3.4).

$$Energy(kWh) = 3 * Average\ Volts \times 10^{-3} \times (timestep^{-1}) \sum_{0}^{24/timestep(hr^{-1})} Amps \quad \text{(Equation 3.4)}$$

Where amps are variable depending on run conditions

Volts is the average volts for a 3 phase motor

Timestep is 1/# readings per hour in which the data is stored

The energy used by aeration and mixing equipment in observed ponds can be classified as aeration energy or mixing energy. While all of the machines used accomplish some degree of aeration and mixing simultaneously they are classified according to the primary purpose for which they are used. Paddlewheel aerators are only run during the nighttime when DO levels are low so their energy use was classified in this study as aeration energy only. Diffused air hoods are mainly aeration machines with moderate mixing capability. However, because of their relatively small motor size (1.875 kW) and minimal surface turbulence compared to a paddlewheel aerator they are used even during periods when surface waters contain supersaturated oxygen levels. Energy use during the day while oxygen levels were above saturation was considered mixing energy while energy spent by diffused air hoods at or below saturation was considered aeration energy. The S&N mixer (Greenwood, MS) to some extent aids in oxygen transfer although its primary purpose is mixing water. The benefits of mixing are to circulate oxygen, waste, and temperature levels to promote decomposition of waste while conserving supersaturated oxygen levels from the surface. Therefore, the S&N mixer’s energy was only considered in this study as mixing energy even when used at night. Total kW per pond area will be plotted versus total production ((harvest weight minus stocking weight)/ water area area).

Production and profitability was expected to increase with oxygen management. Daily DO range and WPR was expected to increase with total feed. This data was graphed in excel (x,y) plots and the regression for the linear model was calculated. For Open Pond graphs, ponds with paddlewheel aeration only are considered for the regression. This regression allows other treatments to be compared to the standard paddlewheel aeration. Correlation (R) was calculated by Equation 3.5 for bivariate data. Correlations below |0.5| will be considered weak and those above |0.8| will be considered strong.

$$correlation\ (R) = \frac{N\sum xy - (\sum x)(\sum y)}{\sqrt{[N\sum x^2 - (\sum x)^2][N\sum y^2 - (\sum y)^2]}} \qquad \text{Equation 3.5}$$

The linear approximation for confidence interval for the slope in a linear regression analysis was calculated by Equation 3.6 in Excel. The linear approximation was used when data was correlated to compare the ponds with diffused air hoods and SN mixing equipment to the ponds with paddlewheel aeration only.

$$\Delta y_{CI} = \frac{t_{\alpha,v} \times Se_y}{\sqrt{df+2}} \qquad \text{Equation 3.6}$$

Where $t_{\alpha,v}$ is the t-value
Se_y is the standard error in the y
df is the degrees of freedom

3.3 Enterprise Budgets

This section is sub-divided into economic analysis of in-pond raceway and open pond systems. Enterprise budgets were used to estimate the cost to grow a kg of fish. Fixed cost items are the infrastructure and equipment that are required to produce fish including as raceways, trucks, tractors, aeration equipment, and pond construction. These costs exist whether or not fish are raised in the system. Variable costs are items dependent on growing fish, such as fingerlings, energy, feed, chemicals, and labor cost that approach zero if a farm suspends growing fish. Interest was assumed to be 10% for the purpose of this farm case study. Income ($) was calculated as the sale price ($/kg) multiplied by the mass of fish sold (kg). Profits were calculated by amount of money received after accounting for costs. Profits were normalized by pond area. Below is a list of the assumed prices of many of the variable cost items (Table 3.6) used in budget analysis. The farm case studies take place in two locations with different electrical services available. One electrical price ($0.11/kWh) was assumed for comparison, even though west Alabama typically pays $.09/kWh for electric aeration (Courtwright, 2013).

Table 3.6 Price assumptions of variable input items used in budget analysis.

Variable Price Assumptions		
Item	Unit	Quantity
32 % Protein Feed	$/kg	0.495
28 % Protein Feed	$/kg	0.462
Seine and transport	$/kg	0.11
Formaldehyde	$/L	2.12
Potassium Permanganate	$/kg	5.10
Copper Sulfate, crystal	$/kg	2.02
Salt	$/kg	0.13
Electrical	$/kWh	0.11
Fuel (Diesel)	$/L	0.89

3.3.1 In-pond Raceways System Enterprise Budget

Harvested fish were weighed and stocked into the same open pond containing the raceway cell. Fish are not usually sold at this pre-market size so there is not a usual market price available. Sale prices were estimated using interpolation from foodfish and stocker size fish prices (Table 3.7). Generally, hybrids are considered more valuable than channels ($/kg) for the same size. However, as fish get closer to 0.68 kg, price approaches standard market price paid by processors for foodfish.

Table 3.7 Sale Price Estimations.

Item	Unit	Quantity
0.4 kg Hybrid	$/kg	2.75
0.18 kg Channel	$/kg	2.75
0.68 kg Foodfish	$/kg	2.20

Fixed cost included equipment and capital infrastructure such as tractors, feed trucks, pond construction, gravel, and floating in-pond raceways on a proportional basis (Appendix Table B.3). Proportion of use was determined by number of ponds that shared the item. Fixed cost items were depreciated using straight line depreciation and expected life cycle (Appendix B.3) (Courtwright, 2013). Since fish were only grown for four months. To normalize annual fixed costs, fix costs are multiplied by the fraction of the year (1/3) that fish were grown.

The number of raceway cells per pond area for this west Alabama farm was below what is believed commercially optimum (2.43 cells/ha) (personal conversation Jesse Chappell, 2014). For additional economic analysis, the scale of the raceway was increased from 0.81 cells/ha to 2.43 cells/ha. based on several simplifying assumptions (Table B.9). The first assumption for increasing scale to 2.43 cells/ha is that fixed cost items associated with purchasing the raceways would increase directly with additional cells, in this case by a factor of three. Feed, energy, and fingerling cost are also assumed to increase directly by the same factor. Fixed cost associated with the farm and pond would remain the same such as tractors, trucks, pond construction, and office building.

Labor use on the raceway was divided into direct work on the raceways and things that took time to set-up. If the number of raceways increased the amount of direct work on the raceways would proportionally increase, however the amount of time required to set-up would remain relatively unchanged. Labor was assumed to be seventy-five percent direct work on the raceways and twenty-five percent set-up.

3.3.2 Open Ponds Enterprise Budget

To balance the extremes of industry volatility, a sale price of \$2.2/kg is assumed in the enterprise budget (Figure 3.13).

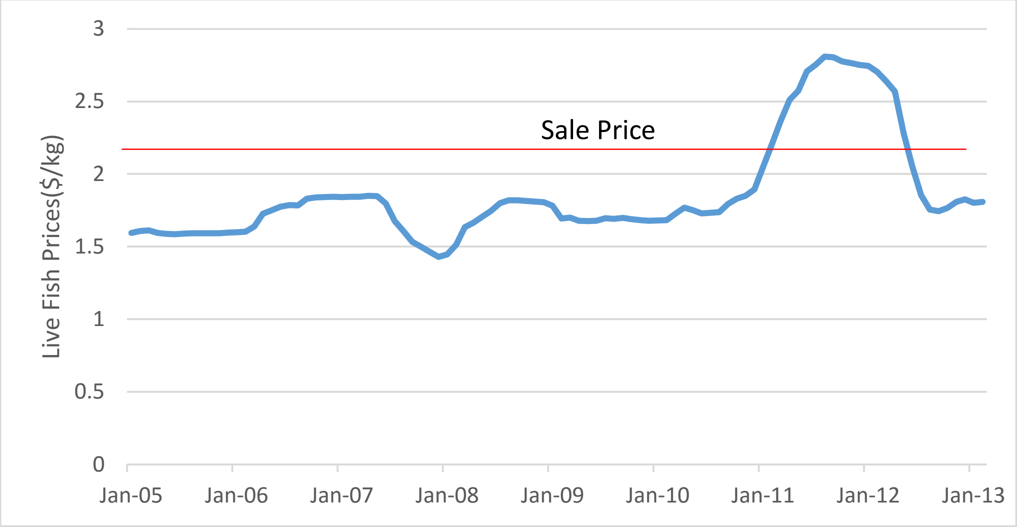


Figure 3.13 Sale Price offered by Processors for live catfish (adapted from USDA, 2013).

The variable cost for each pond setup was slightly different depending on area and use of supplementary PTO aeration (Table 3.6 , see section 3.1.5). The smaller ponds were assumed to provide adequate fish access to paddlewheel aeration and therefore not need supplementary emergency PTO aeration. Labor and infrastructure allocation was assumed to be a function of the number of ponds and pond area. This dynamic can be seen in how it would require more labor to manage 40 one-hectare ponds than to manage 1 forty-hectare pond. Likewise, it also seems logical that 1 forty-hectare pond requires more labor than 1 one-hectare pond. For simplicity allocation was split into two uses, fish feeding and supervision tasks. Base labor is assumed to be the part of labor that is near constant regardless of increase or decrease in-pond surface area. Coverage labor is the pond labor that scales directly with changes in pond area. Feed labor was assumed as 60% area coverage labor and 40% base labor. While supervision tasks were to be totally dependent on the area of the pond. Relative size of each pond indicates the surface area of a pond compared to other ponds on the farm as calculated below (Equation 3.7).

$$Relative\ Pond\ Size = {}^{Indiviual\ Pond\ Surface\ Area}/_{Average\ Pond\ Surface\ Area}$$ Equation 3.7

Fixed cost items included regularly used equipment and capital infrastructure used directly in the culture process (Appendix Table C.1 to C.6). Allocation of percent resources dedicated to an individual pond was based on use of that equipment, number of ponds that share the equipment, and the relative size of the pond (Table 3.8). Some items are shared among the entire farm such as the office, workshop, and landscaping and are divided by the total number of ponds and adjusted for the size of the pond. Electric information includes the cost of all electronic controls and data storage infrastructure cost shared among all ponds. Cost of electronic controls is not affected by the area of the pond. Other pieces of equipment and infrastructure items are to be used only by the ponds near it and used locally. Items such as these include feed trucks, feed bins, and supplemental aeration. Local share items are divided by the number of local pond that share these resources and adjusted for size.

Table 3.8 Open pond fixed cost assumptions.

Fixed Cost Percent Allocation Calculation Assumptions		
Type	Calculation	Items
Whole Farm Share	1/ (total pond number) *Relative size proportion	Office, Shop, Tool, landscaping tractors, tools and accessories
Local Share	1/ (local pond number) *(Relative Size proportion*.6+.4)	Trucks, Feed Trucks, Feed Bins, and PTO Aeration Tractors
Electronic Information	1/ (total pond number)	Computer

Chapter 4 Results and Discussion

The results and discussion chapter is divided into several sections including dissolved oxygen and water quality, harvest and production, and economic analysis. Each section presents results separately for both in-pond raceway and the open pond systems.

4.1 Dissolved Oxygen levels and Water Quality

This section is subdivided into the in-pond raceway system and open ponds setups. This section includes dissolved oxygen levels, the measurement of water movement, and water quality.

4.1.1 In-pond Raceway System Dissolved Oxygen levels and Water Quality

The air that is diffused into the incoming water for the in-pond raceways forces oxygen levels to move toward the oxygen saturation point. This effect causes the maximum DOs to be lower in the raceway cells and the minimums to be higher inside the raceway cells compared to the pond water source. The daily range (defense between daily high and low) is an indication of the stability of DO levels. The daily range in DO in the pond was significantly different ($p<.001$) from the DO in the raceways cells (Figure 4.1). The graph shows an example of DO levels that came from a raceway cell (Figure 4.1). A difference in DO levels in the pond source and raceway cell is expected because the diffused air aerates the water coming from the pond source into the raceway cell. This aeration rate increases as incoming DO in the (pond) gets further away from saturation. This aeration can be seen as the pond source approaches it daily minimum the difference between the raceway and pond becomes greater. Probes were cleaned on Mondays, Wednesdays, and Fridays. Oxygen data was significantly different ($p<0.01$) during the weekends than during the week so it is not shown (see Methods section 3.16).

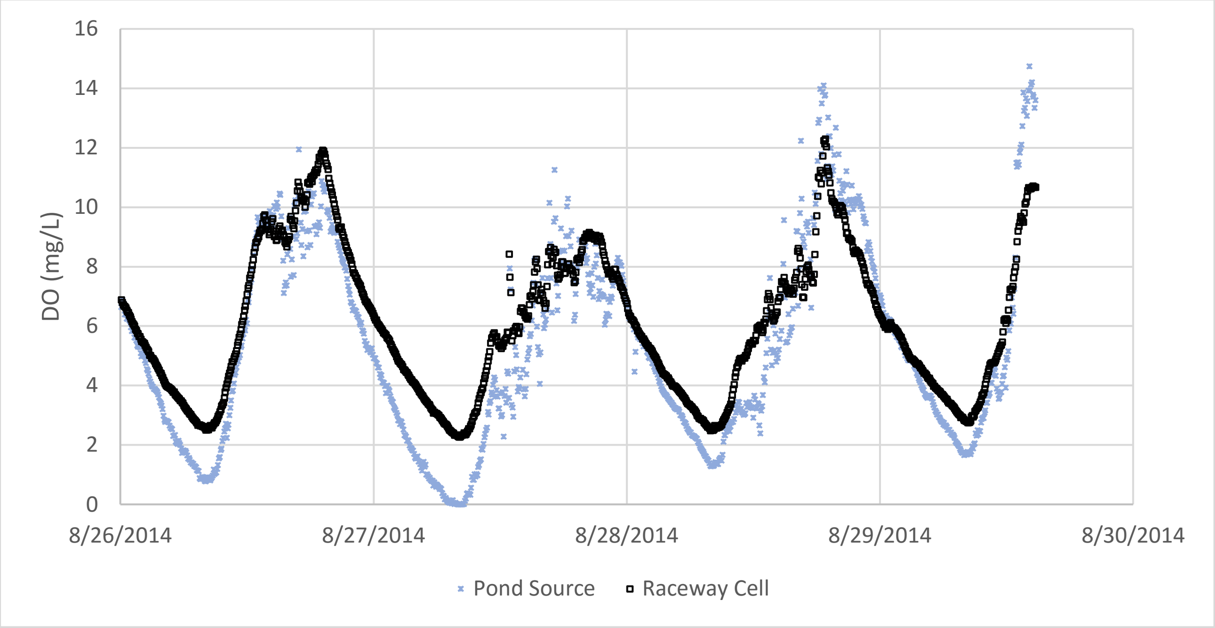


Figure 4.1 DO levels for a raceway cell 8/25/14.

The daily DO range and daily DO minimum in the channel raceway cells and the hybrid raceway cells was not significantly different (p>.1) even though the fish biomass of the hybrid catfish was nearly twice the channels fish mass (3500 and 1800 kg at this date, respectively) (Figure 4.2). The lack of a difference in DO levels at different fish biomass loads may indicate that for the range of biomass studied, fish respiration was not a large factor influencing DO level inside the raceway cells.

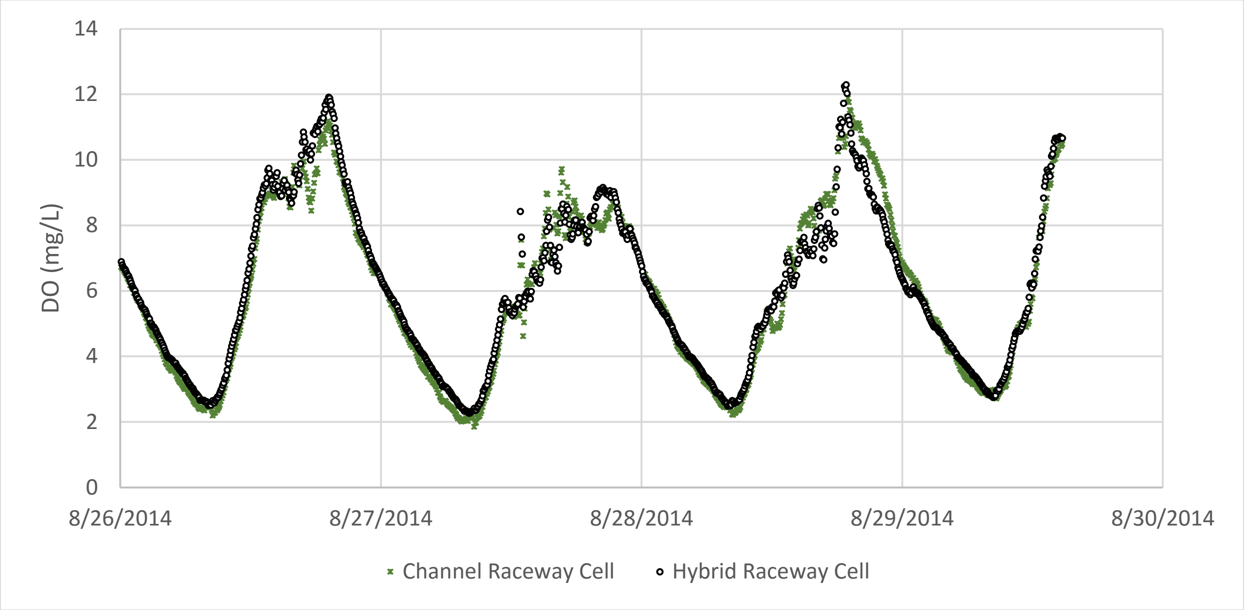


Figure 4.2 DO of hybrid and channel raceway cells for week of 8/25/14.

Over the entirety of the project the lowest DO levels in the raceways cells that were in pond 1 and pond 2 were 2.2 and 1.5 (mg/L), respectively (Figure 4.3). Raceways cells experienced less extreme swings than the pond source in DO as the maximum and the minimum are closer to saturation. The average daily minimum DO for cells 1 and 2 were 3.5 mg/L. The average daily minimum DO for cells 3 and 4 were 4.0 mg/L. For all cells minimum DO levels were above 3 mg/L (Objective #1 In-pond Raceway System).

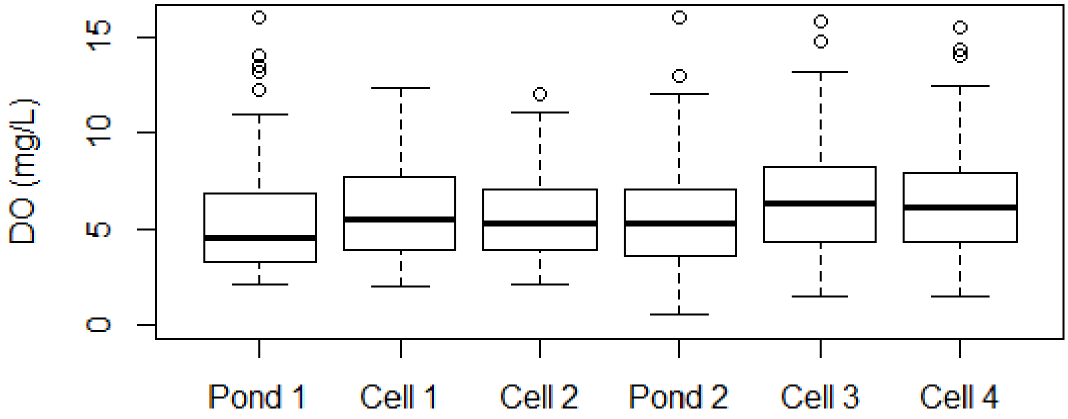


Figure 4.3 Boxplot of In-pond Raceway System DO (for July to October from Tuesday through Friday).

4.1.2 Open Ponds Dissolved Oxygen and Water Quality

Oxygen was measured for each pond continuously by a floating self-cleaning DO probe in each pond. Oxygen was only analyzed for warmer months when fish were feeding (see Methods section 3.2.3). The daily DO ranges of the open pond treatments are displayed in a boxplot below (Figure 4.4). The mean daily oxygen ranges were highest ($P<.05$) for the greatest (XSP) and lowest (XLP) horsepower per area ponds (7.7 and 8.6 mg/L), respectively (Figure 4.4 and Table 4.1). Wide DO ranges are usually associated with higher waste loads and could lead to low DO minimums (Objective #1 Open Pond) or that the unassimilated waste load for the pond is high (Objective #4 Open Pond).

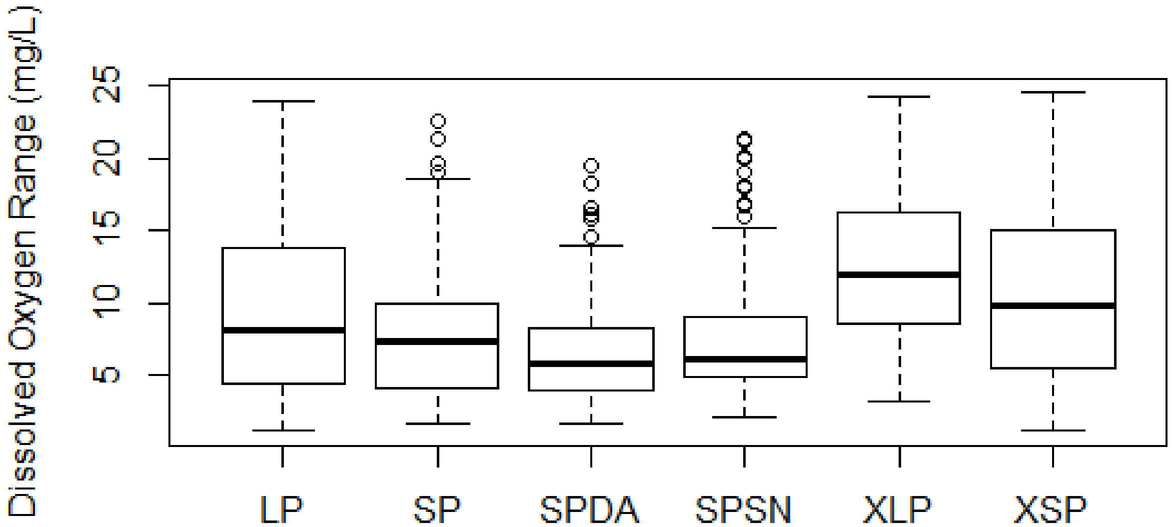


Figure 4.4 DO ranges (mg/L) for open ponds (excludes reduced feeding months of Nov.-March). Note: LP-Large pond with paddlewheel aeration, SP-Small pond with paddlewheel aeration, SPDA-Small pond with paddlewheel aeration and diffused air hood, SPSN-Small pond with paddlewheel aeration and SN mixer, XLP-Extra large pond with paddlewheel aeration, XSP-Extra small pond with paddlewheel aeration.

Table 4.1 Mean daily DO range (mg/L) for open ponds.

	XSP	SP	SPDA	SPSN	LP	XLP
Average Range (mg/L)	7.7^{ab}	6.2^{bc}	4.9^{d}	5.2^{cd}	6.9^{bc}	8.6^{a}

Note: Ponds with same letter are not significantly different at α=0.05, Excludes colder reduced feeding months of Nov. 2014-March 2015. LP-Large pond with paddlewheel aeration, SP-Small pond with paddlewheel aeration, SPDA-Small pond with paddlewheel aeration and diffused air hood, SPSN-Small pond with paddlewheel aeration and SN mixer, XLP-Extra large pond with paddlewheel aeration, XSP-Extra-small pond with paddlewheel aeration.

The mean daily oxygen ranges for SPDA and SPSN ponds (4.9 and 5.2 mg/L) were lower than all other treatments except the small intense paddlewheel ponds (SP) (Table 4.1 and Figure 4.4). This lower DO range could be an indication that the water column was proactively managed and more stable (Objective #4 Open Ponds). These SPDA and SPSN ponds had either the diffused air hoods or SN mixing equipment running during daytime plankton production. The increased water movement during the daytime reduced the difference between daytime DO highs and nightly DO lows. This difference indicates that the mixing equipment is working and in fact reduces the difference between super-saturation high and the nightly minimum DO.

A boxplot summary of daily oxygen minimums are given below for all six open pond treatments (Figure 4.6). Surprisingly, even though a wide range of oxygen treatment methods were used the DO minimums were similar to each other at an average 3.0 mg/L (Objective #1 Open Pond) (Table 4.2 and Figure 4.6). The SN mixer ponds (SPSN) experienced lower minimum dissolved oxygen than other ponds (Table 4.2). This difference in oxygen levels cannot be explained because it was expected to be the same or higher. The fact that daily minimum DO was typically between 3 and 4 mg/L indicates that the fish biomass was appropriate for the oxygen management. However, increasing the minimum DO to closer to 4 mg/L would be expected to improve fish performance (Torrans, 2005 and 2008. Green, 2012). The lack of a significant difference in minimum DO level between most treatments (all except SPSN) could be explained by increased feeding. Increased oxygen management allows fish to increase in feeding(Figure 4.5). The increased feeding increases the pond bioload and theoretically decreases oxygen levels. This reasoning is supported by the high correlation of total feed to oxygen management (R>0.95).

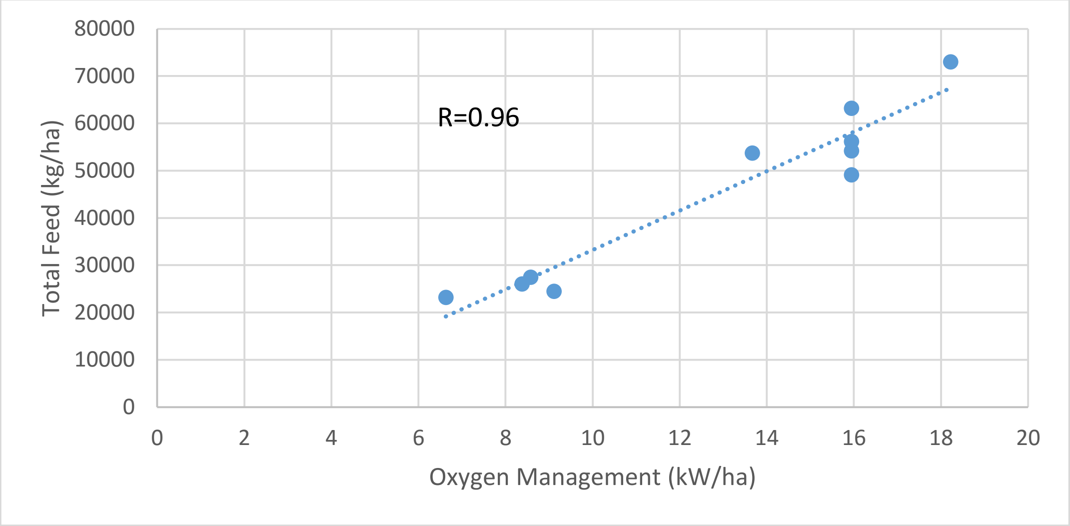


Figure 4.5 Total Feed versus Oxygen Management.

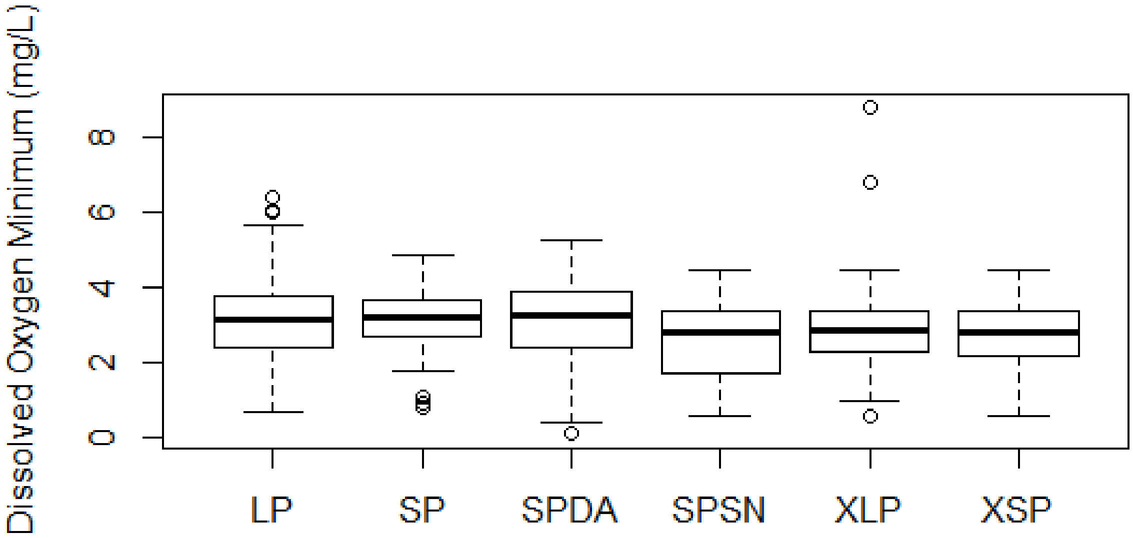


Figure 4.6 Daily minimum DO for open ponds (excludes reduced feeding months of Nov 2014.-March 2015). Note: LP-Large pond with paddlewheel aeration, SP-Small pond with paddlewheel aeration, SPDA-Small pond with paddlewheel aeration and diffused air hood, SPSN-Small pond with paddlewheel aeration and SN mixer, XLP-Extra large pond with paddlewheel aeration, XSP-Extra small pond with paddlewheel aeration.

Table 4.1 Mean daily minimum of dissolved oxygen for open ponds.

	XSP	SP	SPDA	SPSN	LP	XLP
Average Min(mg/L)	2.8^{ab}	3.1^{a}	3.1^{a}	2.6^{b}	3.1^{a}	2.9^{ab}

Note: Ponds with same letter are not significantly different at α=0.05, Excludes colder reduced feeding months of Nov. 2014-March 2015. LP-Large pond with paddlewheel aeration, SP-Small pond with paddlewheel aeration, SPDA-Small pond with paddlewheel aeration and diffused air hood, SPSN-Small pond with paddlewheel aeration and SN mixer, XLP-Extra large pond with paddlewheel aeration, XSP-Extra small pond with paddlewheel aeration.

The buoy that measured DO in the open ponds was also capable of measuring temperature and reached a high of 31 C during the summer growing months and a low of 3 C during the winter as shown by the graph of temperature below (Figure 4.7). Temperature is shown because temperature greatly affects feeding rates of catfish (Buentello, 2001). The temperature was lower from November 2014 to March 2015, leading to reduced feeding.

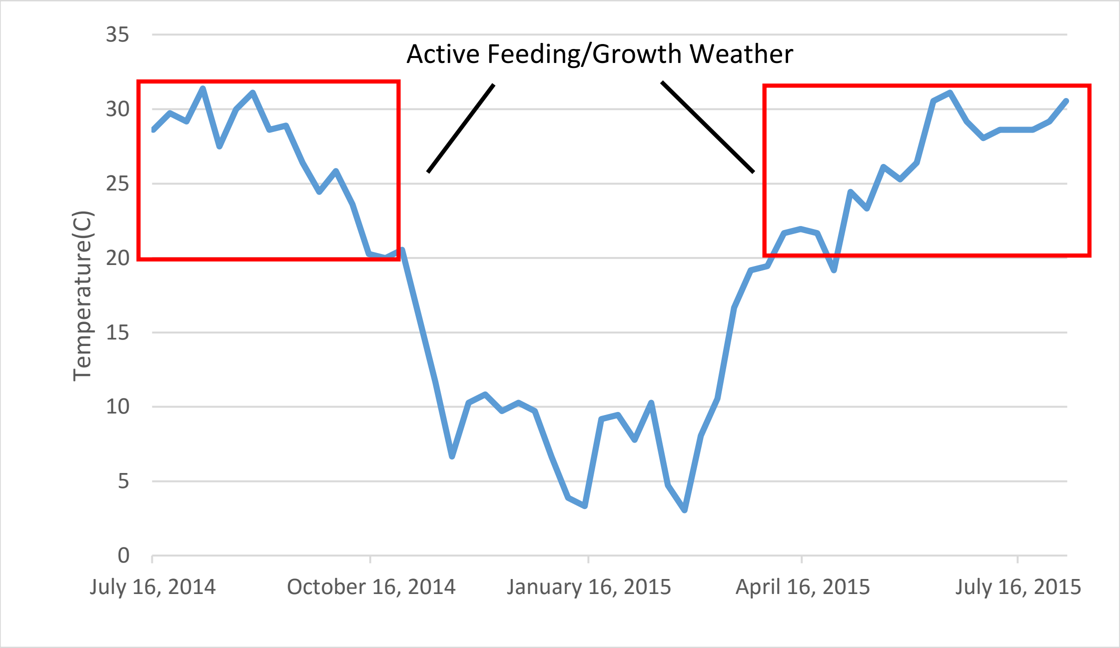


Figure 4.7 Daily temperature and active feeding windows for open ponds.

Nitrogen based water quality can limit production (Objective #2 Open Pond) especially above 20,000 kg/ha (Avnimelech, 2006). Nitrogen based water quality parameters of interest for the six open treatments are shown below (Table 4.2). While TAN appeared higher for the smallest paddlewheel pond (2.6 mg/L) there was no significant statistical difference between the experimental farm setups in this study (Table 4.2).

Table 4.2 Nitrogen based water quality parameters for open ponds.

	XSP	SP	SPDA	SPSN	LP	XLP
TAN Ammonia(mg/L)	2.6±4.3	1.5±3.0	1.2±1.9	1.6±2.9	1.0±2.0	0.6±1.2
Nitrite(mg/L)	0.7±10	0.6±1.0	0.6±1.0	0.7±1.2	0.5±1.4	0.2±0.6

Note: Not statistically different at α=0.05, LP-Large pond with paddlewheel aeration, SP-Small pond with paddlewheel aeration, SPDA-Small pond with paddlewheel aeration and diffused air hood, SPSN-Small pond with paddlewheel aeration and SN mixer, XLP-Extra large pond with paddlewheel aeration, XSP-Extra small pond with paddlewheel aeration.

For the XSP pond and SPSN pond #1 TAN was over 10 mg/L twice between April and May of 2015. This increase in TAN coincided with high fish mortalities due to anemia. Usually nitrogen loads are input by feeding, however when fish die and decompose in the pond, nitrogen levels can increase significantly. This increase in TAN does indicate a potential problem with intensification techniques in reduced water volume. Reducing the overall water volume increases the concentration of any harmful chemicals that are introduced or produced by the system by limiting the dilution effect. Observed alkalinity and chlorides were higher than recommended minimum levels (115 mg/L and 100 mg/L, respectively) (Courtwright, 2013) and are typical for Mississippi Delta ponds.

The whole pond respiration (WPR) value is used for comparison to other pond treatments, and to determine how well waste driven bioload is managed (Objective #4 Open Pond). A lower WPR indicates waste are more proactively managed. The average WPR of all ponds was 1.4 mg L^{-1} hr^{-1}. This result is higher than Hargreaves (1999) which averaged 0.7 mg L^{-1} hr^{-1}. However, an increase in whole pond respiration (WPR) is expected as fish harvest averaged 17,500 kg/ha which is 2.5 times larger than the industry average of 6,500 kg/ha (Courtwright, 2013). Nevertheless, a fish harvest mass had a moderate correlation (R>0.5) to WPR. Higher fish load requires a higher feeding rate. This higher feeding rate increases plankton levels which affect dissolved oxygen levels. A box plot summary of WPR for all six open pond treatments is given below (Figure 4.8). The smallest most intensely aerated paddlewheel pond (XSP) had the highest observed respiration rate (2.3 mg L^{-1} hr^{-1}) (Figure 4.8 and Table 4.3).

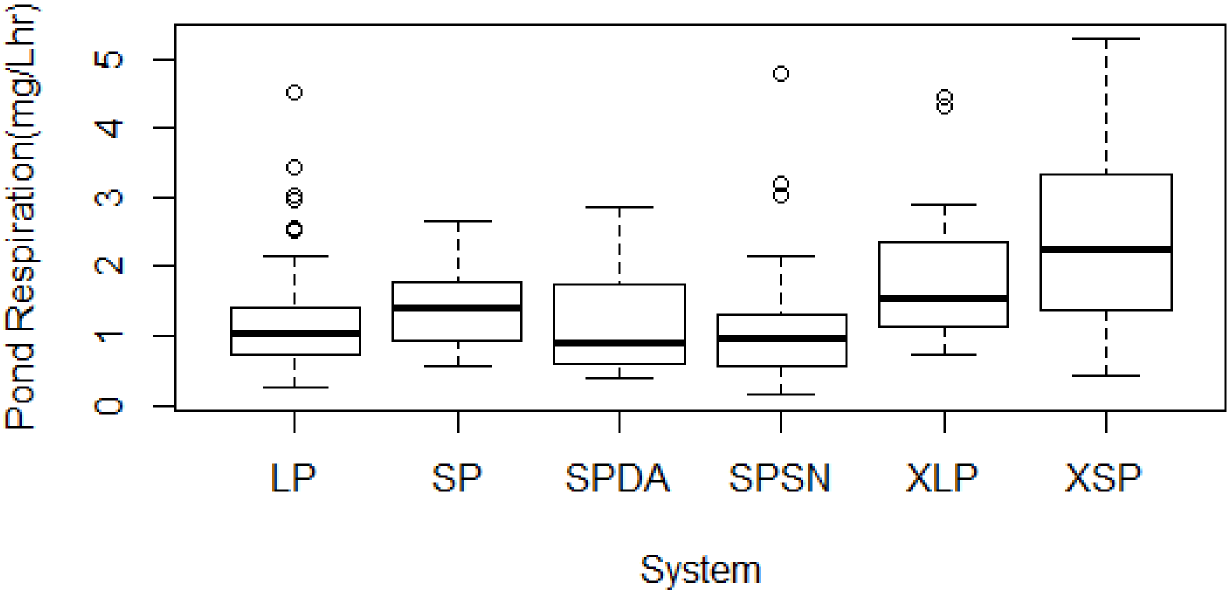


Figure 4.8 Boxplot of whole pond respiration rate (WPR) excludes reduced feeding months of Nov. 2014-March 2015. Note: LP-Large pond with paddlewheel aeration, SP-Small pond with paddlewheel aeration, SPDA-Small pond with paddlewheel aeration and diffused air hood, SPSN-Small pond with paddlewheel aeration and SN mixer, XLP-Extra large pond with paddlewheel aeration, XSP-Extra small pond with paddlewheel aeration.

Table 4.3 Mean of whole pond respiration with statistical differences for open ponds.

	XSP	SP	SPDA	SPSN	LP	XLP
WPR (mg L^{-1} hr^{-1})	2.3^{a}	1.4^{bc}	1.2^{bc}	1.2^{b}	1.3^{b}	1.9^{ac}

Note: Results with same letter are not statistically different at α=0.05, Excludes reduced feeding months of Nov. 2014-March 2015, LP-Large pond with paddlewheel aeration, SP-Small pond with paddlewheel aeration, SPDA-Small pond with paddlewheel aeration and diffused air hood, SPSN-Small pond with paddlewheel aeration and SN mixer, XLP-Extra large pond with paddlewheel aeration, XSP-Extra small pond with paddlewheel aeration.

Both the daily DO range and whole pond respiration (WPR) are affected by plankton levels and graphed below (Figure 4.9). When all open ponds are considered, daily DO range was moderately correlated (R>.6) to respiration rate when graphed below (Figure 4.9). This similarity between DO range and WPR is likely because plankton have been shown to be the largest factor in daily DO extremes and respiration rate (Steeby et al, 2004 and Sun, Yao, et al. 2001).

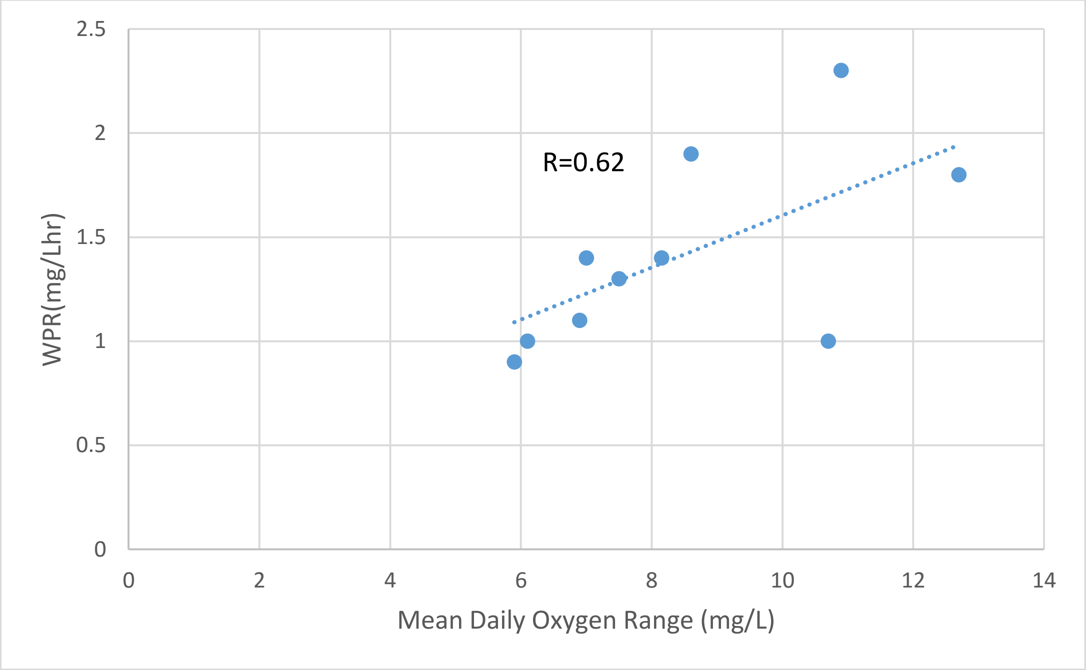


Figure 4.9 WPR versus DO range for open ponds excludes reduced feeding months of Nov. 2014-March 2015.

Feed is the primary source of external organic matter. Total feed was graphed with whole pond respiration to assess how feed affected WPR (Figure 4.10). For paddlewheel aeration only ponds, WPR was moderately correlated to total feed (R>0.5) (Objective #4 Open Pond). However, the SPDA and SPSN ponds fell below the paddlewheel aeration alone relationship for whole pond respiration and feed. The SPDA and SPSN ponds each have one pond inside the 95% confidence interval and one pond outside the 95% confidence interval (Objective #4 Open Pond). Nevertheless, this regression only uses six paddlewheel aeration ponds limiting the importance of this difference (Objective #4 Open Pond). The SPDA and SPSN ponds' lower whole pond respiration could be an indication that the water column is more proactively managed than paddlewheel aeration alone treatments as the WPR level is likely tied to plankton levels in the water column.

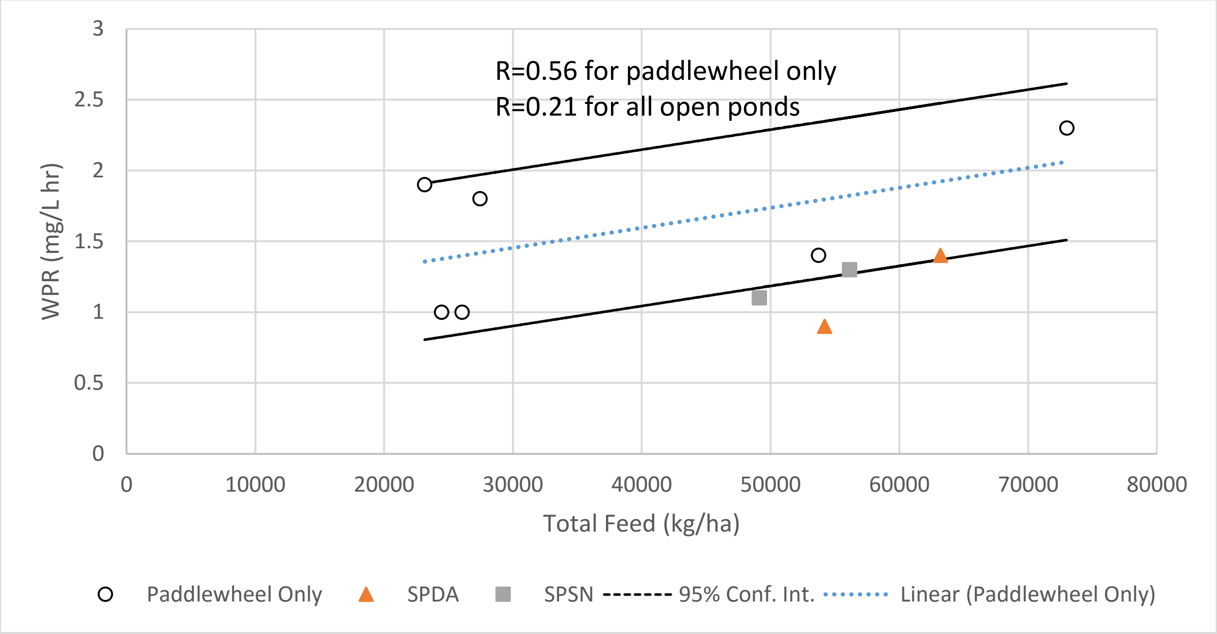


Figure 4.10 Whole Pond Respiration Rate (WPR) versus total feed for open ponds. Note: Excludes reduced feeding months of Nov. 2014-March 2015, SPDA-Small pond with paddlewheel aeration and diffused air hood, SPSN-Small pond with paddlewheel aeration and SN mixer.

4.2 Harvest and Production

This section is subdivided into the in-pond raceways and open ponds and contains harvest results and production characteristics.

4.2.1 In-pond Raceway Setup Harvest and Production

Fish were harvested in November of 2014 and then restocked into the open pond. The total mass of catfish harvested in both floating in-pond raceways was 13,315 kg. The total mass harvested for channels and hybrids was 4323 kg and 8992 kg, respectively, with a grown mass of 3039 kg and 6750 kg for channels and hybrids. The total mass of fish harvested per cell was 2161 kg and 4496 kg, respectively, for channels and hybrids (Table 4.4). These harvest numbers are the basis for calculating the performance characteristics used to compare the raceway cells.

Table 4.4 In-pond raceway harvest data.

Pond	Pond 1	Pond 1	Pond 2	Pond 2
Catfish Species	Channel	Hybrid	Channel	Hybrid
	Cell 1	Cell 2	Cell 3	Cell 4
Harvest Date	11/12/2014	11/12/2014	11/12/2014	11/12/2014
Crop Duration (days)	132	125	132	125
Harvest Weight (kg)	1,782	4,462	2,540	4,530
Harvest Numbers	7,963	10,901	10,406	11,769
Harvest Size (kg/each)	0.22	0.41	0.24	0.38

Channels were in the cells for 132 days, and hybrids for 125 days. The growth rate (g/fish/day) was greater for hybrids compared to channels at 2.4 and 1.2, respectively (Table 4.5). Note fish did not start at the same size nor were they grown to market foodfish size. These growth (g/fish/day) results are similar to those observed in previous raceway studies (Brown, 2011), 1.4 for channels and 2.0 for hybrids, respectively. FCRs were 1.8 and 1.5 for channels and hybrids, respectively (Table 4.5). Improved feed conversion increases the likelihood that a system is profitable (Objective #2 In-pond Raceway System). This number would be higher if fish were grown to market size as metabolic efficiency decreases in larger fish. Higher feed conversion also appeared to be impacted by lower survival (Table 4.5). A table of production characteristics calculated from stocking, harvesting, and feed numbers is shown below (Table 4.5).

Table 4.5 In-pond raceway production characteristics.

Pond	1	1	2	2
Species	Channel	Hybrid	Channel	Hybrid
	Cell 1	Cell 2	Cell 3	Cell 4
Weight Gained(kg)	1,210	3,350	1,828	3,400
Gain per Day(g/fish/day)	1.2	2.5	1.3	2.3
FCR (feed fed/ [End wt.-beg wt.])	2.09	1.48	1.52	1.45
Survival %	61	89	89	94

Brown (2011) observed similar feed conversion ratios (FCR) of 1.7 and 1.4 for channels and hybrids, respectively. Brown (2011) fed fish multiple times a day which improves feed conversion. All of these results are lower than the west Alabama industry average FCR of 2.3 (Courtwright, 2013). This improvement in FCR is important considering feed is usually the most significant cost element at current prices. The survival in this experiment for channel catfish was lower than for hybrid catfish at 75% and 92%, respectively. Low alkalinity appeared to reduce survival (Table 4.5 and Table A.2 in Appendix) and was lower than recommended by Courtwright (2013). A full table of water quality for the raceways is shown in the Appendix (Table A.2). Pond 1 with an alkalinity of 40 (mg/L) showed higher channel mortalities than pond 2 with an alkalinity of 58 (mg/L). These water quality problems appeared to increase Columanaris mortalities, which in turn decreased the harvest mass and feed conversion. Both harvest mass and feed conversion play an important role in profitability of a system (Objective #2 In-pond Raceway System).

Samples were taken from each raceway cell and individually measured for mass and length. Length-mass measurements roughly followed a logarithmic function similar to previous studies (Steeby, 1995) and are shown below for channel (R>0.8) and hybrids (R>0.7) (Equation 4.1 and Equation 4.2).

$$M = 12.2e^{0.096L} \qquad \text{Equation 4.1}$$

$$M = 44.1e^{0.061L} \qquad \text{Equation 4.2}$$

Where M=mass(g) and L=length in cm

Channel catfish had 54% of fish between 0.1-0.3kg with around 25% falling below that and just over 20% reaching a size above that. For hybrids catfish, 54% of fish massed between 0.3-0.5 kg with 22% above 0.5 kg and 24% falling below 0.3 kg (Table 4.6). Harvest sizes are mentioned because feed efficiency of a population decreases with increased variation in sizes. Also as size increases and depending on foodfish demand, catfish foodfish processors may only pay for shipping “big fish” (2 kg +) because there is not an adequate market for these fish so the farmer receives no payment for fish in this size class. A decreased feed efficiency decreases the economic viability of a system (Objective #2 In-pond Raceway System). While there likely could be improvements in population uniformity, uniformity likely did not negatively impact the profitability of the system (Objective #2 In-pond Raceway System).

Table 4.6 Size distribution from In-pond Raceway System.

	Pond 1		Pond 2	
Catfish Species	Channel	Hybrid	Channel	Hybrid
Mass Range(kg)	Cell 1	Cell 2	Cell 1	Cell 2
0.0-0.1	24%	1%	25%	1%
0.1-0.2	30%	3%	29%	5%
0.2-0.3	26%	17%	17%	23%
0.3-0.4	13%	36%	12%	35%
0.4-0.5	3%	20%	7%	17%
>0.5	7%	24%	11%	21%

4.2.2 Open Production Harvest and Production

Energy use can be an effective tool to increase production through improved water quality (Torrans, 2015). Total energy use from stocking to harvest for each pond is graphed below (Figure 4.11). Nightly aeration use was graphed on a secondary axis (Figure 4.11). As expected, energy use increased in ponds with increased oxygen management intensity as seen in a bar graph of energy usage below (Figure 4.11).

The ponds with mixing equipment (SPDA and SPSN) used more energy than ponds with traditional paddlewheel aeration only (XSP, SP, LP, and XLP). This power usage makes sense because equipment was run continuously. The nightly aeration hours were higher for the more intensively managed ponds (XSP, SP, SPDA, and SPSN). Increased aeration hours leads to higher energy cost (Objective #3 Open Pond). However, if a larger mass of fish is grown this may offset any additional energy cost (Objective #3 Open Pond). Increased aeration run time in this study indicates that the system is more reliant on supplemental oxygen and less dependent on plankton production. Increased aeration runtime in ponds with mixing equipment (SPDA and SPSN) is surprising because mixing was expected to increase the amount of productivity oxygen (photosynthesis) that the pond stores and uses (Tucker, 1995).

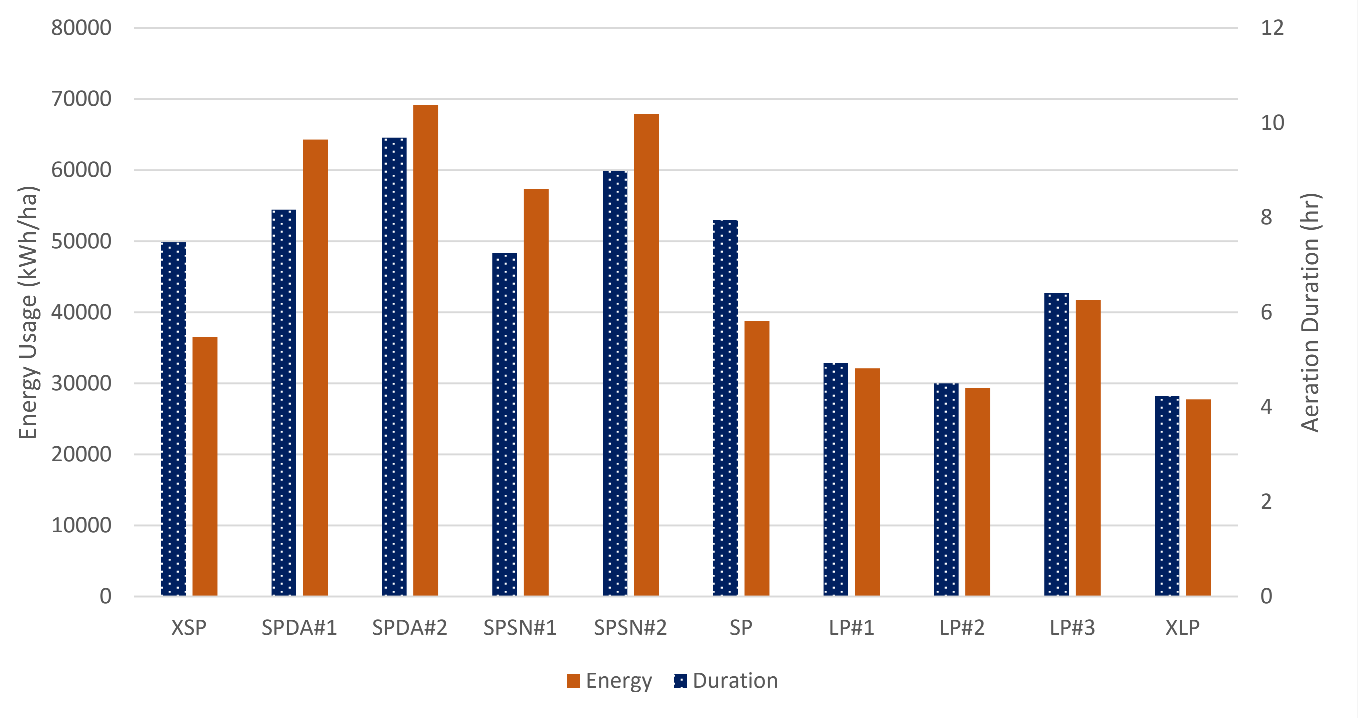


Figure 4.11 Energy usage and aeration duration by each pond. Note: Listed in order of intensity, LP-Large pond with paddlewheel aeration, SP-Small pond with paddlewheel aeration, SPDA-Small pond with paddlewheel aeration and diffused air hood, SPSN-Small pond with paddlewheel aeration and SN mixer, XLP-Extra large pond with paddlewheel aeration, XSP-Extra small pond with paddlewheel aeration.

All ponds took approximately one year to complete a growth cycle. Harvest size breakdown of each pond is listed below (Table 4.7). Fish that cover a wide range of sizes typically are less efficiently grown in terms of feeding, and fish that are larger have less efficient weight gain than smaller fish (Objective #3 Open Ponds). Therefore, it is important to harvest the majority of fish above the 0.68 kg and less than 1.4 kg. At harvest, all open ponds except the SP pond had 75% of fish between 0.45 and 1.36 kg/fish (Table 4.7). All open pond's average size was above 0.68 kg/fish (Table 4.7) which is considered market size. Length and weight were moderately correlated (R was between 0.75 and 0.95) (Appendix Table C.3-C.12).

Table 4.7 Harvested catfish size distribution for open ponds.

	Diffused Air Hoods		Mixing Equipment		Paddlewheel Aeration Only					
Mass(kg)	SPDA #1	SPDA #2	SPSN #1	SPSN #2	XSP	SP	LP #1	LP #2	LP #3	XLP
0-0.45	8%	5%	1%	19%	12%	0%	15%	7%	6%	12%
0.45-0.68	22%	20%	19%	27%	34%	1%	41%	31%	18%	32%
0.68-0.91	36%	33%	37%	26%	29%	12%	27%	34%	23%	26%
0.91-1.36	29%	34%	30%	23%	22%	26%	15%	25%	37%	24%
1.36-1.82	4%	6%	11%	4%	3%	33%	1%	3%	12%	5%
>1.82	2%	2%	2%	0%	0%	28%	0%	1%	3%	1%

Note: LP-Large pond with paddlewheel aeration, SP-Small pond with paddlewheel aeration, SPDA-Small pond with paddlewheel aeration and diffused air hood, SPSN-Small pond with paddlewheel aeration and SN mixer, XLP-Extra large pond with paddlewheel aeration, XSP-Extra small pond with paddlewheel aeration.

The profitability of a system can be dependent on system income and feed cost (Objective #3 Open Pond). These costs come directly from production characteristics of harvest mass/area and feed conversion ratio (FCR). A table of production characteristics for all open ponds is listed below (FCR, Survival, and Production) (Table 4.8).

Five out of six of the most intensively managed open ponds (SPDA1, SPDA2, SPSN1, SP, and XSP) had a net yield of over 22,000 kg/ha (Objective #2 Open Pond). This level of production is significant because the industry average is near 6,500 kg/ha (Courtwright, 2013). Feed conversion ratios (FCR) ranged from 2.3 to 2.9 (Table 4.8). These FCRs are slightly above the industry average of 2.3 (Courtwright, 2013). The highest FCR values are impacted by poor survival as the four ponds with the worst survival had FCRs above 2.5.

A miscommunication with the feed maker had fish fed with feed without extra iron and vitamins. The lack of sufficient iron and vitamin uptake in the fish likely was the cause of the anemia outbreak. Anemia was chronic (mortality events lasted over a month) in five of the ten ponds in the study (XSP, SP, SPSN #1, SPSN #2, and LP #3). The overall problem with anemia is restriction in oxygen carried by the blood. Largely, red blood cells and specifically hemoglobin in the red blood cells carries oxygen throughout the body.

One additional factor that may have led to the anemia outbreak is the gradual increase in phytate (phytic acid) in catfish feeds (Peatman, personal conversation 2015). Phytate is a component in plant based feeds that can bind up minerals and nutrients in the feed. Phytate is difficult for single stomached (poultry, fish, and swine) animals to digest (Peatman, personal conversation. The increase in phytate may have made the increased iron in feed more important because it decrease the amount of iron that was digestible by the fish.

Table 4.8 Open pond production metrics.

	Diffused Air Hoods		Mixing Equipment		Paddlewheel Aeration Only					
Production Metrics	SPDA Pond 1	SPDA Pond 2	SPSN Pond1	SPSN Pond2	XSP	SP	LP Pond 1	LP Pond 2	LP Pond 3	XLP
Pond size(ha)	1.6	1.6	1.6	1.6	1.2	1.6	3.5	3.6	3.3	4.5
Production period(year)	0.95	0.98	0.99	1.01	1.05	1.01	1.01	1.01	0.99	0.99
Cycle start and end dates	7/5/2014	7/29/2014	7/17/2014	7/17/2014	7/17/2014	7/25/2014	7/25/2014	7/5/2014	7/5/2014	7/7/2014
(month/year)	6/18/2015	7/23/2015	7/14/2015	7/21/2015	8/4/2015	7/29/2015	7/30/2015	7/7/2015	7/1/2015	7/5/2015
Stocking Rate(Fish/ha)	36,190	35,504	32,695	33,736	44,744	33,830	19,440	18,993	19,389	17,209
Stocking Size(kg)	0.07	0.07	0.07	0.07	0.07	0.07	0.05	0.07	0.06	0.07
Aeration(kW/ha)										
Total Harvested(kg)	41,616	44,841	39,027	34,450	31,753	36,545	45,586	42,630	33,439	48,346
Grown Mass(kg)	37,563	40,864	35,365	30,672	27,994	32,756	42,184	37,844	29,600	42,925
Net yield (kg ha-1 year-1)	23,477	25,540	22,103	19,170	23,328	20,472	12,053	10,512	8,970	9,539
Harvest Size(kg)	0.84	0.86	0.87	0.84	0.88	0.83	0.73	0.73	0.82	0.73
Survival (%)	84%	89%	79%	72%	64%	78%	92%	86%	64%	85%
Total Feed(kg/ha)	54,793	60,831	58,124	48,278	66,814	50,273	27,406	24,391	23,302	22,762
FCR	2.3	2.4	2.6	2.5	2.9	2.5	2.3	2.3	2.6	2.4

Note: LP-Large pond with paddlewheel aeration, SP-Small pond with paddlewheel aeration, SPDA-Small pond with paddlewheel aeration and diffused air hood, SPSN-Small pond with paddlewheel aeration and SN mixer, XLP-Extra large pond with paddlewheel aeration, XSP-Extra small pond with paddlewheel aeration.

Survival in the SPDA ponds averaged 87% (Table 4.8). Ponds 3.2 ha and larger average 81% survival over the production cycle (Table 4.8). Only one of the ponds 3.2 ha and larger exhibited visual chronic mortalities from anemia and had survival below 85% (Table 4.8). However, one large pond (LP#3) did get anemia and exhibited survival of 64% percent (Table 4.8). Four of the six ponds smaller than 1.7 ha exhibited chronic mortalities from anemia (The other two exhibited minor mortalities to anemia over the first week). The two SPDA ponds average a survival of 86% as mortalities to anemia were less significant (Table 4.8).

Since anemia is a lack of ample oxygen flow through the blood. Any increase in survival could be due to reduced hemoglobin problems or increased oxygen levels in a way not detectable by single probe detection. This on farm case study did not have replicated trials therefore statistical difference in survival was not performed. Fish survival was moderately correlated to FCR (R>0.8) to profit/ha (R=0.8) (Objective #3 Open Pond).

Production (kg/ha) was graphed with oxygen management (kW/ha) for all open ponds using paddlewheel aeration alone (XLP, LP, SP, and XSP) (Figure 4.12). Oxygen management with increased production correlated well with increased in paddlewheel aeration as graphed below(R>0.95) (Figure 4.12) (Objective #2 Open Pond). This indicates that for the range studied increased aeration is a dependable way to increase production at least up to approximately 18 kW/ha.

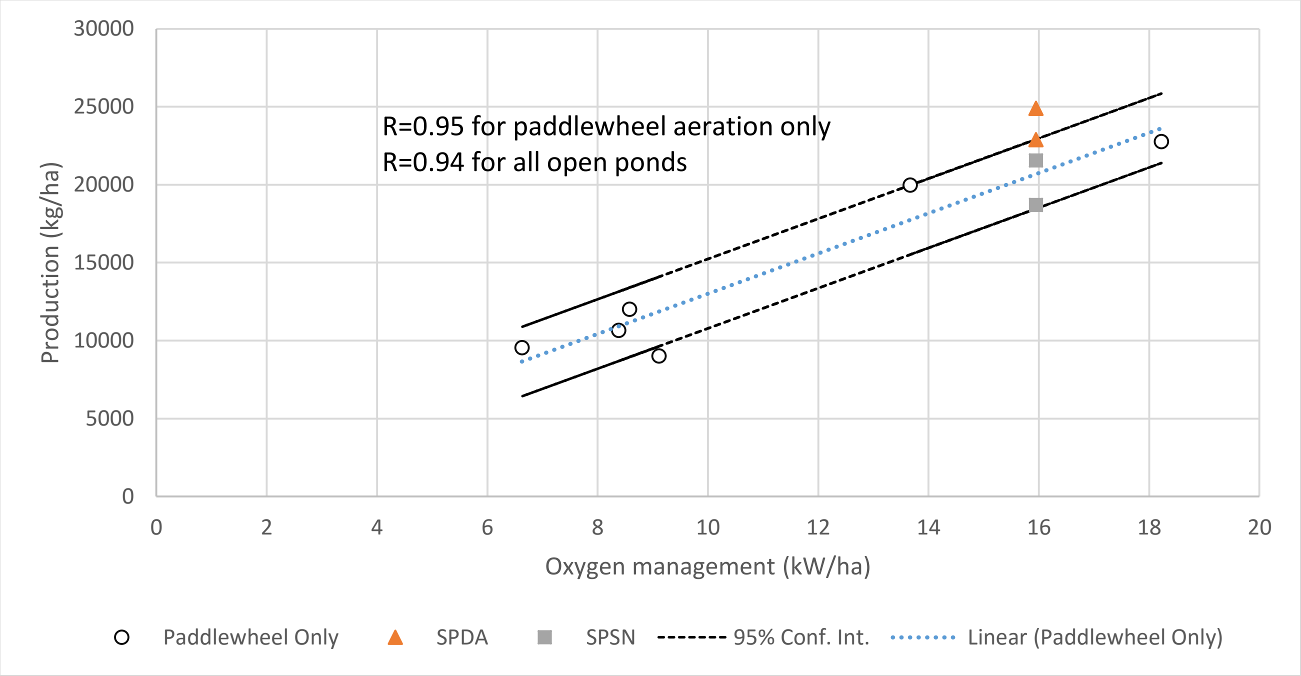


Figure 4.12 Oxygen management effect on fish production with 95% confidence interval. Note: SPDA-Small pond with paddlewheel aeration and diffused air hood, SPSN-Small pond with paddlewheel aeration and SN mixer.

The most intense pond (XSP) had a production of 23,328 kg ha^{-1} yr^{-1} (Table 4.8). The ponds with paddlewheel aeration and SN mixers (SPSN) fell on the regression of the paddlewheel aeration (Objective #2 Open Pond). The ponds with diffused air hoods (SPDA) outperformed the regression of production for paddlewheel aeration and is above the 95% confidence interval (Figure 4.12) (Objective #2 Open Pond). The SPDA ponds had an average production of 24,508 kg ha^{-1} yr^{-1} (Table 4.8). This level of production is significant because the highest reported farm production in west Alabama from the two year survey was 24,000 kg (Courtwright, 2013).

4.3 Economic Analysis

This section contains the enterprise budgets showing the cost of production and additional economic analysis. This section is subdivided into in-pond raceways and open ponds.

4.3.1 In-pond Raceway System Economic Analysis

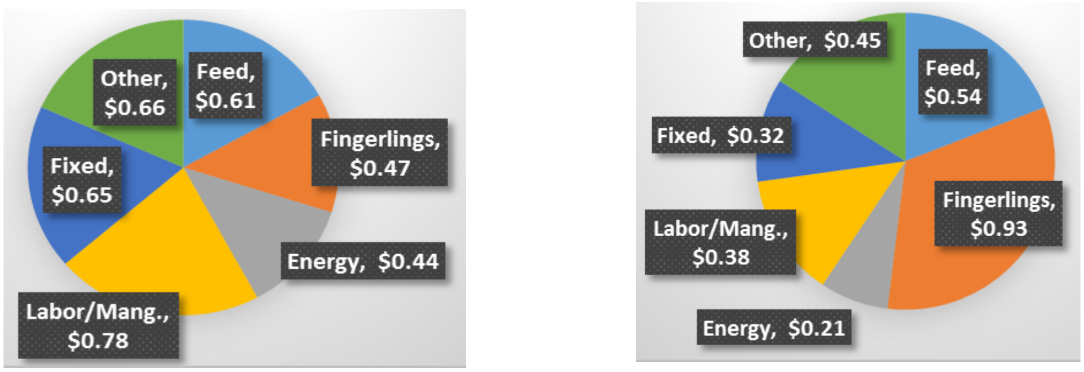
An enterprise budget was created to determine the cost to produce one kg of fish. Fish were not grown to marketable foodfish size rather restocked in the traditional open pond. A sale price of $2.75/kg was assumed based on interpolation of fingerling and foodfish prices. The cost to produce ($/kg) is usually compared to the sale price to determine if the system is profitable. At the experimental setup of 0.8 cells/ha neither the hybrid nor channel in-pond raceways made money as seen below (Table 4.9) (Objective #2 In-pond raceway setup). For the experimental setup raising channel catfish the price to produce was $4.55/kg and $3.39/kg for ponds 1 and 2, respectively. The hybrid catfish had a lower and more consistent price to produce ($/kg) at 2.83 and 2.82 in pond 1 and 2, respectively. This table shows in the first column the total cost of each item (Table 4.9). The table shows the cost normalized by area and mass, respectively in columns two and three. When channel catfish were grown, the largest cost was labor. Second was fixed costs for the system when channel catfish were grown. When hybrid catfish were grown, the largest costs were fingerlings. Second was feed costs (for more detail see Appendix Tables B.3-B.8). For the hybrid catfish produced feed accounted for less than 20% of total cost (Table 4.9).

Table 4.9 Budget for studied 0.86 cells/ha in-pond raceway at 10% interest.

Budget parameter	Pond 1						Pond 2					
Species	Channel catfish			Hybrid catfish			Channel catfish			Hybrid catfish		
	$	$/ha	$/kg	$	$/ha	$/kg	$	$/ha	$/kg	$	$/ha	$/kg
Harvest Mass(kg)	3,351			8,980			4,504			8,958		
Growth Period(months)	4			4			4			4		
Projected Income	9,215	3,732	2.75	24,696	10,002	2.75	12,387	5,017	2.75	24,634	9,977	2.75
Variable Costs												
Feed	2,353	953	0.70	4,935	1,999	0.55	2,259	915	0.50	4,820	1,952	0.54
Labor and Management	3,370	1,365	1.01	3,370	1,365	0.38	3,370	1,365	0.75	3,370	1,365	0.38
Fingerlings	2,035	824	0.61	8,305	3,364	0.92	2,035	824	0.45	8,305	3,364	0.93
Harvest and Transport	369	149	0.11	988	400	0.11	495	200	0.11	985	399	0.11
Energy	2,024	820	0.60	2,024	820	0.23	2,024	820	0.45	2,024	820	0.23
Chemicals	1,398	566	0.42	1,398	566	0.16	1,398	566	0.31	1,398	566	0.16
Interest on operating capital	866	351	0.26	1,576	638	0.18	868	352	0.19	1,568	635	0.18
Total variable costs	12,413	5,027	3.70	22,596	9,151	2.52	12,448	5,041	2.76	22,468	9,100	2.51
Income above variable cost	(3,198)	(1,295)	(0.95)	2,100	851	0.23	(61)	(25)	(0.01)	2,166	877	0.24
Total Fixed Costs (adjusted to 4 months)	2,826	1,145	0.84	2,826	1,145	0.31	2,826	1,145	0.63	2,826	1,145	0.32
Total Costs	15,239	6,172	4.55	25,422	10,296	2.83	15,275	6,186	3.39	25,294	10,244	2.82
Net returns to land	(6,024)	(2,440)	(1.80)	(726)	(294)	(0.08)	(2,888)	(1,170)	(0.64)	(660)	(267)	(0.07)

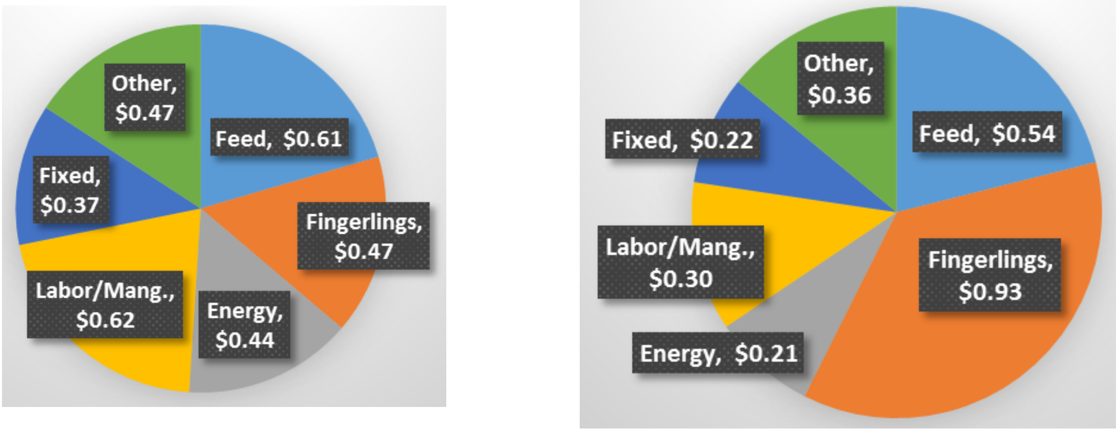
It can be seen that for the experimental setup (Table 4.9) labor and electrical cost can be relatively significant if fish biomass is not successfully grown. This effect is different from traditional pond culture which only aerates in response to low DO. Currently the raceway cells use energy and labor inputs constantly regardless of fish load. Traditional open pond culture on the other hand typically reacts to problems. Managing the system rather than reacting to problems has the benefit of managing them before they become catastrophic. However, this proactive management can become expensive if enough fish are not grown to offset these inputs. This price dynamic can be seen in channel catfish in pond 1 by labor and energy cost accounting for $1.61/kg of the cost (Table 4.9). Fern in prototype research floating in-pond raceways (2014) saw similar price dynamics where fingerling, feed, electricity, and capital depreciation were the highest costs when channel and hybrid catfish fingerlings were raised to stocker size.

A pie chart was created showing for the floating in-pond raceways the largest cost elements for the experimental 0.8 cells/ha setup and the projected 2.43 cells/ha setup. The economics change favorably as the number of raceways increase to 2.43 cells/ha (Figure 4.13). The projected production over the four months for channels and hybrid catfish grown in a 2.43 cells/ha setup would be 3,708 and 8,201 kg/ha, respectively. This graphic shows that as the number of cells increase labor cost and fixed cost decrease (Figure 4.13).



A. Experimental 0.8 cell/ha channels
Total cost $3.61 per kg

B. Experimental 0.8 cell/ha hybrids
Total cost $2.83 per kg



C. Projected 2.43 cell/ha channels
Total cost $2.98 per kg

D. Projected 2.43 cell/ha hybrids
Total cost $2.56 per kg

Figure 4.13 Pie chart of cost per kg of and total cost for in-pond raceway system.

If the number of raceways per pond is increased, fixed cost per kg, should decrease and work should be done more efficiently further decreasing labor cost (for full budget see Appendix Table B.9-B.12). However even when the raceways were projected to 2.43 cells/ha raising channel catfish was not profitable (Objective #3 In-pond Raceway System). The projected hybrid catfish 2.43 cells/ha setup theoretically made a profit, but the profitability was dependent on the market value of fish at this size (Figure 4.14 and Figure 4.15) (Objective #3 In-pond Raceway System).

A spider plot of the profit for the projected 2.43 cells/ha setup is shown below where the largest factors of the enterprise budget were independently varied (static) in a sensitivity analysis (Figure 4.14 and Figure 4.15). Factors were varied from -50% to +50% to determine each factors effect on profitability ($/ha).

Fish are rarely not sold above 0.2 kg until they reach market size of 0.68 kg for food fish so the estimated value of fish in this study may not be accurate. In reality, it may be hard to find someone willing to pay much more than the market foodfish price ($2.2 per kg) for fish near market size. As expected profitability of all systems was more dependent on income (payment received for fish) than all other factors. An increase in market price of just 10% could cause the hybrid catfish in a 2.43 cells/ha setup to almost double in profit (money farmer makes after accounting for expenses) (Objective #3 In-pond Raceway System) and brought the farmer near profitability (Objective #3 In-pond Raceway System) when raising channels channel (Figure 4.14 and Figure 4.15).

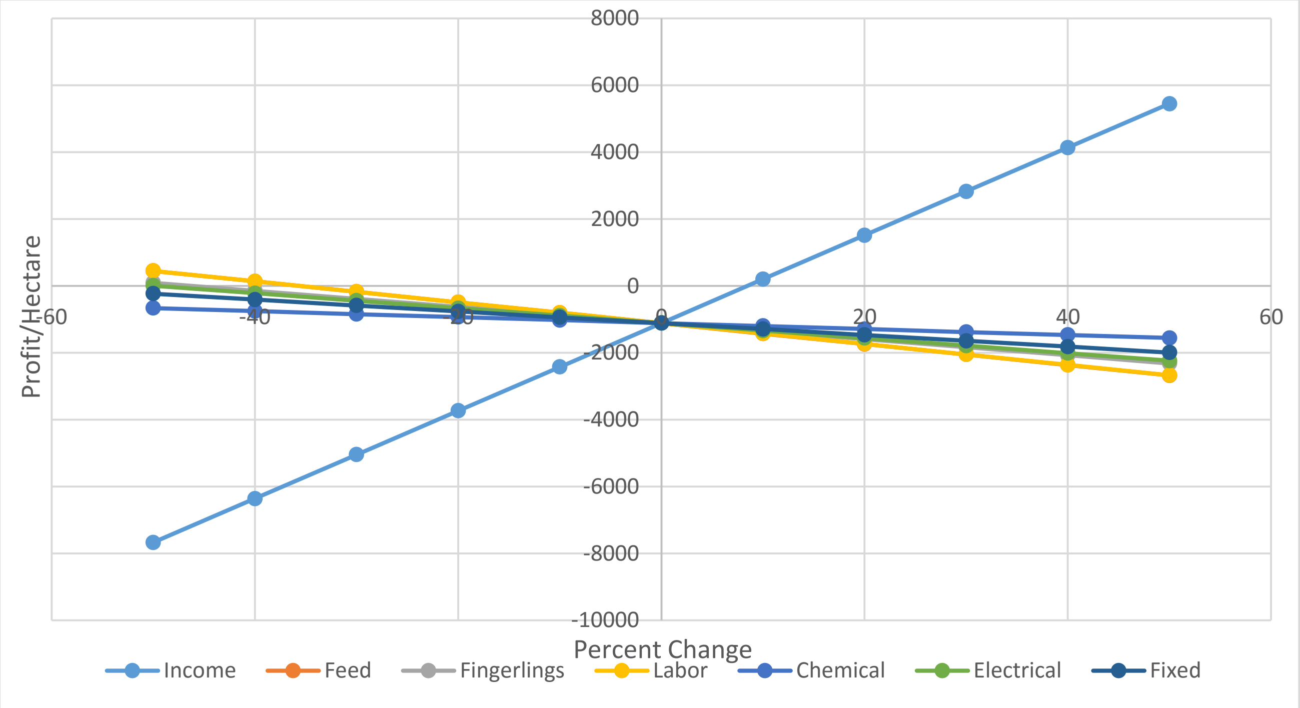


Figure 4.14 Profit spider plot (Sensitivity) of 2.43 cells/ha raceway raising channel catfish.

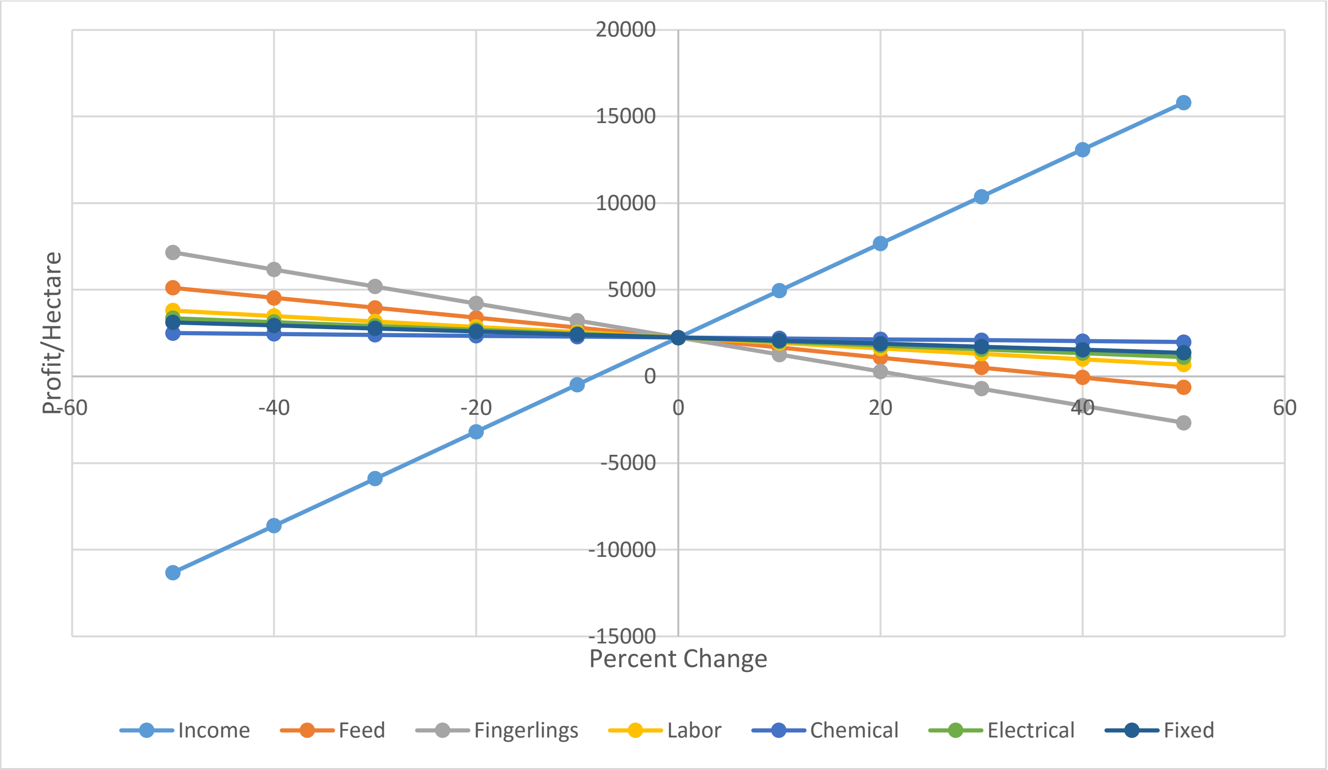


Figure 4.15 Profit spider plot (Sensitivity) of 2.43 cells/ha raceway raising hybrid catfish.

Likewise, with a 10% decrease in market price the farmer growing hybrids (2.43 cells/ha) would start to lose money and the farmer growing channels would lose money at nearly double the rate (Figure 4.14 and Figure 4.15) (Objective #3 In-pond Raceway System). For the projected set-up (2.43 cells/ha) while growing channel catfish (Figure 4.14), labor and electricity were some of the most important factors affecting profitability of the system. Feed was just as significant as labor but difficult to see for channel catfish grown in 2.43 cells/ha raceways (Figure 4.14). These factors show that while these cost were not as significant for the hybrids (Figure 4.15) they can be significant if fish biomass is not successfully grown (Objective #3 In-pond Raceway System). A common improvement for the energy usage is to interconnect air lines between raceway cells so the number of blowers operated is scaled to biomass. If raceways are used commercially, the industry will likely simplify much of the labor task as the natural process of adapting it to the industry.

For hybrid catfish grown to 0.4 kg, price of fingerlings was one of the largest costs (Figure 4.15). This distribution of cost is different from the rest of the industry (mostly channels) (Courtwright, 2013) and the intensive hybrid ponds studied at the other farm case study (Figure C.13-C.18) where feed price dominates cost. This distribution of cost should change as fish are grown to market size. Higher fingerling costs does not mean that buying cheaper fingerlings leads to increased profitability. It is obviously not the case or channel catfish should be used exclusively and that is not the case. Rather, high fingerling cost means that fingerlings should be bought carefully making sure that fingerling quality is worth the price being paid for better survival and higher annual production.

These floating in-pond raceways have a much lower capital cost (2.5 times) than the fixed in-pond raceways tested by Brown (2011). Even though the experimental floating in-pond raceways in this study were not shown to be profitable, under the conditions tested continual improvements should make these raceways more viable.

4.3.2 Open Pond Economic Analysis

A complete enterprise budget for each pond is given in the tables below (Table 4.10, Table 4.11, and Table 4.12) (For more details on fixed cost see Appendix Table C.1-C.6). Variable cost and fixed cost are broken down and shown how they affect the cost per kg and profit per acre. The ponds with diffused air hoods (SPDA) largely increased profits($/ha) (Objective #3 Open Ponds) over the other intensive treatments (XSP, SP, and SPSN) by raising more kg of fish while holding steady most variable cost and fixed costs except feed.

All open ponds that lost money had survival rate less than 75% (Table 4.10, Table 4.11, and Table 4.12). In fish culture, large mortality events can lead to a negative feedback loop where decaying fish compromise water quality in terms of oxygen, bioload, and disease population. This result is likely not typical as anemia may have been avoided with increased digestible iron and vitamins in the feed.

Nevertheless, this result does indicate that with high production ponds there is a significant level of risk. If significant losses occur, realizing a profit can be difficult. Costs of production for XP, SP, SPDA, SPSN, LP and XLP ponds were 2.31, 2.04, 1.94, 2.26, 2.09, and 2.10 ($/kg), respectively (Table 4.10, Table 4.11, and Table 4.12). Oxygen management did not correlate ($R<0.5$) well with cost of production ($/kg) (Objective #3 Open Pond).

Sensitivity analysis is shown in the Appendix (Figure C.13-C.18) where each factor was varied independently from -50% to +50%. Largely all plots had the same general sensitivity for each factor. The main differences economically between treatments were income (related to production) and feed cost (related to FCR).

Table 4.10 Enterprise budget for SPDA and SPSN open ponds at 10% interest.

	Diffused Air Hoods						Mixing Equipment					
	SPDA Pond 1			SPDA Pond 2			SPSN Pond1			SPSN Pond2		
	$	$/ha	$/kg	$	$/ha	$/kg	$	$/ha	$/kg	$	$/ha	$/kg
Harvest Mass(kg)	45,399			46,791			39,027			34,450		
Growth Period(months)	11			12			12			12		
Projected Income	99,878	60,676	2.20	102,939	62,536	2.20	85,860	52,160	2.20	75,790	46,042	2.20
Variable Costs												
Feed	47,226	28,690	1.04	50,428	30,635	1.08	45,837	27,846	1.17	39,668	24,098	1.15
Labor and Management	1,685	1,024	0.04	1,685	1,024	0.04	2,376	1,444	0.06	2,376	1,444	0.07
Fingerlings	14,297	8,686	0.31	13,416	8,150	0.29	13,680	8,311	0.35	13,680	8,311	0.40
Harvest and Transport	4,994	3,034	0.11	5,147	3,127	0.11	4,293	2,608	0.11	3,790	2,302	0.11
Energy	7,635	4,638	0.17	8,314	5,051	0.18	6,866	4,171	0.18	8,031	4,879	0.23
Chemicals	979	595	0.02	979	595	0.02	979	595	0.03	979	595	0.03
Interest on operating capital	5,761	3,500	0.13	5,998	3,644	0.13	5,552	3,373	0.14	5,139	3,122	0.15
Total variable costs	82,578	50,166	1.82	85,967	52,225	1.84	79,584	48,347	2.04	73,664	44,751	2.14
Income above variable cost	17,300	10,510	0.38	16,972	10,311	0.36	6,276	3,813	0.16	2,126	1,292	0.06
Total Fixed Costs	5,051	3,068	0.11	5,051	3,068	0.11	5,979	3,632	0.15	6,616	4,019	0.19
Total Costs	87,629	53,234	1.93	91,017	55,293	1.95	85,563	51,980	2.19	80,279	48,770	2.33
Net returns to land	12,250	7,442	0.27	11,922	7,242	0.25	297	180	0.01	(4,489)	(2,727)	(0.13)

Note: SPDA-Small pond with paddlewheel aeration and diffused air hood, SPSN-Small pond with paddlewheel aeration and SN mixer.

Table 4.11 Enterprise Budget XSP and SP open ponds at 10% interest.

	Paddlewheel Aeration					
	XSP			SP		
	$	$/ha	$/kg	$	$/ha	$/kg
Harvest Mass(kg)	31,710			36,532		
Growth Period(months)	12			12		
Projected Income	69,762	56,507	2.20	80,370	48,825	2.20
Variable Costs						
Feed	40,912	33,138	1.29	39,050	23,723	1.07
Labor and Management	1,791	1,450	0.06	2,090	1,270	0.06
Fingerlings	12,320	9,979	0.39	13,680	8,311	0.37
Harvest and Transport	3,488	2,825	0.11	4,019	2,441	0.11
Energy	4,412	3,574	0.14	4,825	2,931	0.13
Chemicals	789	639	0.02	979	595	0.03
Interest on operating capital	4,778	3,870	0.15	4,848	2,945	0.13
Total variable costs	68,490	55,477	2.16	69,492	42,217	1.90
Income above variable cost	1,272	1,030	0.04	10,878	6,608	0.30
Total Fixed Costs	4,794	3,883	0.15	5,019	3,049	0.14
Total Costs	73,284	59,360	2.31	74,512	45,266	2.04
Net returns to land	(3,522)	(2,853)	(0.11)	5,858	3,559	0.16

Note: XSP-Extra small pond with paddlewheel aeration, SP-Small pond with paddlewheel aeration.

Table 4.12 Enterprise Budget for LP and XLP ponds open ponds at 10% interest.

	Paddlewheel Aeration											
	LP Pond 1			LP Pond 2			LP Pond 3			XLP		
	$	$/ha	$/kg	$	$/ha	$/kg	$	$/ha	$/kg	$	$/ha	$/kg
Harvest Mass(kg)	49,731			44,509			33,439			48,346		
Growth Period(months)	11			12			12			12		
Projected Income	109,407	31,278	2.20	97,920	27,350	2.20	73,565	22,345	2.20	106,360	23,496	2.20
Variable Costs												
Feed	51,066	14,599	1.03	46,937	13,110	1.05	39,403	11,969	1.18	52,784	11,660	1.09
Labor and Management	3,370	963	0.07	3,791	1,059	0.09	3,370	1,024	0.10	4,845	1,070	0.10
Fingerlings	16,320	4,666	0.33	14,960	4,178	0.34	14,043	4,266	0.42	17,138	3,786	0.35
Harvest and Transport	5,470	1,564	0.11	4,896	1,368	0.11	3,678	1,117	0.11	5,318	1,175	0.11
Energy	4,809	1,375	0.10	4,665	1,303	0.10	5,867	1,782	0.18	4,884	1,079	0.10
Chemicals	1,338	383	0.03	1,362	380	0.03	1,279	388	0.04	1,635	361	0.03
Interest on operating capital	6,178	1,766	0.12	5,746	1,605	0.13	5,073	1,541	0.15	6,495	1,435	0.13
Total variable costs	88,552	25,315	1.78	82,357	23,003	1.85	72,714	22,087	2.17	93,099	20,566	1.93
Income above variable cost	20,855	5,962	0.42	15,563	4,347	0.35	851	258	0.03	13,262	2,930	0.27
Total Fixed Costs	6,196	1,771	0.12	7,413	2,070	0.17	6,066	1,843	0.18	8,267	1,826	0.17
Total Costs	94,748	27,087	1.91	89,770	25,074	2.02	78,780	23,929	2.36	101,366	22,393	2.10
Net returns to land	14,659	4,191	0.29	8,150	2,276	0.18	(5,215)	(1,584)	(0.16)	4,995	1,103	0.10

Note: LP-Large pond with paddlewheel aeration, XLP-Extra large pond with paddlewheel aeration.

Total oxygen management cost for each crop of fish is the sum of the initial cost (normalized for duration of crop), aeration energy cost, and mixing energy cost was graphed for all six open pond treatments and the 2.43 cells/ha in-pond raceway setup (Figure 4.16). As expected, the biomass of fish produced generally increased with oxygen management.

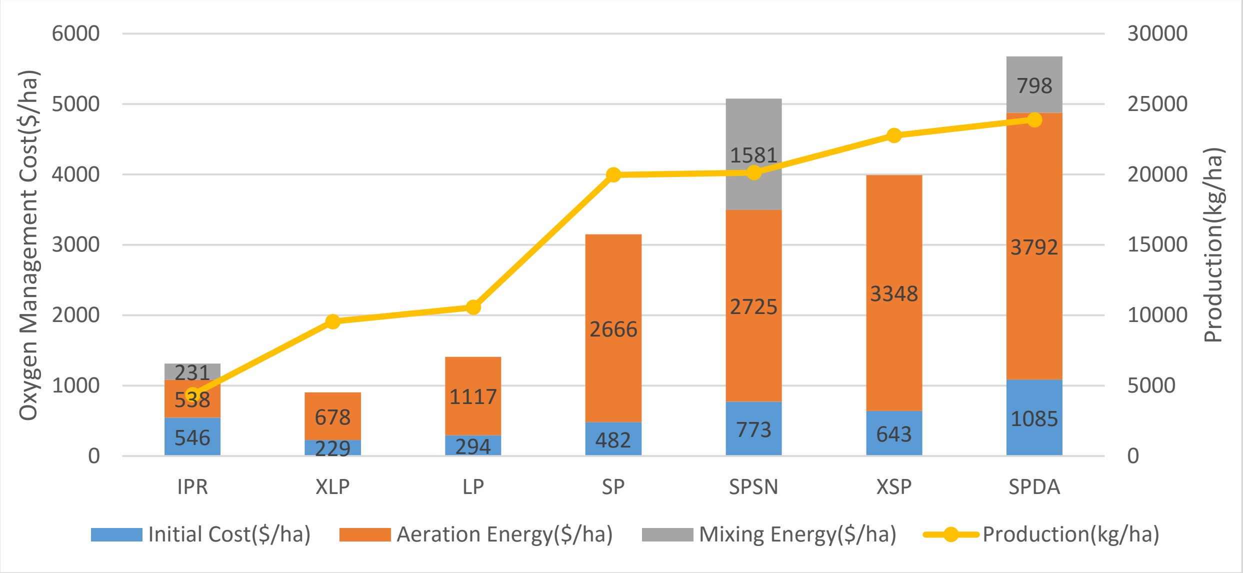


Figure 4.16 Oxygen management cost breakdown and fish production per crop for each system. Note: LP-Large pond with paddlewheel aeration, SP-Small pond with paddlewheel aeration, SPDA-Small pond with paddlewheel aeration and diffused air hood, SPSN-Small pond with paddlewheel aeration and SN mixer, XLP-Extra large pond with paddlewheel aeration, XSP-Extra small pond with paddlewheel aeration.

Energy use was higher (kW/ha) in SPDA ponds and SPSN ponds compared to other open ponds (Figure 4.16 and Figure 4.11). Energy use was likely higher due to daytime energy use (Figure 4.16). These ponds with mixing equipment had higher energy cost and higher initial cost ($/ha). Energy use could likely be reduced by using a mixing schedule during the afternoon between 1400 and 1700 similar to Szyper (1990). However, mixing equipment was run constantly to see if there were any improvements in water quality or fish production characteristics. Compared to paddlewheel aeration alone ponds, pond mixing equipment and paddlewheel aeration (SPSN and SPDA) was a more expensive way to increase production (Figure 4.16).

Figure 4.17 shows the production by cost of oxygen management for each system (\$ ha^{-1} crop^{-1}). Systems that proactively managed water (IPRS, SPDA, and SPSN) or operated on a regular basis rather than in response to water quality problems (DO levels waste loads, and nitrogen level) had higher initial costs and higher operating costs (Figure 4.16 and Figure 4.17).

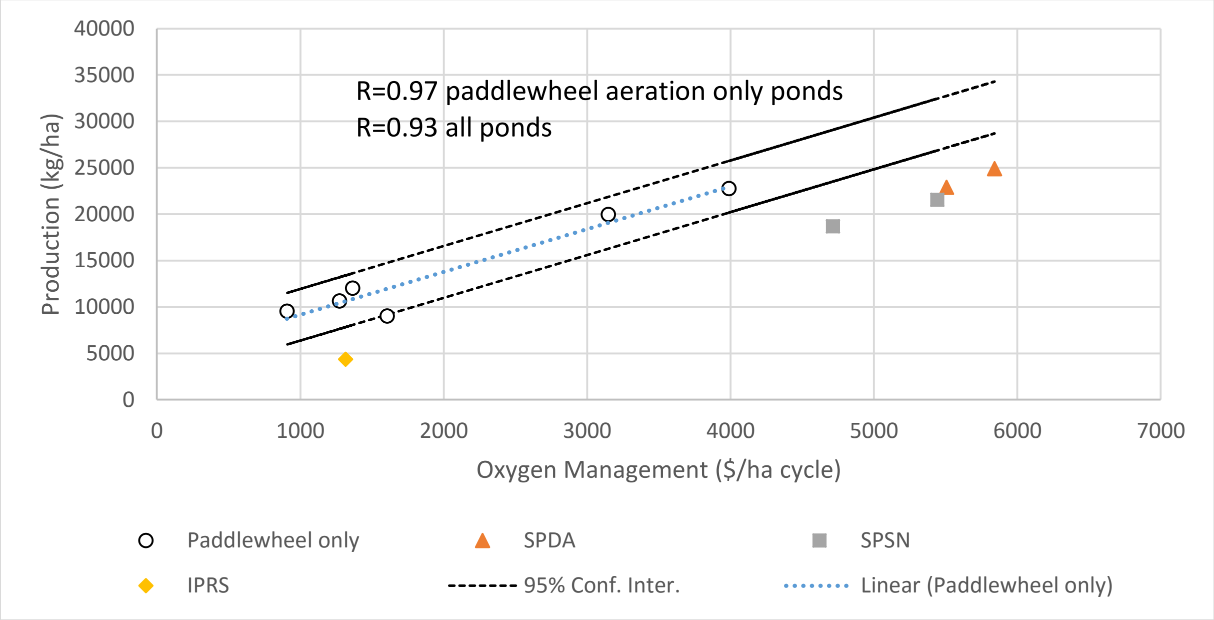


Figure 4.17 Production versus oxygen management costs with 95% confidence interval. Note: SPDA-Small pond with paddlewheel aeration and diffused air hood, SPSN-Small pond with paddlewheel aeration and SN mixer, IPRS-In-pond Raceway System.

Traditional paddlewheel aeration ponds alone resulted in larger increases in production than ponds that used proactive oxygen management based on the regression of the money spent on oxygen management over the other types of ponds (IPRS, SPSN, and SPDA) (Figure 4.17). However, one large pond (LP#3) (1606, 9010) was also outside the confidence interval with deviation is due to decreased survival (64%). Paddlewheel aeration has been commercially available for over 20 years and there are a large number of inexpensive pre-owned paddlewheel aerators available. Normally economic viability is the best metric to evaluate system viability. However, production is used in this case because it is less impacted by losses due to anemia.

Surprisingly, profit (income minus expenses) did not correlate with oxygen management as shown in the graph below (Figure 4.18). In fact, profit actually decreased with increased oxygen management (Objective #3 Open Ponds). The reason for this is largely survival as profit was moderately correlated to survival (R=0.8). It is assumed that if ponds had not broken out with anemia profit would be better correlated to oxygen management.

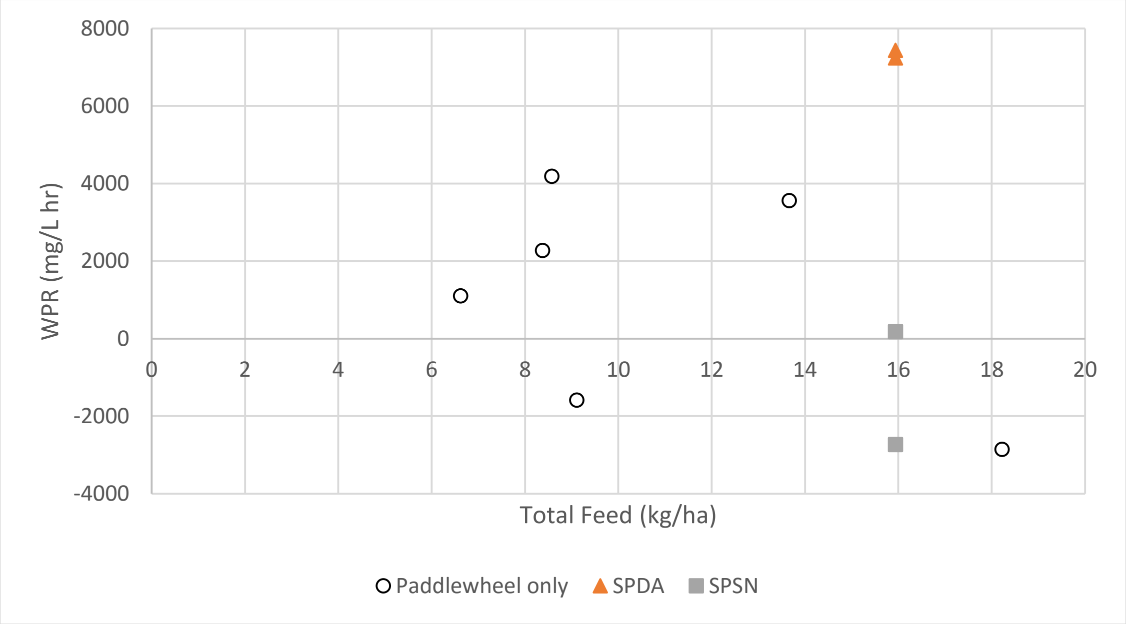


Figure 4.18 Oxygen management versus profit for open pond. Note: SPDA-Small pond with paddlewheel aeration and diffused air hood, SPSN-Small pond with paddlewheel aeration and SN mixer.

This profit/oxygen management relationship is different from results observed by Courtwright (2013) in which aeration rates were one of the largest determining factors for profit. It should be noted that over 70% of farmers surveyed by Courtwright (2013) used a multi-batch system. However increased profit with aeration observed by Courtwright (2013) likely came from increased production or feed conversion. It would be expected that this increase in profits with increased aeration would translate into profitability for single batch systems raising hybrid catfish. The difference is likely due to the poor survival and FCR seen in this study due to anemia. Ponds SPSN #2, XSP, and LP3 all lost money and experienced anemia with a survival of less than 75% (Figure 4.18).

Chapter 5 Summary and Future Recommendations

This chapter contains one section briefly summarizing the final results and discussion of research objectives. The last section contains recommendations for future work and is divided into in-pond raceways and open ponds.

5.1 Summary

Financial hurdles in US catfish show the need to grow fish more efficiently to maintain operational viability. Feed cost has been shown to be the largest cost element to grow US catfish. Previous in-pond raceways have shown improved catfish feed conversion ratios over conventional open ponds but initial construction costs have made the system unprofitable based on catfish sales alone. Mixing equipment has also been shown to be effective in lake remediation. However, mixing has not improved profitability in previous tests of US catfish ponds. In intensive Southeast Asian aquaculture for example, either aerators are run throughout the day or regular water exchange is used to manage water quality. Intensive systems (recirculation, PAS, split pond, and raceways) have many aspects in common, largely fish confinement, preventative waste treatment, and intensified aeration. One farm was set up to test prototype in-pond raceways in West Alabama. The Mississippi Delta farm was setup to test a range of paddlewheel aeration in open ponds. A treatment of diffused air hoods and paddlewheel aeration (SPDA) and a second treatment of a mechanical mixer (SN) and paddlewheel aeration were used to compare to paddlewheel aeration alone.

All raceway cells had an average minimum DO at or above 3.5 mg/L. The fish in the raceways **were not grown to market size** during the time of the trial. Therefore, it is difficult to compare actual production to comparable commercial results. However, the economic analysis conducted indicated the experimetal in-pond raceways were not profitable as they were set up. Since feed cost is typically the most significant cost element for catfish production, improvements in FCR could easily translate into economic profitability. The projected setup of increasing the number of cells from the actual setup (0.8 cells/ha) to the commercial recommendation setup (2.43 cells/ha) is projected to make money if hybrid fingerlings are stocked. However, this result is based on a theoretical sensitivity analysis which needs further research testing. Survival with the channel catfish reduced economic viability even though fish were only in raceways for four months. Poor survival of catfish was likely exacerbated by low alkalinity in the pond water of one of the two ponds. Survival was found to be critical in this study as it is in commercial farms.

Open ponds were set up with automated DO monitoring systems. The monitoring system was used to find the daily DO minimum and daily DO range, and to calculate whole pond respiration and power usage. Power usage was estimated using amperage readings, and oxygen was measured from a DO probe from monitoring system.

Overall, production (kg/ha) in open ponds increased with increased aeration (R>0.9). Diffused air ponds (SPDA) showed (15%) improvement in production (kg/ha) over the paddlewheel only aeration. Average FCR for XSP, SPDA, SPSN, SP, LP, and XLP ponds was 2.9, 2.4, 2.6, 2.5, 2.4, and 2.4. Average production (kg ha $^{-1}$) for XSP, SPDA, SPSN, SP, LP, and XLP ponds was 23,328, 24,509, 20,637, 20,472, 10512, and 9,539.

WPR was moderately correlated to feeding rate (R>0.5) for paddlewheel aeration. As feed is the primary source of external organic matter, both SPDA and SPSN showed improved WPR for the feeding rate of the pond which indicates better waste assimilation and degradation. This improvement was supported by the treatments displaying a reduced daily DO range.

Fish losses due to anemia caused three out of the ten open pond treatments to be unprofitable. Anemia driven mortalities are not normal and increased production would likely have translated into profits in the absence of the anemia. The open ponds with diffused air hoods and paddlewheel aeration produced the highest level of profits. However, the monetary losses associated with fish kills in ponds managed intensively should not be considered insignificant as they greatly affect profitability. Increased treatment of TAN and nitrite by aggressive aeration may reduce the risk of negative feedback where breakdown of decaying fish carcasses cause more water quality problems. For the open ponds both survival and FCR (R>0.8) were moderately correlated to profit (R=0.8).

In conclusion, these floating in-pond raceways exhibited improved feed efficiency like previous in-pond raceways. The projected commercial (2.43 cells/ha) raceways showed signs of economic viability when hybrid catfish were grown. All open ponds produced a crop in approximately one year. Five open ponds showed production above 20,000 kg/ha, which is 3 times the industry average of 6,500 kg/ha (Courtwright, 2013). This result if verified through replication would be important to the catfish industry. Production was shown to increase with enhanced oxygen management (R>0.9). This means that for the range studied increased aeration is a dependable way to increase production at least up to 18 kW/ha.

5.2 Objectives

In-pond Raceways

1. **Determine if average daily minimum DO levels were above 3 mg/L.**

   For in-pond raceway cells 1 and 2, the average daily minimum DO level was 3.5 mg/L. For cells 3 and 4 the average was 4.0 mg/L, therefore, the average daily minimum DO levels in the in-pond raceway were above 3 mg/L. This finding indicates that the dissolved oxygen which is the most common limiting factor for pond aquaculture was above acceptable levels.

2. **Determine if the experimental 0.8 cells/ha setup was profitable.**

   While the hybrid catfish had a lower cost of production than the channel catfish, for this trial of in-pond raceways neither the hybrid nor the channel catfish were profitable. This indicates that even with improved feed efficiency the experimental setup needs further improvement for economic viability.

3. **Determine if a projected 2.43 cells/ha setup was profitable.**

   For the projected 2.43 cells/ha setup, the in-pond raceways were profitable when raising hybrid catfish but resulted in a profit loss when raising channel catfish. This finding indicates that the raceway may have economic viability if hybrid catfish are raised and setup according to commercial recommendations.

Open Ponds

1. **Determine if average daily minimum DO levels were above 3 mg/L.**

   All ponds except the small ponds with paddlewheel aeration and the SN mixer (SPSN) had observed daily minimum DO levels near 3.0 mg/L. This finding indicates that most open ponds had dissolved oxygen levels above acceptable levels.

2. **Evaluate whether higher levels of oxygen management (kW/ha) increased fish production (kg/ha).**

   For the ponds with paddlewheel aeration only, fish production (kg/ha) increased as a result of higher levels of oxygen management (kw/ha) ($R>0.95$). The ponds with the diffused air hoods and paddlewheel aeration (SPDA) achieved higher production than ponds with paddlewheel aeration alone. Therefore, production increased with oxygen management at least up to 18.75 kW/ha.

3. **Evaluate whether higher oxygen management (kW/ha) raised the net profit ($/ha).**

   For the open ponds studied, profits ($/ha) were not correlated to oxygen management. The small ponds with paddlewheel aeration and diffused air hoods (SPDA), however, proved to be more profitable ($/ha) than all other ponds.

4. **Evaluate whether the observed pond respiration rate increased with increased feeding.**

   Whole pond respiration (WPR) was moderately increased with total feed (R>0.5). Both the small ponds with paddlewheel aeration and diffused air hoods (SPDA) and the small ponds with paddlewheel aeration and the SN mixer had lower average whole pond respiration for the level of total feed. This finding indicates that ponds with mixing may proactively manage waste better than paddlewheel aeration alone.

5.3 Future Recommendations for Research

5.3.1 In-pond Raceways Systems Future Recommendations for Research

Raceway profitability would likely improve if energy and labor cost could be reduced during periods of reduced fish biomass. Self-cleaning DO probes would increase the accuracy of DO data and reduce unnecessary upkeep. However, when hybrid catfish are raised raceways may still be viable even without these improvements. The economic viability of the raceways is difficult to determine until a 2.43 cells/ha trial is conducted that stocks the raceways with market size hybrid fingerlings and grows the fish until market foodfish size. Growing the fish to market size of 0.68 kg/fish would increase the ability to compare the in-pond raceways to commercial averages using pond systems.

5.3.2 Open Pond Future Recommendations for Research

Both daily DO range and estimated pond respiration can be related to pond plankton load. Future testing on the viability of using the DO range to indicate organic biomass is recommended. Such a relationship between DO range may not have as high a correlation to organic bioload as respiration but would be simpler to measure on a large scale. Additionally, with the increase in pond DO monitoring systems the infrastructure is already in place. Further research on feed assimilation capacity of catfish ponds as a function of oxygen management is needed to better understand how dissolved oxygen limits production.

If DO range monitoring is not a viable option for monitoring waste loading, then future research may work to improve whole pond respiration by experimenting with sampling frequency and sampling range. While the set points (10 mg/L on and 6 mg/L off) for the WPR were chosen to reduce the distortion from water- atmosphere diffusion, diffusion can distort the calculated WPR respiration as nearly 25% of the measured change in DO (communitive diffusion (Boyd, et al., 1978) compared to measured change in DO). However, reducing the range of set points for WPR calculation may reduce diffusion error but limits the number of data points over which the calculation is performed. The maximum number of data points can be described by the Equation 5.1.

$$Daily\ maxium\ number\ of\ points = \frac{DO\ range({}^{mg}/_{L})}{WPR({}^{mg}/_{L\ hr})} \times Sample\ Frequency({}^{\#}/_{hr}) \qquad \text{(Equation 5.1)}$$

The most daily data points possible for the SPDA ponds for calculation of the mean data would be ten data points. For ponds with a higher WPR such as XSP ponds (2.3 mg L^{-1} hr^{-1}) the daily maximum would be five data points. Considering the complex nature of oxygen dynamics any internal movement of dissolved oxygen could be falsely identified as part of the WPR if it occurs at the time when the water at the depth of the probe (35 cm) is near saturation (Szyper et al. 1993). In the future WPR could likely be calculated more accurately with a decreased range of sampling around saturation while increasing the sampling rate of DO. DO probes may not be representative of the DO content the entire pond water. However, the DO probe becomes a better representative of pond water when paddlewheel aeration comes on because the aeration increases the homogenization of pond water by mixing. Therefore, the accuracy of the DO probe near saturation (WPR calculation) is lower than when aerators are on (daily DO minimum calculation).

This project's method of estimating power based on amperages and run times needs to be verified with a power meter. If the power estimation is lacking in accuracy the formula may need to be improved with a correction factor, or power factor correction coefficient, or increasing sampling times. If the power estimate is accurate decreasing sample rates to determine the threshold for accuracy may be useful.

Further testing of oxygen management is recommended above 18 kW/ha. In addition, testing could aid the industry in improving ways to reduce risk of mortalities at fish biomasses above 20,000 kg/ha. Profit likely would correlate to oxygen management if fish do not succumb to anemia. A point of diminishing return on oxygen management was not determined for the range studied, so additional research needs to be done at higher levels of oxygen management.

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Appendix A

Table A.1 Stocking and harvesting densities in-pond raceways (West Alabama).

Pond	Cell Number and Fish species	Stocking Density(kg/m^2)	Stocking Density(kg/m^3)	Harvest Density(kg/m^2)	Harvest Density(kg/m^3)
1	Cell 1 Channel	15	13	48	39
1	Cell 2 Hybrid	30	25	120	98
2	Cell 3 Channel	19	16	68	56
2	Cell 4 Hybrid	30	25	122	100

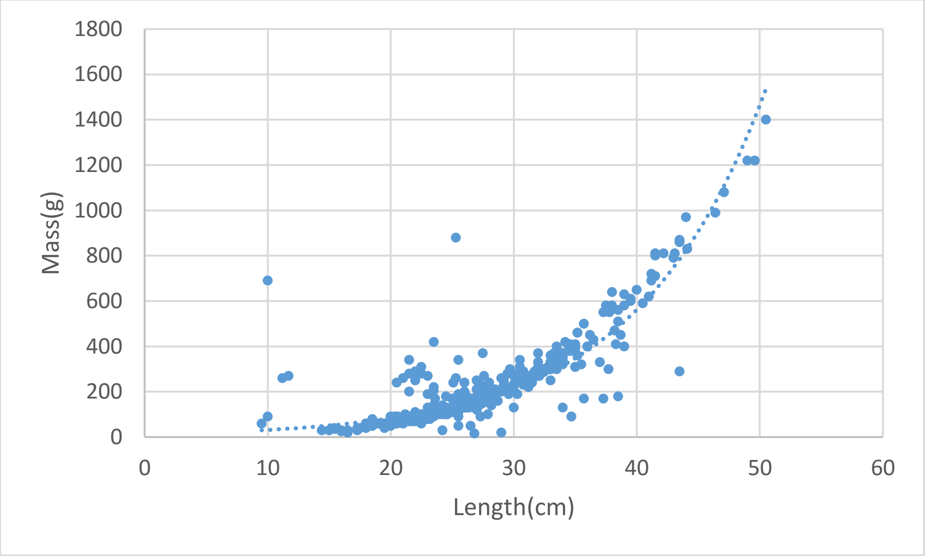

Figure A.6.1 In-pond raceway channel length-mass curve.

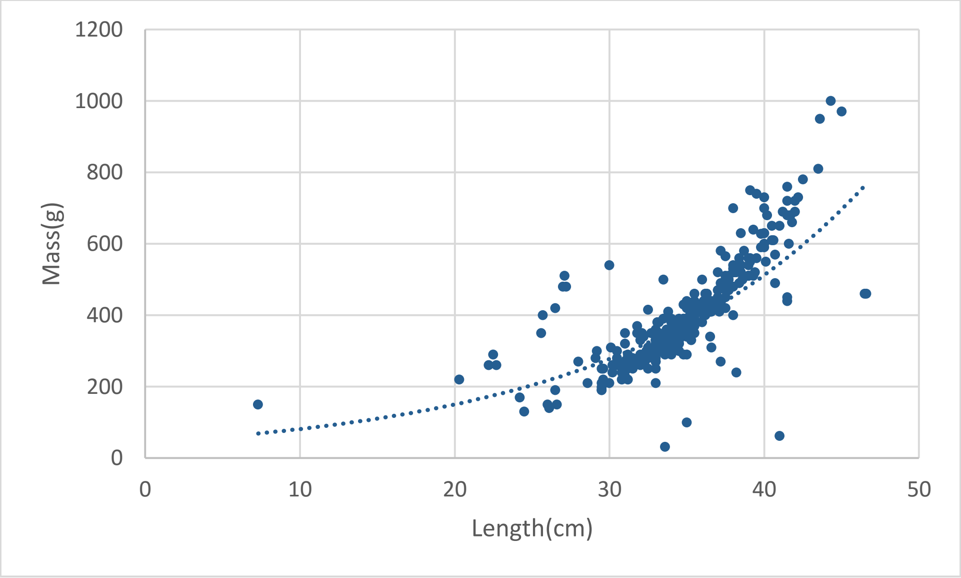

Figure A.6.2 In-pond raceway hybrid length-mass curve.

Table A.2 Water quality in-pond raceways (West Alabama).

Water Quality Variable	Pond 1	Standard Deviation	Pond 2	Standard Deviation
Dissolved Oxygen(mg/L)	5.6	±2.8	6.0	±3.0
pH	8.3	±.8	8.4	±.8
TAN(mg/L)	.8	±.5	1.0	±.7
Nitrite-N(mg/L)	.05	±.03	.05	±.01
Total alkalinity(mg/L)	39.6	±6.3	58.3	±15.9
Total hardness(mg/L)	38.7	±8.2	56.3	±4.3
Chloride(mg/L)	160	±50	166	±32

Appendix B

Table B.3 Fixed cost current setup (0.85 cells/ha) In-pond Raceway System at 10 % interest (not adjusted to 4 months).

Fixed Cost for 2.5 ha with commercial raceway cells												
Item	Unit	Cost/unit	Number	Percent to Pond	Cost	SV	Usefullife	Depreciation	Average Investm	Interest on Inv	% Repairs	Repairs Cost
A. Capital Cost												
Land	$/ha	$ 4,860	3	100.0%	$ 14,400							
Raceways	$/cell	$ 6,000	2	100.0%	$ 12,000	$700	10	$ 1,130	$ 6,000	$ 600	5%	$ 600
Pond Construction	$/ha	$ 3,038	3	100.0%	$ 9,000		15	$ 600	$ 4,500	$ 450	1%	$ 90
Electric work	$	$ 600	5	100.0%	$ 3,000	$ 50	10	$ 295	$ 1,500	$ 150	5%	$ 150
Gravel	$/Load	$ 235	21	100.0%	$ 4,994		8	$ 666	$ 2,497	$ 250	1%	$ 25
Office	$	$ 30,000	1	1.0%	$ 300	$ -	15	$ 20	$ 150	$ 15	1%	$ 3
Shop	$	$ 80,000	1	1.0%	$ 800	$ -	15	$ 53	$ 400	$ 40	1%	$ 8
Tools and Equipment	$	$ 10,000	1	1.0%	$ 100	$ 25	10	$ 8	$ 50	$ 5	5%	$ 5
Subtotal (excluding land)				100.0%	$ 30,194			$ 2,772		$ 910		$ 881
B. Equipment												
Trucks, 1/2 ton	$	$ 22,000	2	1.0%	$ 440	$ 5	6	$ 73	$ 220	$ 22	17%	$ 73
Feed Truck (International 30000 gvw)	$	$ 42,000	2	1.0%	$ 840	$ 5	15	$ 56	$ 420	$ 42	7%	$ 56
Feed Bins(20 ton)	$	$ 7,000	2	1.0%	$ 140	$ -	20	$ 7	$ 70	$ 7	5%	$ 7
Tractors(pump, bushhog)	$	$ 9,000	1	1.0%	$ 90	$ 15	12	$ 6	$ 45	$ 5	0%	$ -
Generators	$	$ 4,570	1	100.0%	$ 4,570	$500	15	$ 271	$ 2,285	$ 229	5%	$ 229
Aerators, 7.5 kW	$	$ 1,800	2	100.0%	$ 3,600	$ -	7	$ 514	$ 1,800	$ 180	20%	$ 720
PTO pump	$	$ 1,500	1	1.0%	$ 15	$ -	10	$ 2	$ 8	$ 1	10%	$ 2
Bush hog/mower	$	$ 4,000	1	1.0%	$ 40	$ -	10	$ 4	$ 20	$ 2	10%	$ 4
Monitoring System, Pentair	$	$ 971	5	100.0%	$ 4,855	$ -	10	$ 486	$ 2,428	$ 243	10%	$ 486
Computer and Electronic Equipment	$	$ 500	1	50.0%	$ 250	$ -	5	$ 50	$ 125	$ 13	0%	$ -
Subtotal					$ 14,840			$ 1,468		$ 742		$ 1,576
Total					**$45,034**			**$ 4,240**		**$ 1,652**		$ 2,457

Table B.4 Variable item usage current setup (0.85 cells/ha) In-pond Raceway System.

	Unit	Unit amount	Quanity	Percentage	Total	New Unit
Channel Fingerlings	$/cm	0.006	14	100%	0.08	$/head
Salt	mg/L	170	43209877	100%	8.08	tons
Energy	kWh/day run	138	125	100%	17,250	kWh/4 months
Feed Fuel	L/Day	15	125	1%	18.75	L/4 months
Night Men Fuel	L/Day	15	125	1%	18.75	L/4 months
Bird Men Fuel	L/Day	0	125	1%	-	L/4 months
Copper Fuel	L/Day	0	125	1%	-	L/4 months
Management (Account, Managers, Owners)	$	67500	0.25	1%	168.75	$/4 months
Labor	hours/day	2.5	125	100%	314.29	hours/4 months
Rent	$/Months	1400	4.17	1%	58.33	$/4 months

Table B.5 Channel catfish in pond 1 (0.85 cells/ha) In-pond Raceway System.

Water (Hectares)	FCR	Survival	Sale Price	Harvest Size(kg)	Stocking(#/ha)	Start Weight(kg)
2.47	2.09	61%	$ 1.00	0.22	9,989	0.04
	Unit Cost	Harvest(kg)	Total Income			Interest Rate
Income($/kg)	$ 2.75	3,351	$ 9,215			10%
Variable Cost						
Type	Unit Cost	Quantity	Total Cost	Cost/Ha	Cost/kg	Percent of Cost
32 % Feed($/kg)	0.495	4,754	$ 2,353	$ 953.12	0.70	19%
Fingerlings($/fing)	0.08	24,665	$ 2,035	$ 824	0.61	16%
Seine and Trans($/lbs)	0.11	3,351	$ 369	$ 149	0.11	3%
Farm Management Personel($/year)	169	1	169	68	0.05	1%
Chemical					-	
Formaldihyde($/50 gal)	2.1	94.5	$ 200	$ 81	0.06	2%
Potassium Permangante($/lb)	5.1	44.6	$ 228	$ 92	0.07	2%
Salt($/ton)	0.1	7345.7	$ 970	$ 393	0.29	8%
Electrical Energy($/kWh)	0.1	17250	$ 1,898	$ 768	0.57	15%
Fuel($/gal)	0.9	142	$ 126	$ 51	0.04	1%
Labor($/year)	3201	1	$ 3,201	$ 1,296	0.96	26%
Interest on Capital(%)	10%	$ 8,660	$ 866	$ 351	0.26	7%
Total Variable Cost			**$ 12,413**	**$ 5,027**	3.70	100%
Income over Variable Cost			$ (3,198)	$ (1,295)	(0.95)	
Fixed Cost						
Capital Depreciation			$ 924	$ 374	0.28	33%
Equipement Depreciation			$ 489	$ 198	0.15	17%
Capital Interest			$ 303	$ 123	0.09	11%
Equipement Interest			$ 247	$ 100	0.07	9%
Repairs and Mainteance Capital			$ 294	$ 119	0.09	10%
Repairs and Mainteance Equipment			$ 525	$ 213	0.16	19%
Taxes($/acre)	29.2	2.5	$ 24	$ 10	0.01	1%
Insurance	24.3	2.5	$ 20	$ 8	0.01	1%
Total Fixed Cost (Adjusted to 4 months)			$ 2,827	1,145	0.84	
Total Cost			$ 15,240	6,172	4.55	
Net Return Above Expenses			**$ (6,025)**	**(2,440)**	**(1.80)**	
Breakeven Price to Cover, Variable			$ 3.70			
Breakeven Price to Cover, Total			$ 4.55			

Table B.6 Channel catfish in pond 2 (0.85 cells/ha) In-pond Raceway System.

Water (Hectare)	FCR	Survival	Sale Price	Harvest Size(kg)	Stocking(#/ha)	Start Weight(kg)
2.5	1.52	74%	$ 1.00	0.25	9,989	0.061
	Unit Cost	Harvest(lbs.)	Total Income			Interest Rate
Income($/kg)	$ 2.75	4,504	$ 12,387			10%
Variable Cost						
Type	Unit Cost	Quantity	Total Cost	Cost/Ha	Cost/kg	Percent of Cost
32 % Feed($/kg)	0.495	4,563	$ 2,259	$ 914.76	0.50	18%
Fingerlings($/fing)	0.08	24,665	$ 2,035	$ 824	0.45	16%
Seine and Trans($/kg)	0.11	4,504	$ 495	$ 201	0.11	4%
Farm Management Personel($/year)	169	1	169	68	0.04	1%
Chemical					-	
Formaldihyde($/L)	2.116402	94.5	$ 200	$ 81	0.04	2%
Potassium Permangante($/kg)	5.1	44.6	$ 228	$ 92	0.05	2%
Salt($/kg)	0.1	7345.7	$ 970	$ 393	0.22	8%
Electrical Energy($/kWh)	0.11	17250	$ 1,898	$ 768	0.42	15%
Fuel($/L)	0.886243	142	$ 126	$ 51	0.03	1%
Labor($/year)	3201	1	$ 3,201	$ 1,296	0.71	26%
Interest on Capital(%)	10%	$ 8,685	$ 868	$ 352	0.19	7%
Total Variable Cost			**$ 12,448**	**$ 5,041**	2.76	100%
Income over Variable Cost			$ (61)	$ (25)	(0.01)	
Fixed Cost						
Capital Depreciation			$ 924	$ 374	0.21	33%
Equipement Depreciation			$ 489	$ 198	0.11	17%
Capital Interest			$ 303	$ 123	0.07	11%
Equipement Interest			$ 247	$ 100	0.05	9%
Repairs and Mainteance Capital			$ 294	$ 119	0.07	10%
Repairs and Mainteance Equipment			$ 525	$ 213	0.12	19%
Taxes($/ha)	29	2	$ 24	$ 10	0.01	1%
Insurance	24.3	2.47	$ 20	$ 8	0.00	1%
Total Fixed Cost (Adjusted to 4 months)			$ 2,827	1,145	0.63	
Total Cost			$ 15,275	6,186	3.39	
Net Return Above Expenses			**$ (2,888)**	**(1,170)**	**(0.64)**	
Breakeven Price to Cover, Variable			$ 2.76			
Breakeven Price to Cover, Total			$ 3.39			

Table B.7 Hybrid catfish in pond 1 (0.85 cells/ha) In-pond Raceway System.

Water (Hectare)	FCR	Survival	Sale Price	Harvest Size(kg)	Stocking(#/Ha)	Start Weight(kg)
2.47	1.48	89%	$ 2.75	0.41	9,989	0.091
	Unit Cost	Harvest(kg)	Total Income			Interest Rate
Income($/kg)	$ 2.75	8,980	$ 24,696			10%
Variable Cost						
Type	Unit Cost	Quantity	Total Cost	Cost/Ha	Cost/lbs	Percent of Cost
32 % Feed($/kg)	0.50	9,972	$ 4,936	$ 1,999.19	0.55	22%
Fingerlings($/fing)	0.34	24,665	$ 8,305	$ 3,363	0.92	37%
Seine and Trans($/kg)	0.11	8,980	$ 988	$ 400	0.11	4%
Farm Management Personel($/year)	168.75	1	169	68	0.02	1%
Chemical					-	
Formaldihyde($/L)	2.12	94.5	$ 200	$ 81	0.02	1%
Potassium Permangante($/kg)	5.10	44.6	$ 228	$ 92	0.03	1%
Salt($/kg)	0.13	7345.7	$ 970	$ 393	0.11	4%
Electrical Energy($/kWh)	0.11	17,250	$ 1,898	$ 768	0.21	8%
Fuel($/L)	0.89	142	$ 126	$ 51	0.01	1%
Labor($/year)	3201.19	1	$ 3,201	$ 1,296	0.36	14%
Interest on Capital(%)	0.10	$ 15,765	$ 1,576	$ 638	0.18	7%
Total Variable Cost			**$ 22,596**	**$ 9,151**	2.52	100%
Income over Variable Cost			$ 2,100	$ 850	0.23	
Fixed Cost						
Capital Depreciation			$ 923.89	$ 374	0.10	33%
Equipement Depreciation			$ 489.35	$ 198	0.05	17%
Capital Interest			$ 303.23	$ 123	0.03	11%
Equipement Interest			$ 247.33	$ 100	0.03	9%
Repairs and Mainteance Capital			$ 293.66	$ 119	0.03	10%
Repairs and Mainteance Equipment			$ 525.28	$ 213	0.06	19%
Taxes($/ha)	29	2	$ 24.00	$ 10	0.00	1%
Insurance	24.3	2.47	$ 20.00	$ 8	0.00	1%
Total Fixed Cost (Adjusted to 4 months)			$ 2,826.73	1,145	0.31	
Total Cost			$ 25,422	10,296	2.83	
Net Return Above Expenses			**$ (727)**	**(294)**	**(0.08)**	
Breakeven Price to Cover, Variable			$ 2.52			
Breakeven Price to Cover, Total			$ 2.83			

Table B.8 Hybrids in pond 2 (0.85 cells/ha) In-pond Raceway System.

Water (Hectare)	FCR	Survival	Sale Price	Harvest Size(kg)	Stocking(#/ha)	Start Weight(kg)
2.47	1.45	94%	$ 2.75	0.39	9,989	0.091
	Unit Cost	Harvest(kg)	Total Income			Interest Rate
Income($/kg)	$ 2.75	8,958	$ 24,634			10%
Variable Cost						
Type	Unit Cost	Quantity	Total Cost	Cost/Ha	Cost/kg	Percent of Cost
32 % Feed($/kg)	0.50	9,738	$ 4,820	$ 1,952	0.54	21%
Fingerlings($/fing)	0.34	24,665	$ 8,305	$ 3,363	0.93	37%
Seine and Trans($/kg)	0.11	8,958	$ 985	$ 399	0.11	4%
Farm Management Personel($/year)	169	1	169	68	0.02	1%
Chemical					-	
Formaldihyde($/L)	2.12	94.5	$ 200	$ 81	0.02	1%
Potassium Permangante($/kg)	5.10	44.6	$ 228	$ 92	0.03	1%
Salt($/kg)	0.13	7345.7	$ 970	$ 393	0.11	4%
Electrical Energy($/kWh)	0.11	17250	$ 1,898	$ 768	0.21	8%
Fuel($/L)	0.89	142	$ 126	$ 51	0.01	1%
Labor($/year)	3201	1	$ 3,201	$ 1,296	0.36	14%
Interest on Capital(%)	0.10	$ 15,675	$ 1,568	$ 635	0.17	7%
Total Variable Cost			**$ 22,468**	**$ 9,100**	2.51	100%
Income over Variable Cost			$ 2,166	$ 877	0.24	
Fixed Cost						
Capital Depreciation			$ 923.89	$ 374	0.10	33%
Equipement Depreciation			$ 489.35	$ 198	0.05	17%
Capital Interest			$ 303.23	$ 123	0.03	11%
Equipement Interest			$ 247.33	$ 100	0.03	9%
Repairs and Mainteance Capital			$ 293.66	$ 119	0.03	10%
Repairs and Mainteance Equipment			$ 525.28	$ 213	0.06	19%
Taxes($/ha)	29	2.5	$ 24.00	$ 10	0.00	1%
Insurance	24	2.5	$ 20.00	$ 8	0.00	1%
Total Fixed Cost (Adjusted to 4 months)			$ 2,826.73	1,145	0.32	
Total Cost			$ 25,295	10,244	2.82	
Net Return Above Expenses			**$ (661)**	**(268)**	**(0.07)**	
Breakeven Price to Cover, Variable			$ 2.51			
Breakeven Price to Cover, Total			$ 2.82			

Table B.9 Fixed cost projected setup (2.43 cells/ha) In-pond Raceway System at 10 % interest not adjusted to 4 months.

Item	Unit	Cost/unit	Number	Percent to Pond	Cost	SV	Usefullife	Depreciation	Average Invest	Interest	% Repairs	Repairs Cost
A. Capital Cost												
Land	$/ha	$ 4,860	3	100%	$ 14,400							
Raceways	$/cell	$ 6,000	6	100%	$ 36,000	$ 700	10	$ 3,530	$ 18,000	$ 1,800	5.0%	$ 1,800
Pond Construction	$/ha	$ 3,038	3	100%	$ 9,000		15	$ 600	$ 4,500	$ 450	1.0%	$ 90
Electric work	$	$ 600	9	100%	$ 5,400	$ 100	10	$ 530	$ 2,700	$ 270	5%	$ 270
Gravel	$/Load	$ 235	21	100%	$ 4,994		7.5	$ 666	$ 2,497	$ 250	0.5%	$ 25
Office	$	$ 30,000	1	1%	$ 300	$ -	15	$ 20	$ 150	$ 15	1.0%	$ 3
Shop	$	$ 80,000	1	1%	$ 800	$ -	15	$ 53	$ 400	$ 40	1.0%	$ 8
Tools and Equipment	$	$ 10,000	1	1%	$ 100	$ 25	10	$ 8	$ 50	$ 5	5.0%	$ 5
Subtotal(excluding land)				100%	56,594			$ 5,407		$ 2,830		$ 2,201
B. Equipment												
Trucks, 1/2 ton	$	$ 22,000	3	1%	$ 660	$ 5	6	$ 109	$ 330	$ 33	17%	$ 110
Feed Truck(International 30000 gvw)	$	$ 42,000	2	1%	$ 840	$ 5	15	$ 56	$ 420	$ 42	7%	$ 56
Feed Bins(20 ton)	$	$ 7,000	2	1%	$ 140	$ -	20	$ 7	$ 70	$ 7	5%	$ 7
Tractors(pump, bushhog)	$	$ 9,000	1	1%	$ 90	$ 15	12	$ 6	$ 45	$ 5	0%	$ -
Generators(20KVA)	$	$ 4,570	0.5	100%	$ 2,285	$ 500	15	$ 119	$ 1,143	$ 114	5%	$ 114
Aerators, 7.5 kW	$	$ 1,800	2	100%	$ 3,600	$ -	7	$ 514	$ 1,800	$ 180	20%	$ 720
PTO pump	$	$ 1,500	1	1%	$ 15	$ -	10	$ 2	$ 8	$ 1	10%	$ 2
Bush hog/mower	$	$ 4,000	1	1%	$ 40	$ -	10	$ 4	$ 20	$ 2	10%	$ 4
Monitoring System, Pentair	$	$ 971	7	100%	$ 6,797	$ -	10	$ 680	$ 3,399	$ 340	10%	$ 680
Computer and Electronic Equipment	$	$ 500	1	50%	$ 250	$ -	5	$ 50	$ 125	$ 13	0%	$ -
Subtotal					$ 14,717			$ 1,547		$ 736		$ 1,692
Total					**$71,311**			**$ 6,953**		**$3,566**		$ 3,893

Table B.10 Variable item usage projected setup (2.43 cells/ha) In-pond Raceway System.

	Unit	Unit amount	Quanity	Percentage	Total	New Unit
Channel Fingerling	$/cm	0.0059	13.97	100%	0.08	$/head
Salt	mg/L	170	43209877	100%	8.08	tons
Energy	kWh/day run	138	125	100%	17,250	kWh/4 months
Feed Fuel	L/Day	15	125	1%	18.75	L/4 months
Night Men Fuel	L/Day	15	125	1%	18.75	L/4 months
Bird Men Fuel	L/Day	0	125	1%	-	L/4 months
Copper Fuel	L/Day	0	125	1%	-	L/4 months
Management(Account, Managers, Owners)	$	67500	0.25	1%	168.75	$/4 months
Labor	hours/day	2.5	125	100%	785.71	hours/4 months
Rent	$/Months	1400	4.2	1%	58.33	$/4 months

Table B.11 Channel catfish in projected 2.43 cells/ha setup In-pond Raceway System.

Water (Ha)	FCR	Survival	Sale Price	Harvest Size(kg)	Stocking(#/ha)	Start Weight(kg)
2.47	1.75	74%	$ 2.75	0.24	29,968	0.05
	Unit Cost	Harvest(kg)	Total Income	Months to Harvest		Interest Rate
Income($/kg)	$ 2.75	13,012	$ 35,784	4		10%
Variable Cost						
Type	Unit Cost	Quantity	Total Cost	Cost/Ha	Cost/kg	Percent of Cost
32 % Feed($/kg)	0.50	16,003	$ 7,921	$ 3,208.15	0.61	23%
Fingerlings($/fing)	0.08	73,995	$ 6,105	$ 2,472	0.47	18%
Seine and Trans($/kg)	0.11	13,012	$ 1,431	$ 580	0.11	4%
Farm Management Personel($/year)	169	1	169	68	0.01	0%
Chemical						
Formaldihyde($/L)	2.12	283.5	$ 600	$ 243	0.05	2%
Potassium Permangante($/kg)	5.1	133.9	$ 683	$ 277	0.05	2%
Salt($/kg)	0.1	7345.7	$ 970	$ 393	0.07	3%
Electrical Energy($/kWh)	0.11	51750	$ 5,693	$ 2,305	0.44	17%
Fuel($/L)	0.89	142	$ 126	$ 51	0.01	0%
Labor($/year)	7915	1	$ 7,915	$ 3,206	0.61	23%
Interest on Capital(%)	10%	$ 23,709	$ 2,371	$ 960	0.18	7%
Total Variable Cost			**$ 33,983**	**$ 13,763**	**2.61**	100%
Income over Variable Cost			$ 1,801	$ 729	0.14	
Fixed Cost						
Capital Depreciation			$ 1,802	$ 730	0.14	37%
Equipement Depreciation			$ 516	$ 209	0.04	11%
Capital Interest			$ 943	$ 382	0.07	19%
Equipement Interest			$ 245	$ 99	0.02	5%
Repairs and Mainteance Capital			$ 734	$ 297	0.06	15%
Repairs and Mainteance Equipment			$ 564	$ 228	0.04	12%
Taxes($/ha)	29	2	$ 24	$ 10	0.00	0%
Insurance	24.3	2	$ 20	$ 8	0.00	0%
Total Fixed Cost (Adjusted to 4 months)			$ 4,848	1,963	0.37	
Total Cost			$ 38,831	15,727	2.98	
Net Return Above Expenses			**$ (3,047)**	**(1,234)**	**(0.23)**	
Breakeven Price to Cover, Variable			$ 2.61			
Breakeven Price to Cover, Total			$ 2.98			

Table B.12 Hybrid catfish in projected 2.43 cells/ha setup In-pond Raceway System.

Water (ha)	FCR	Survival	Sale Price	Harvest Size(kg)	Stocking(#/ha)	Start Weight(kg)
2.47	1.46	92%	$ 2.75	0.40	29,968	0.09
	Unit Cost	Harvest(kg)	Total Income	Months to Harvest		Interest Rate
Income($/kg)	$ 2.75	26,891	$ 73,952	4		10%
Variable Cost						
Type	Unit Cost	Quantity	Total Cost	Cost/Hectare	Cost/kg	Percent of Cost
32 % Feed($/kg)	0.50	29,440	$ 14,573	$ 5,902.06	0.54	23%
Fingerlings($/fing)	0.34	73,995	$ 24,914	$ 10,090	0.93	40%
Seine and Trans($/kg)	0.11	26,891	$ 2,958	$ 1,198	0.11	5%
Farm Management Personel($/year)	169	1	169	68	0.01	0%
Chemical						
Formaldihyde($/L)	2.12	283.5	$ 600	$ 243	0.02	1%
Potassium Permangante($/kg)	5.10	133.9	$ 683	$ 277	0.03	1%
Salt($/kg)	0.1	7345.7	$ 970	$ 393	0.04	2%
Electrical Energy($/kWh)	0.11	51750	$ 5,693	$ 2,305	0.21	9%
Fuel($/L)	0.89	142	$ 126	$ 51	0.00	0%
Labor($/year)	7915	1	$ 7,915	$ 3,206	0.29	13%
Interest on Capital(%)	10%	$ 43,950	$ 4,395	$ 1,780	0.16	7%
Total Variable Cost			**$ 62,995**	**$ 25,513**	**2.34**	100%
Income over Variable Cost			$ 10,956	$ 4,437	0.41	
Fixed Cost						
Capital Depreciation			$ 1,802	$ 730	0.07	30%
Equipement Depreciation			$ 516	$ 209	0.02	9%
Capital Interest			$ 943	$ 382	0.04	16%
Equipement Interest			$ 245	$ 99	0.01	4%
Repairs and Mainteance Capital			$ 734	$ 297	0.03	12%
Repairs and Mainteance Equipment			$ 1,692	$ 685	0.06	28%
Taxes($/ha)	29	2	$ 24	$ 10	0.00	0%
Insurance	24.3	2	$ 20	$ 8	0.00	0%
Total Fixed Cost (Adjusted to 4 months)			$ 5,976	2,420	0.22	
Total Cost			$ 68,972	27,933	2.56	
Net Return Above Expenses			**$ 4,980**	**2,017**	**0.19**	
Breakeven Price to Cover, Variable			$ 2.34			
Breakeven Price to Cover, Total			$ 2.56			

Appendix C

Table C.1 XSP pond fixed cost hybrid catfish open ponds (Mississippi Delta).

Item	Unit	Cost/unit	Number	Percent to Pond	Cost	SV	Usefullife	Depreciation	Average Inves	Interst on Investment	% Repairs	Repairs Cost
A. Capital Cost												
Land	$/ha	$ 4,860	1.48	100.0%	$ 7,200							
Pond Construction	$/ha	$ 3,038	1.48	100.0%	$ 4,500		10	450	2250	225	1.0%	$ 45
Electric work	$	$ 600	4	100.0%	$ 2,400	$100	10	230	1200	120	5%	$ 120
Gravel	$	$ 235	21.25	50.0%	$ 2,497		5	499	1248	125	0.5%	$ 12
Office	$	$ 50,000	1	0.3%	$ 125	$ -	15	8	63	6	2.5%	$ 3
Shop	$	$ 80,000	1	0.3%	$ 200	$ -	15	13	100	10	2.5%	$ 5
Tools and Equipment	$	$ 20,000	1	0.3%	$ 50	$ 6	10	4	25	3	2.5%	$ 1
Subtotal(excluding land)				100.0%	9,772			1205		489		$ 187
B. Equipment												
Trucks, 1/2 ton	$	$ 22,000	2	0.6%	$ 246	$ 3	6	41	123	12	15%	$ 37
Feed Truck(Internation 30000 gvw)	$	$ 42,000	2	0.9%	$ 752	$ 4	15	50	376	38	5%	$ 38
Feed Bins(20 ton)	$	$ 7,000	3	0.9%	$ 188	$ -	20	9	94	9	0%	$ -
Tractors(pump, bushhog)	$	$ 9,000	2	0.3%	$ 45	$ 4	12	3	23	2	20%	$ 9
Aerators, 7.5 kW	$	$ 1,800	3	100.0%	$ 5,400	$ -	7	771	2700	270	20%	$ 1,080
PTO pump	$	$ 1,500	1	0.3%	$ 4	$ -	10	0	2	0	1%	$ 0
Bush hog/mower	$	$ 4,000	1	0.3%	$ 10	$ -	10	1	5	1	10%	$ 1
Monitoring System, In-situ	$	$ 2,000	1	100.0%	$ 2,000	$ -	10	200	1000	100	10%	$ 200
Computer and Electronic Equipment	$	$ 3,000	1	0.6%	$ 17	$ -	5	3	8	1	0%	$ -
Subtotal					$ 8,662			1079		433		$ 1,365
Total					**18,434**			**2285**		**922**		$ 1,551

Table C.2 SP pond fixed cost hybrid catfish open ponds (Mississippi Delta).

Item	Unit	Cost/unit	Number	Percent to Pond	Cost	SV	Usefullife	Depreciation	Average Inves	Interst on Investment	% Repairs	Repairs Cost
A. Capital Cost												
Land	$/ha	$ 4,860	1.98	100.0%	$ 9,600							
Pond Construction	$/ha	$ 3,038	1.98	100.0%	$ 6,000		10	600	3000	300	1.0%	$ 60
Electric work	$	$ 600	3	100.0%	$ 1,800	$ 100	10	170	900	90	5%	$ 90
Gravel	$/Load	$ 235	21.25	50.0%	$ 2,497		5	499	1248	125	0.5%	$ 12
Office	$	$ 50,000	1	0.4%	$ 192	$ -	15	13	96	10	2.5%	$ 5
Shop	$	$ 80,000	1	0.4%	$ 307	$ -	15	20	153	15	2.5%	$ 8
Tools and Equipment	$	$ 20,000	1	0.4%	$ 77	$ 10	10	7	38	4	2.5%	$ 2
Subtotal(excluding land)				100.0%	10,872			1309		544		$ 177
B. Equipment												
Trucks, 1/2 ton	$	$ 22,000	2	0.7%	$ 328	$ 4	6	54	164	16	15%	$ 49.25
Feed Truck(Internation 30000 gvw)	$	$ 42,000	2	1.0%	$ 878	$ 5	15	58	439	44	5%	$ 43.88
Feed Bins(20 ton)	$	$ 7,000	3	1.0%	$ 219	$ -	20	11	110	11	0%	$ -
Tractors(pump, bushhog)	$	$ 9,000	2	0.4%	$ 69	$ 6	12	5	35	3	20%	$ 13.80
Aerators, 7.5 kW	$	$ 1,800	3	100.0%	$ 5,400	$ -	7	771	2700	270	20%	$ 1,080.00
PTO pump	$	$ 1,500	1	0.4%	$ 6	$ -	10	1	3	0	1%	$ 0.06
Bush hog/mower	$	$ 4,000	1	0.4%	$ 15	$ -	10	2	8	1	10%	$ 1.53
Monitoring System, In-situ	$	$ 2,000	1	100.0%	$ 2,000	$ -	10	200	1000	100	10%	$ 200.00
Computer and Electronic Equipment	$	$ 3,000	1	0.7%	$ 20	$ -	5	4	10	1	0%	$ -
Subtotal					$ 8,935			1106		447		1389
Total					**19,807**			**2415**		**990**		$ 1,565.38

Table C.3 SPDA ponds fixed cost hybrid catfish open ponds (Mississippi Delta).

Item	Unit	Cost/unit	Number	Percent to Pond	Cost	SV	Usefullife	Depreciation	Average Inves	Interst on Investment	% Repairs	Repairs Cost
A. Capital Cost												
Land	$/ha	$ 4,860	1.98	100.0%	$ 9,600							
Pond Construction	$/ha	$ 3,038	1.98	100.0%	$ 6,000		15	400	3000	300	1.0%	$ 60
Electric work	$	$ 600	4	100.0%	$ 2,400	$100	15	153	1200	120	5%	$ 120
Diffused Air Hood	$	$ 2,000	2	100.0%	$ 4,000	$350	10	365	2000	200	1%	$ 40
Gravel	$	$ 235	21.25	50.0%	$ 2,497		5	499	1248	125	0.5%	$ 12
Office	$	$ 50,000	1	0.4%	$ 192	$ -	15	13	96	10	2.5%	$ 5
Shop	$	$ 80,000	1	0.4%	$ 307	$ -	15	20	153	15	2.5%	$ 8
Tools and Equipment	$	$ 20,000	1	0.4%	$ 77	$ 10	10	7	38	4	2.5%	$ 2
Subtotal(excluding land)				100.0%	15,472			1458		774		$ 247
B. Equipment												
Trucks, 1/2 ton	$	$ 22,000	2	0.7%	$ 328	$ 4	6	54	164	16	15%	$ 49.25
Feed Truck(Internation 30000 gvw)	$	$ 42,000	2	1.0%	$ 878	$ 5	15	58	439	44	5%	$ 43.88
Feed Bins(20 ton)	$	$ 7,000	3	1.0%	$ 219	$ -	20	11	110	11	0%	$ -
Tractors(pump, bushhog)	$	$ 9,000	2	0.4%	$ 69	$ 6	12	5	35	3	8%	$ 5.75
Aerators, 7.5 kW	$	$ 1,800	3	100.0%	$ 5,400	$ -	7	771	2700	270	14%	$ 771.43
PTO pump	$	$ 1,500	1	0.4%	$ 6	$ -	10	1	3	0	1%	$ 0.06
Bush hog/mower	$	$ 4,000	1	0.4%	$ 15	$ -	10	2	8	1	10%	$ 1.53
Monitoring System, In-situ	$	$ 2,000	1	100.0%	$ 2,000	$ -	10	200	1000	100	5%	$ 100.00
Computer and Electronic Equipment	$	$ 3,000	1	0.7%	$ 20	$ -	5	4	10	1	0%	$ -
Subtotal					$ 8,935			1106		447		972
Total					**24,407**			**2564**		**1220**		$ 1,218.76

Table C.3 SPSN ponds fixed cost hybrid catfish open ponds (Mississippi Delta).

Item	Unit	Cost/unit	Number	Percent to Pond	Cost	SV	Usefullife	Depreciation	Average Inves	Interst on Investment	% Repairs	Repairs Cost
A. Capital Cost												
Land	$/ha	$ 4,860	1.98	100.0%	$ 9,600							
Pond Construction	$/ha	$ 3,038	1.98	100.0%	$ 6,000		10	600	3000	300	1.0%	$ 60
Electric work	$	$ 600	4	100.0%	$ 2,400	$100	10	230	1200	120	5%	$ 120
SN mixer 3.75 kW	$	$ 5,000	1	100.0%	$ 5,000	$350	10	465	2500	250	3%	$ 125
Gravel	$	$ 235	21.25	50.0%	$ 2,497		5	499	1248	125	0.5%	$ 12
Office	$	$ 50,000	1	0.4%	$ 192	$ -	15	13	96	10	2.5%	$ 5
Shop	$	$ 80,000	1	0.4%	$ 307	$ -	15	20	153	15	2.5%	$ 8
Tools and Equipment	$	$ 20,000	1	0.4%	$ 77	$ 10	10	7	38	4	2.5%	$ 2
Subtotal(excluding land)				100.0%	16,472			1834		824		$ 332
B. Equipment												
Trucks, 1/2 ton	$	$ 22,000	2	0.7%	$ 328	$ 4	6	54	164	16	15%	$ 49.25
Feed Truck(Internation 30000 gvw)	$	$ 42,000	2	1.0%	$ 878	$ 5	15	58	439	44	5%	$ 43.88
Feed Bins(20 ton)	$	$ 7,000	3	1.0%	$ 219	$ -	20	11	110	11	0%	$ -
Tractors(pump, bushhog)	$	$ 9,000	2	0.4%	$ 69	$ 6	12	5	35	3	20%	$ 13.80
Aerators, 7.5 kW	$	$ 1,800	3	100.0%	$ 5,400	$ -	7	771	2700	270	20%	$ 1,080.00
PTO pump	$	$ 1,500	1	0.4%	$ 6	$ -	10	1	3	0	1%	$ 0.06
Bush hog/mower	$	$ 4,000	1	0.4%	$ 15	$ -	10	2	8	1	10%	$ 1.53
Monitoring System, In-situ	$	$ 2,000	1	100.0%	$ 2,000	$ -	10	200	1000	100	10%	$ 200.00
Computer and Electronic Equipment	$	$ 3,000	1	0.7%	$ 20	$ -	5	4	10	1	0%	$ -
Subtotal					$ 8,935			1106		447		1389
Total					**25,407**			**2940**		**1270**		$ 1,720.38

Table C.4 LP ponds fixed cost hybrid catfish open ponds (Mississippi Delta).

Item	Unit	Cost/unit	Number	Percent to Pond	Cost	SV	Usefullife	Depreciation	Average Inves	Interst on Investment	% Repairs	Repairs Cost
A. Capital Cost												
Land	$/acre	$ 2,000	4.8	100.0%	$ 9,600							
Pond Construction	$/acre	$ 1,250	4.8	100.0%	$ 6,000		10	600	3000	300	1.0%	$ 60
Electric work	$	$ 600	4	100.0%	$ 2,400	$100	10	230	1200	120	5%	$ 120
SN mixer 3.75 kW	$	$ 5,000	1	100.0%	$ 5,000	$350	10	465	2500	250	3%	$ 125
Gravel	$	$ 235	21.25	50.0%	$ 2,497		5	499	1248	125	0.5%	$ 12
Office	$	$ 50,000	1	0.4%	$ 192	$ -	15	13	96	10	2.5%	$ 5
Shop	$	$ 80,000	1	0.4%	$ 307	$ -	15	20	153	15	2.5%	$ 8
Tools and Equipment	$	$ 20,000	1	0.4%	$ 77	$ 10	10	7	38	4	2.5%	$ 2
Subtotal(excluding land)				100.0%	16,472			1834		824		$ 332
B. Equipment												
Trucks, 1/2 ton	$	$ 22,000	2	0.7%	$ 328	$ 4	6	54	164	16	15%	$ 49.25
Feed Truck(Internation 30000 gvw)	$	$ 42,000	2	1.0%	$ 878	$ 5	15	58	439	44	5%	$ 43.88
Feed Bins(20 ton)	$	$ 7,000	3	1.0%	$ 219	$ -	20	11	110	11	0%	$ -
Tractors(pump, bushhog)	$	$ 9,000	2	0.4%	$ 69	$ 6	12	5	35	3	20%	$ 13.80
Aerators, 7.5 kW	$	$ 1,800	3	100.0%	$ 5,400	$ -	7	771	2700	270	20%	$ 1,080.00
PTO pump	$	$ 1,500	1	0.4%	$ 6	$ -	10	1	3	0	1%	$ 0.06
Bush hog/mower	$	$ 4,000	1	0.4%	$ 15	$ -	10	2	8	1	10%	$ 1.53
Monitoring System, In-situ	$	$ 2,000	1	100.0%	$ 2,000	$ -	10	200	1000	100	10%	$ 200.00
Computer and Electronic Equipment	$	$ 3,000	1	0.7%	$ 20	$ -	5	4	10	1	0%	$ -
Subtotal					$ 8,935			1106		447		1389
Total					**25,407**			**2940**		**1270**		$ 1,720.38

Table C.5 LP ponds fixed cost hybrid catfish open ponds (Mississippi Delta).

Item	Unit	Cost/unit	Number	Percent to Pond	Cost	SV	Usefullife	Depreciation	Average Investment	Interst on Investment	% Repairs	Repairs Cost
A. Capital Cost												
Land	$/ha	$ 4,860	4.20	100.0%	$ 20,400							
Pond Construction	$/ha	$ 3,038	4.20	100.0%	$ 12,750		15	850	6375	638	1.0%	$ 128
Electric work	$	$ 600	4	100.0%	$ 2,400	$ 100	15	153	1200	120	5%	$ 120
Gravel	$/Load	$ 235	10.625	50.0%	$ 1,248		5	250	624	62	0.5%	$ 6
Office	$	$ 50,000	1	0.8%	$ 383	$ -	15	26	192	19	2.5%	$ 10
Shop	$	$ 80,000	1	0.8%	$ 613	$ -	15	41	307	31	2.5%	$ 15
Tools and Equipment	$	$ 20,000	1	0.8%	$ 153	$ 19	10	13	77	8	2.5%	$ 4
Subtotal(excluding land)				100.0%	17,548			1333		877		$ 282
B. Equipment												
Trucks, 1/2 ton	$	$ 22,000	2	1.5%	$ 657	$ 7	6	108	328	33	15%	$ 98.51
Feed Truck(Internation 30000 gvw)	$	$ 42,000	2	1.5%	$ 1,254	$ 7	15	83	627	63	5%	$ 63
Feed Bins(20 ton)	$	$ 7,000	3	1.5%	$ 313	$ -	20	16	157	16	0%	$ -
Tractors(PTO, Aeration)	$	$ 9,000	6	1.5%	$ 806	$ 22	12	65	403	40	20%	$ 161
Tractors(pump, bushhog)	$	$ 9,000	2	0.8%	$ 138	$ 12	12	11	69	7	20%	$ 28
Sidewinder(PTO, Aerator)	$	$ 3,500	6	1.5%	$ 313	$ 22	15	19	157	16	1%	$ 3
Aerators,7.5 hp	$	$ 1,500	4	100.0%	$ 6,000	$ -	7	857	3000	300	20%	$ 1,200
PTO pump	$	$ 1,500	1	0.8%	$ 12	$ -	10	1	6	1	1%	$ 0
Bush hog/mower	$	$ 4,000	1	0.8%	$ 31	$ -	10	3	15	2	10%	$ 3
Monitoring System, In-situ	$	$ 2,000	1	100.0%	$ 2,000	$ -	10	200	1000	100	5%	$ 100
Computer and Electronic Equipment	$	$ 3,000	1	0.7%	$ 20	$ -	5	4	10	1	0%	$ -
Subtotal					$ 11,543			1368		577		1656
Total					**29,092**			**2700**		**1455**		$ 1,938.80

Table C.6 XLP pond fixed cost hybrid catfish open ponds (Mississippi Delta).

Item	Unit	Cost/unit	Number	Percent to Pond	Cost	SV	Usefullife	Depreciation	Average Inves	Interst on Investment	% Repairs	Repairs Cost
A. Capital Cost												
Land	$/ha	$ 4,860	5.4	100.0%	$ 26,400							
Pond Construction	$/ha	$ 1,250	5.4	100.0%	$ 6,790		10	679	3395	340	1.0%	$ 68
Electric work	$	$ 600	4	100.0%	$ 2,400	$ 100	10	230	1200	120	5%	$ 120
Gravel	$/Load	$ 235	10.6	50.0%	$ 1,248		5	250	624	62	0.5%	$ 6
Office	$	$ 50,000	1	1.0%	$ 479	0	15	32	240	24	2.5%	$ 12
Shop	$	$ 80,000	1	1.0%	$ 767	0	15	51	383	38	2.5%	$ 19
Tools and Equipment	$	$ 20,000	1	1.0%	$ 192	$ 24	10	17	96	10	2.5%	$ 5
Subtotal(excluding land)				100.0%	11,876			1259		594		$ 230
B. Equipment												
Trucks, 1/2 ton	$	$ 22,000	2	2.1%	$ 944	$ 11	6	156	472	47	15%	$ 141.60
Feed Truck(Internation 30000 gvw)	$	$ 42,000	2	2.1%	$ 1,802	$ 11	15	119	901	90	5%	$ 90
Feed Bins(20 ton)	$	$ 7,000	3	2.1%	$ 451	$ -	20	23	225	23	0%	$ -
Tractors(PTO, Aeration)	$	$ 9,000	6	2.1%	$ 1,159	$ 32	12	94	579	58	20%	$ 232
Tractors(pump, bushhog)	$	$ 9,000	2	1.0%	$ 173	$ 14	12	13	86	9	20%	$ 35
Sidewinder(PTO, Aerator)	$	$ 3,500	6	1.0%	$ 201	$ 14	15	12	101	10	1%	$ 2
Aerators, 7.5 kW	$	$ 1,800	4	100.0%	$ 7,200	$ -	7	1029	3600	360	20%	$ 1,440
PTO pump	$	$ 1,500	1	1.0%	$ 14	$ -	10	1	7	1	1%	$ 0
Bush hog/mower	$	$ 4,000	1	1.0%	$ 38	$ -	10	4	19	2	10%	$ 4
Monitoring System, In-situ	$	$ 2,000	1	100.0%	$ 2,000	$ -	10	200	1000	100	10%	$ 200
Computer and Electronic Equipment	$	$ 3,000	1	0.7%	$ 20	$ -	5	4	10	1	0%	$ -
Subtotal					$ 14,002			1655		700		2144
Total					**25,878**			**2913**		**1294**		$ 2,374.00

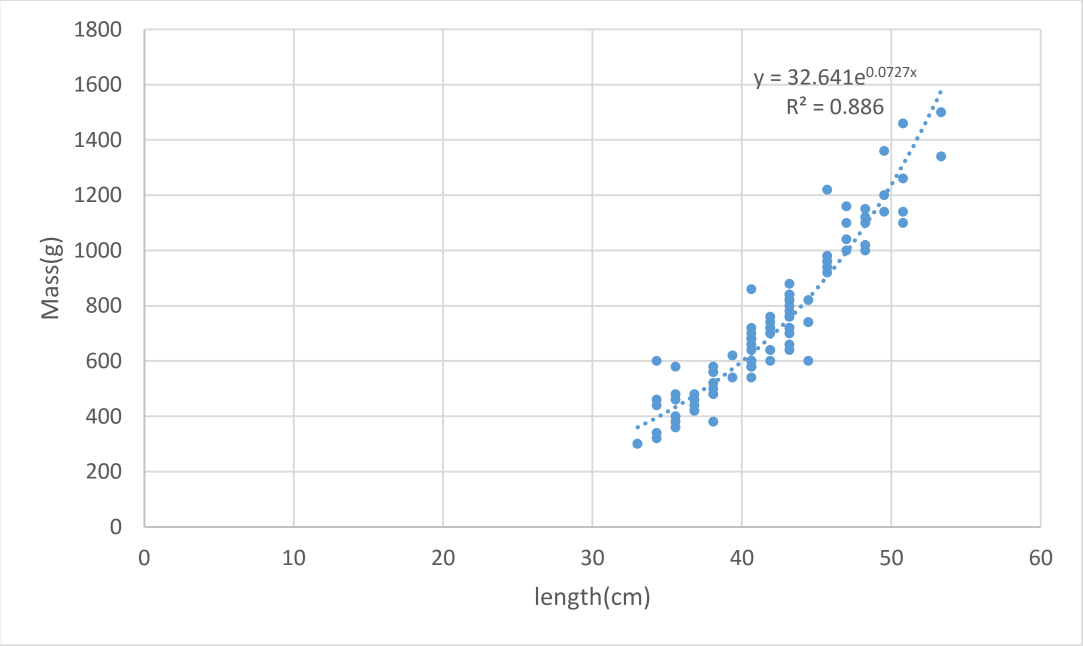

Figure C.6.3 XSP pond length mass relationship hybrid catfish open ponds (Mississippi Delta).

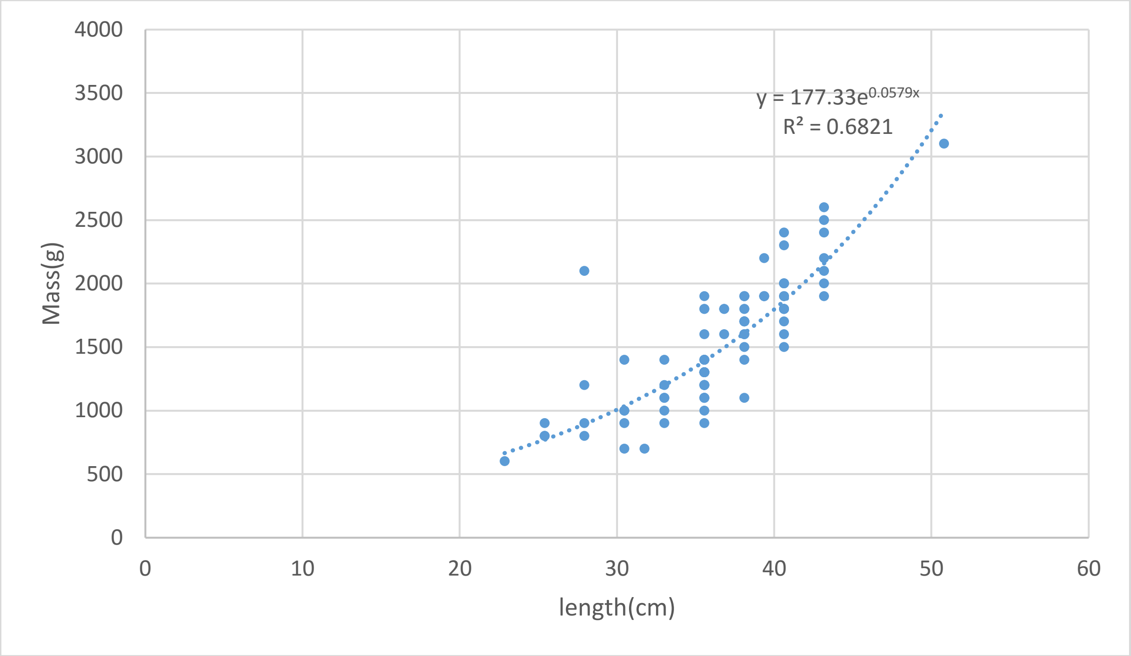

Figure C.6.4 SP pond length mass relationship hybrid catfish open ponds (Mississippi Delta).

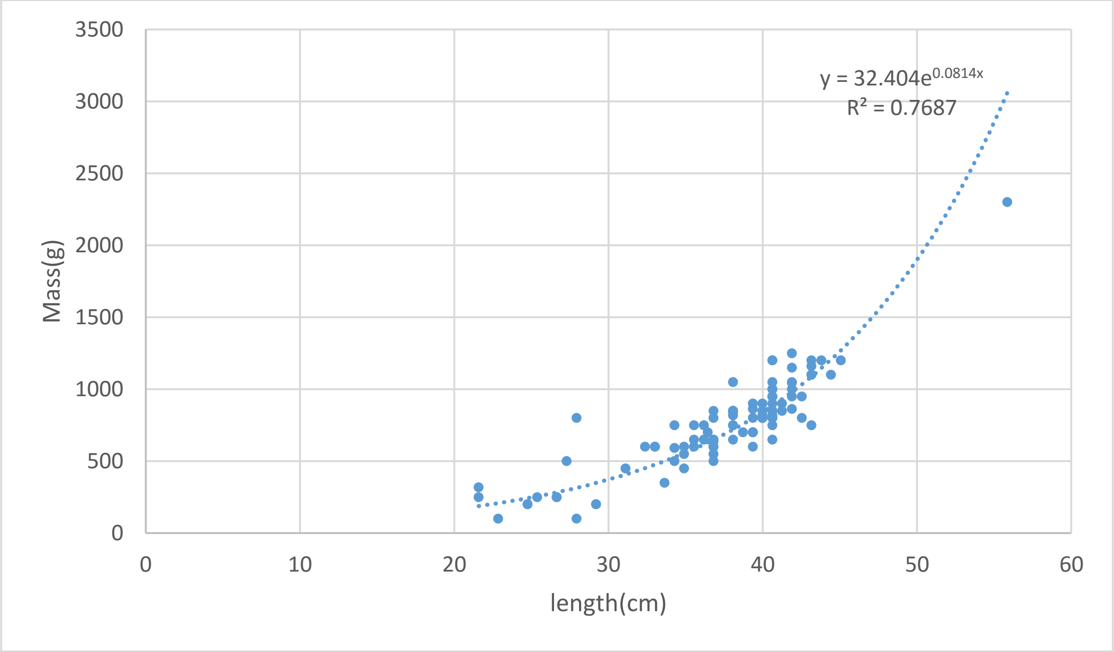

Figure C.6.5 SPDA pond #1 length mass relationship hybrid catfish open ponds (Mississippi Delta).

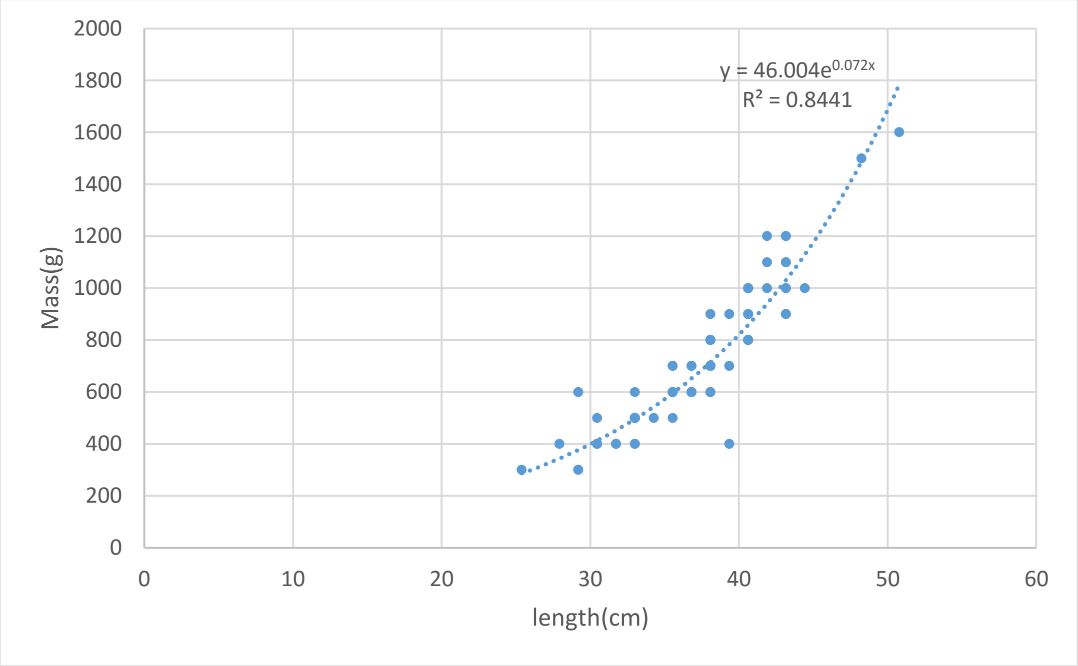

Figure C.6.6 SPDA pond #2 length mass relationship hybrid catfish open ponds (Mississippi Delta).

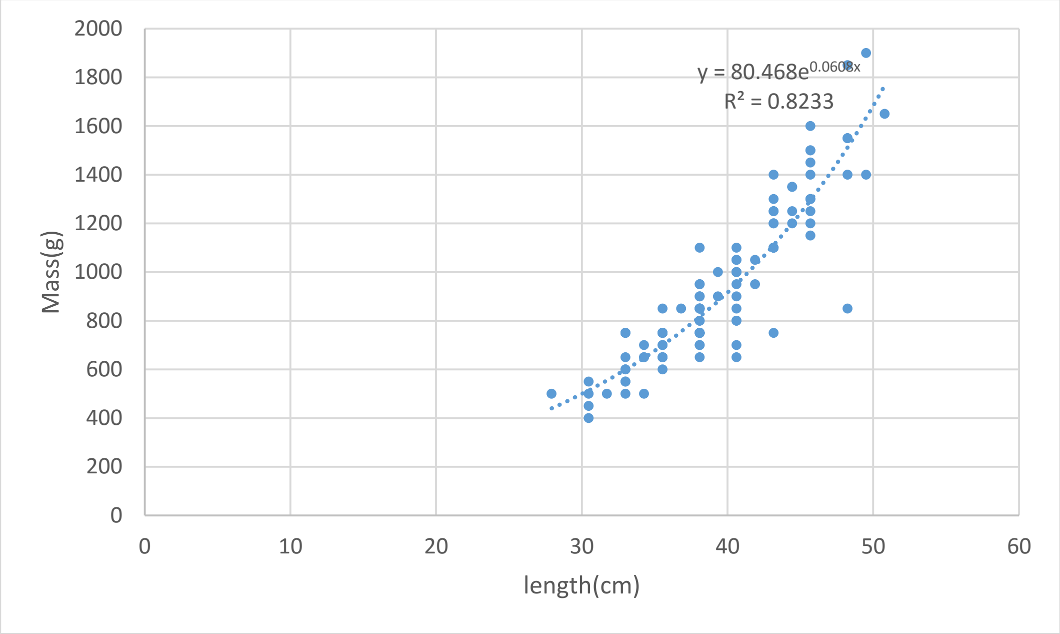

Figure C.6.7 SPSN pond #1 length mass relationship hybrid catfish open ponds (Mississippi Delta).

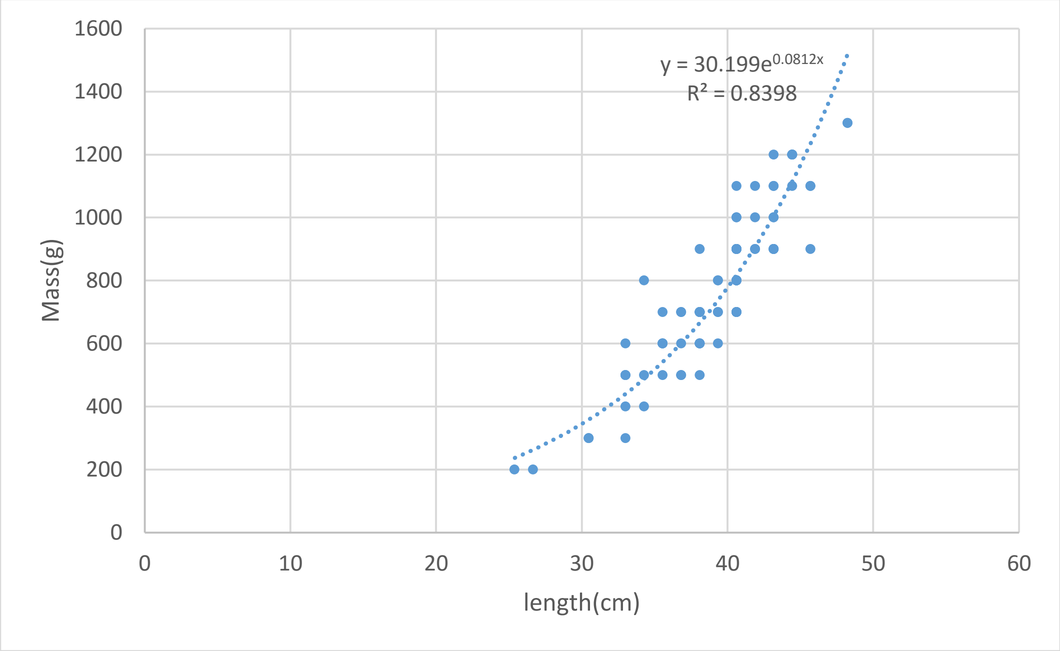

Figure C.6.8 SPSN pond #2 length mass relationship hybrid catfish open ponds (Mississippi Delta).

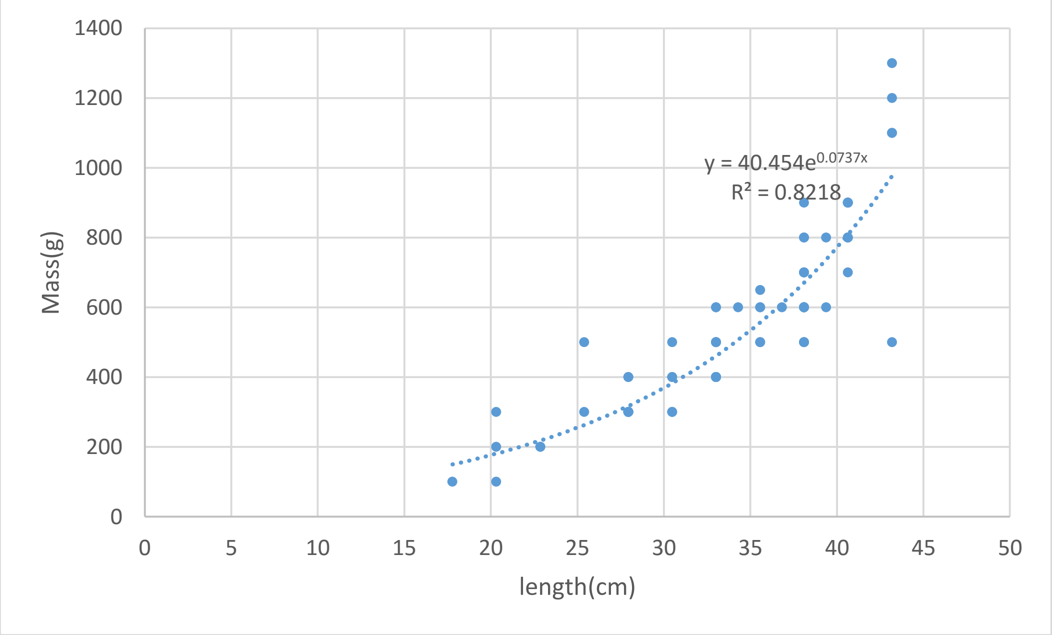

Figure C.6.9 LP pond #1 length mass relationship hybrid catfish open ponds (Mississippi Delta).

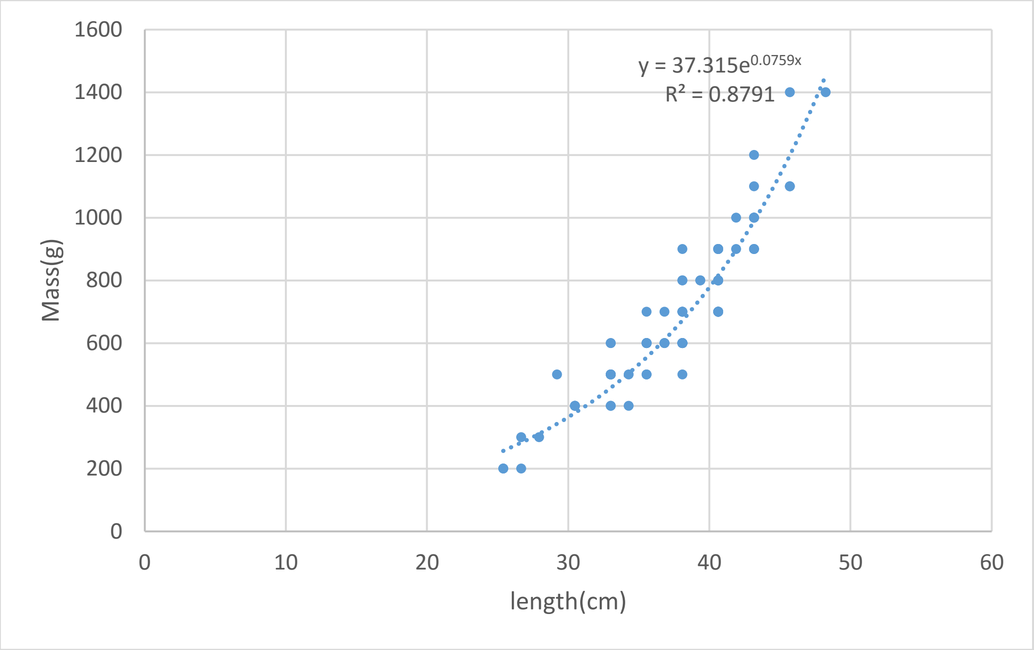

Figure C.6.10 LP #2 length mass relationship hybrid catfish open ponds (Mississippi Delta).

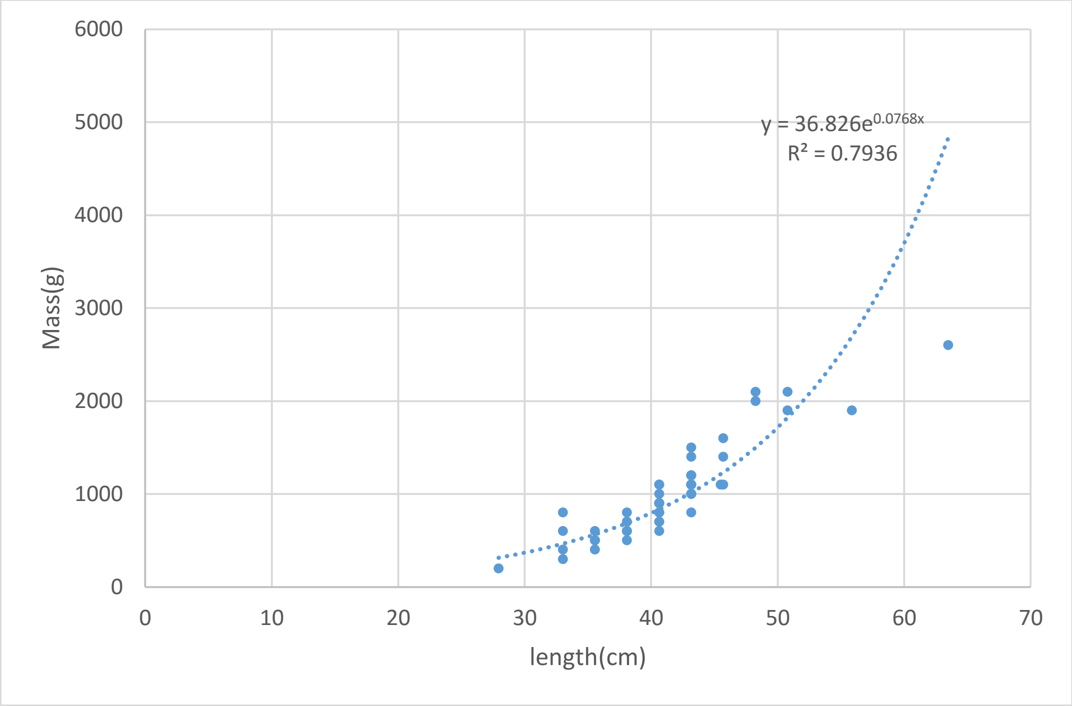

Figure C.6.11 LP pond #3 length mass relationship hybrid catfish open ponds (Mississippi Delta).

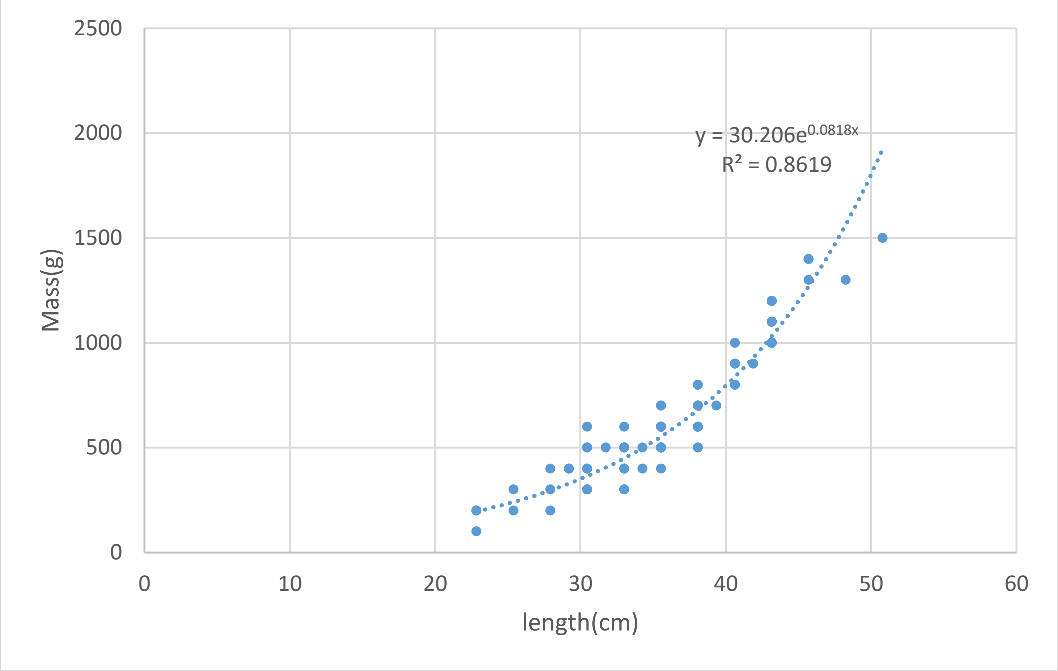

Figure C.6.12 XLP pond length mass relationship hybrid catfish open ponds (Mississippi Delta).

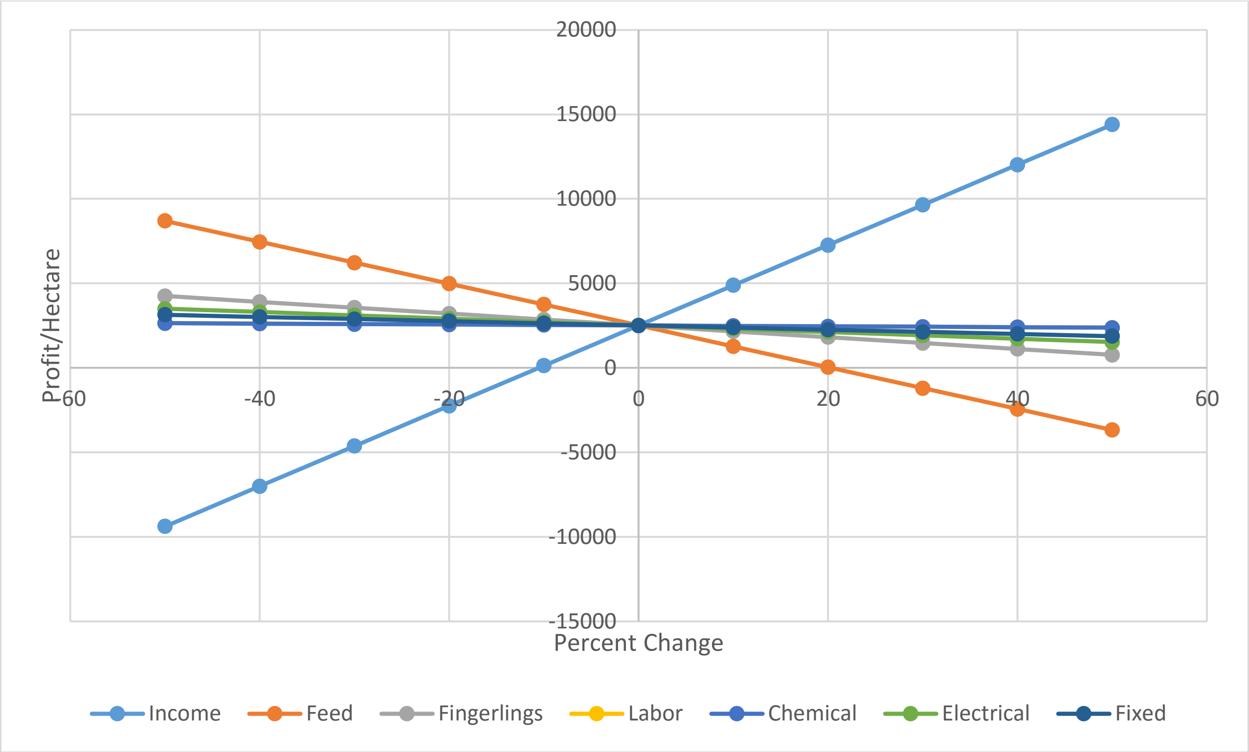

Figure C.6.13 SPDA profit spider plot sensitivity hybrid catfish open ponds (Mississippi Delta).

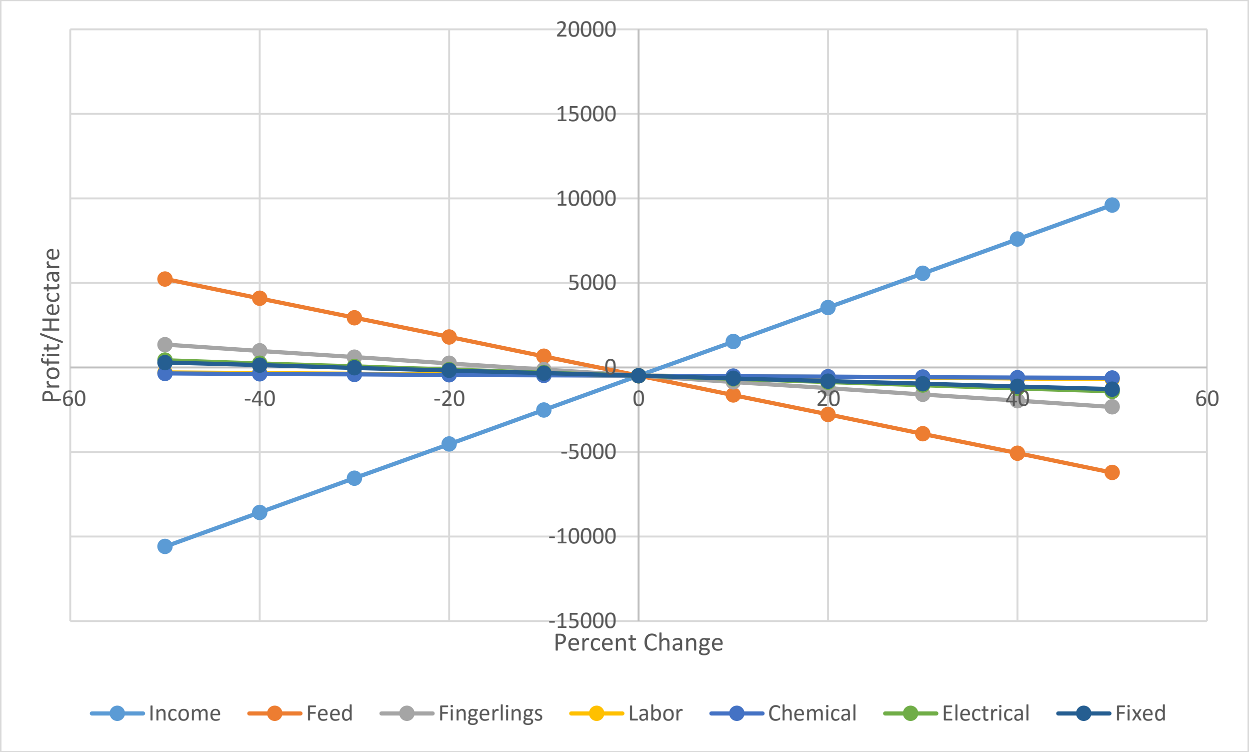

Figure C.6.14 SPSN profit spider plot Sensitivity hybrid catfish open ponds (Mississippi Delta).

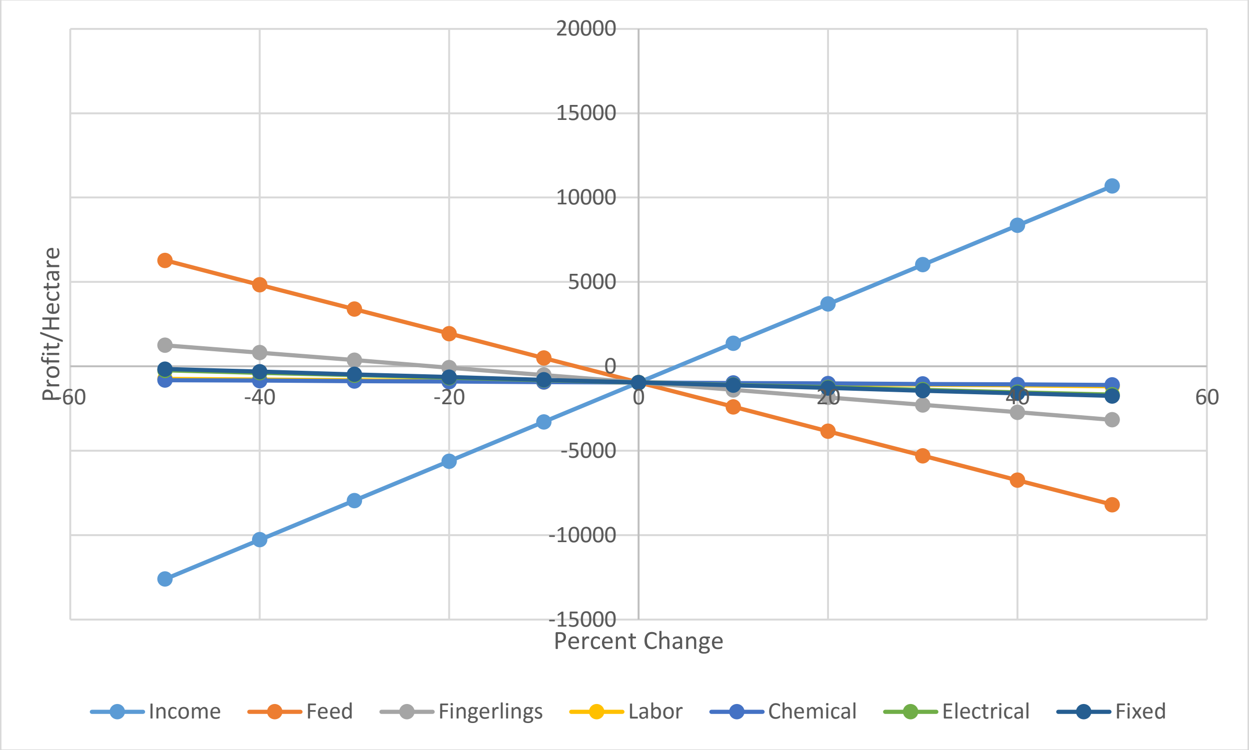

Figure C.6.15 XSP profit spider plot sensitivity hybrid catfish open ponds (Mississippi Delta).

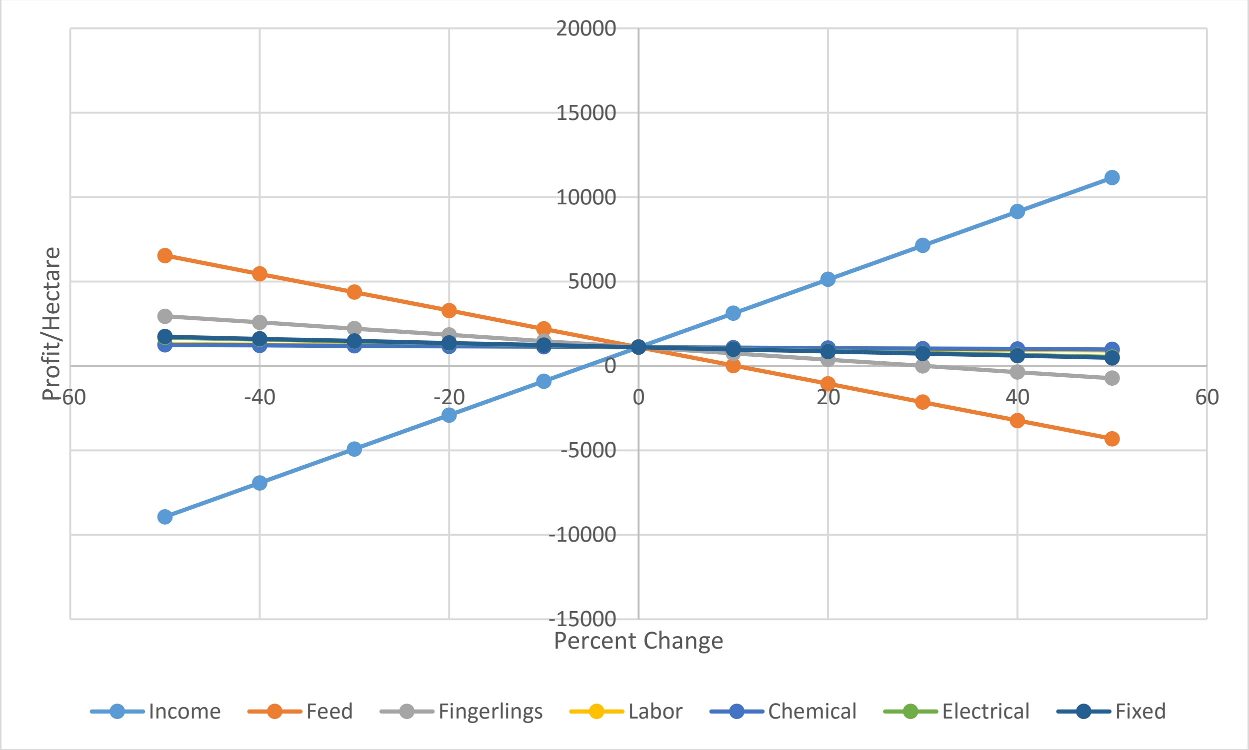

Figure C.6.16 SP profit spider plot Sensitivity hybrid catfish open ponds (Mississippi Delta).

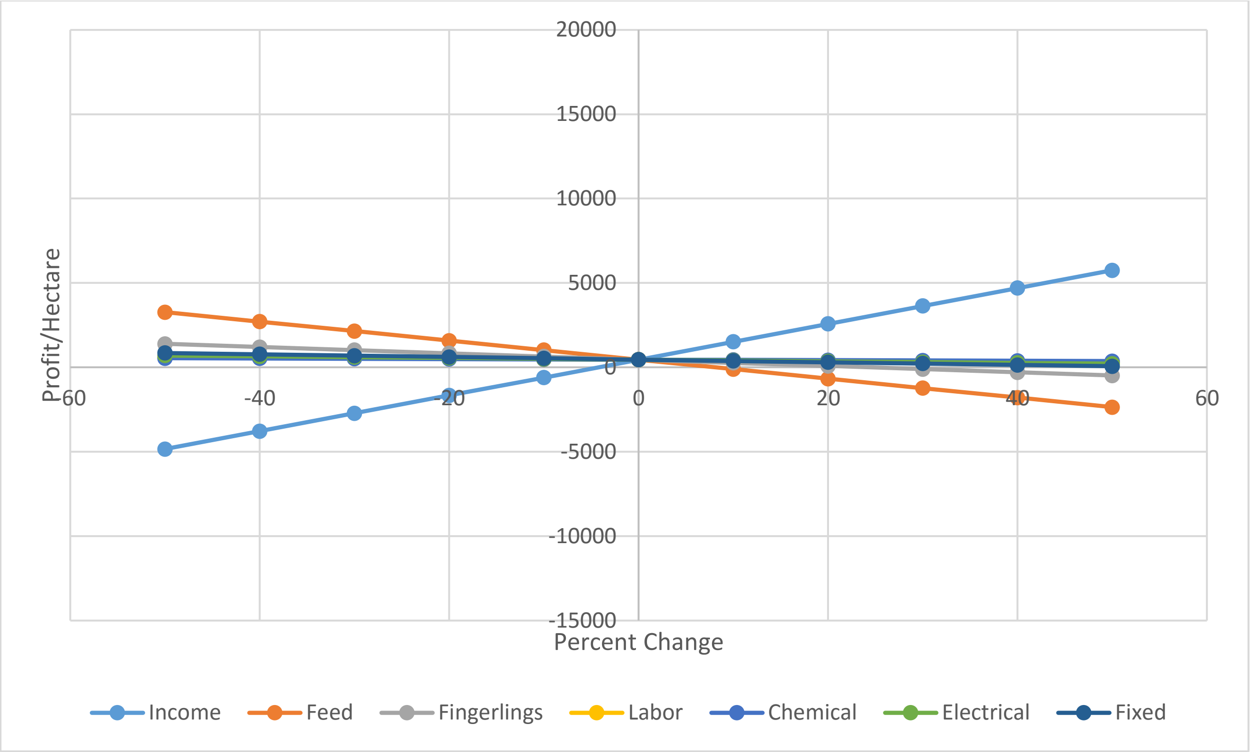

Figure C.6.17 LP profit spider plot sensitivity hybrid catfish open ponds (Mississippi Delta).

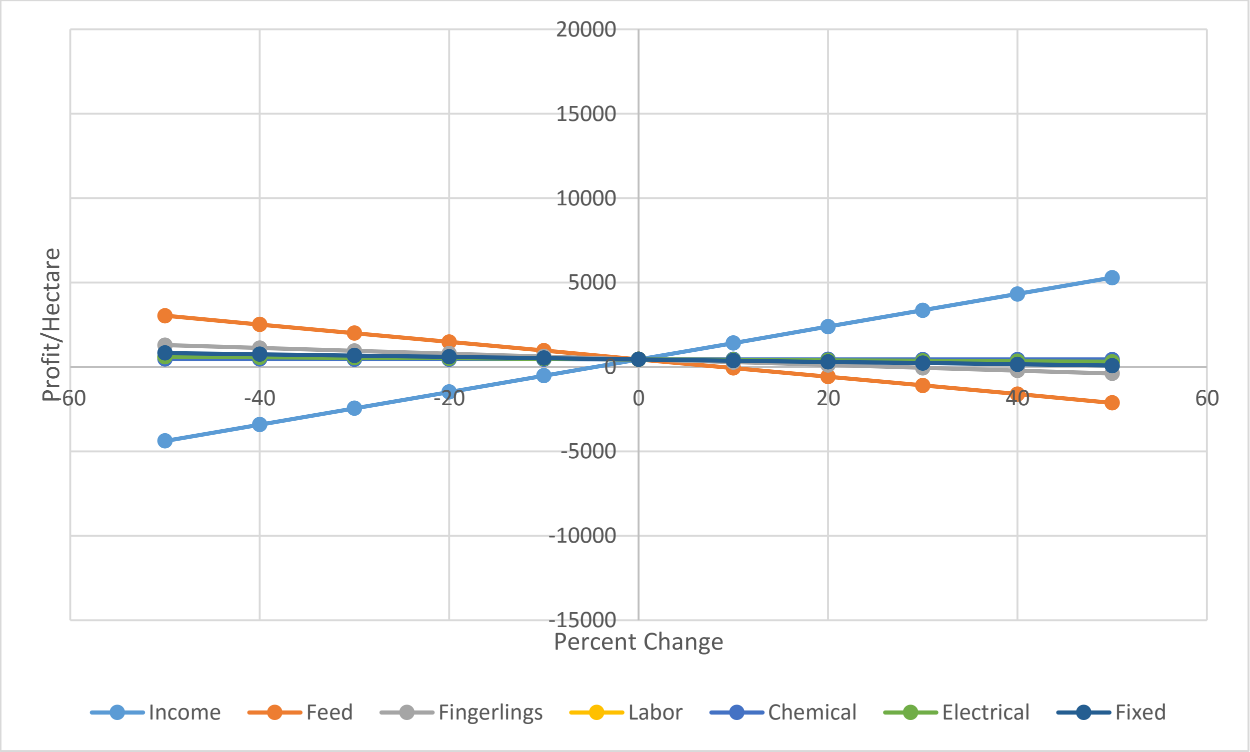

Figure C.6.18 XLP profit spider plot sensitivity hybrid catfish open ponds (Mississippi Delta).