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Epidemiological Study of the Factors that Influence Mortality and Economics on a Commercial Catfish Farm

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Epidemiological study of the factors that influence mortality and economics on a commercial catfish farm

By

Fred L. Cunningham

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Epidemiological study of the factors that influence mortality and economics on a commercial catfish farm

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A Catfish Management Database (CMD) was developed to analyze data from large commercial catfish farms. The CMD was developed so that data collected by the farm could be used for management of the farm and for identifying some of the risk factors associated with important bacteria diseases. This database was designed to 1) to incorporate production data already being recorded for generating reports for use at weekly managerial meetings focused on feeding rates, feed conversion ratios, mortalities and harvesting events 2) be easily used by a catfish farmer to collect management data in order to analyze production efficiency through a series of farmer defined management reports and 3) provide the farm with easy access to management reports. Additional customized reports can be generated as requested by the farm management. The next objective of this research was to determine pond level risk factors associated with columnaris disease and Enteric Septicemia of Catfish related mortalities. The data from the CMD was used to produce two publications detailing the analysis of the data and production of a univariate and multivariate models of pond level risk factors associated with both diseases. These studies showed some commonly recorded production variables were associated with either columnaris and/or ESC associated mortalities and if monitored could help identify “at risk” ponds prior to disease outbreaks. A study was then conducted to examine the cost associated with mortality on Mississippi commercial catfish farms. The mortalities examined included ponds that had mortalities from columnaris disease, ESC and then any ponds that had mortalities from either. The cost of each disease was determined along with other factors such as pond age, feed conversion ratio and feed cost that influence the profitability of a commercial catfish farm.

Key words: Columnaris; *Flavobacterium columnare;* production records; risk factors; Catfish; ESC; *Edwardsiella ictaluri*; epidemiology; Disease cost; Mortality cost

DEDICATION

This dissertation is dedicated to Brenda who is my wife and best friend. I have been extremely lucky to have been with her for over 38 years. She has been very patient and supportive in all phases of our life together.

It is also dedicated to my Mother, Adele, Mother-in-law, Brownie and my sisters, Linda and Adele who believed I could accomplish anything I set out to do. Their support has been invaluable to me.

Dr. John Martin, a great Veterinarian and a better friend and man that had a tremendous influence as a mentor on my life and career. I was fortunate that he took me under his wing while I was still in junior high and working as a helper (dog holder and chief cage cleaner) at his Veterinary Practice. He has encouraged me every step and has been a constant anchor in my life.

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I would also like to thank Dr. John Thomson, former Dean of the Mississippi State University-College of Veterinary Medicine who recruited me to MSU for this project. Dr. David Hardin, Dr. Robert Wills and Dr. Richard Randle who had faith in this project and what it could bring to the catfish industry. I would especially like to thank Dr. Randle for his knowledge of database design, function and initial development. The database would not have been possible without you.

For exceptional help with edits and formatting of this dissertation I would like to recognize and thank Ms. Lorelei Ford.

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CHAPTER I

INTRODUCTION

The majority of catfish production occurs in Mississippi. In fact, this state accounts for more than 58% of the total U.S. catfish production (Hanson*, et al.*, 2004) most of which comes from two counties within the Mississippi River alluvial valley. The economic impact of the catfish industry on Mississippi's state economy in 2001 was 10,761 jobs, $208.25 million in employee income and a total value of $342.33 million (Hanson*, et al.*, 2004). Increased feed cost and imports have caused a reduction in the Mississippi catfish industry. As of January 2012, Mississippi had roughly 51,200 water surface acres in production (Hanson and Sites 2012; Hanson and Sites 2013; Hanson and Sites 2014).

In the late 1990's catfish aquaculture expanded but losses from events such as power outages (thus aeration loss led to lethal decreases in dissolved oxygen), bird depredation, and infectious disease outbreaks continue to plague the industry. One of the main issues of concern is loss due to infectious diseases. To investigate these losses well-designed epidemiological studies are needed.

Infectious disease has become one of the main concerns in aquatic animal production. Numerous investigators have identified infectious disease as the foremost constraint on further development of the aquaculture industry (Georgiadis*, et al.*, 2001). Enteric septicemia of catfish reportedly costs the catfish aquaculture industry $50 to $60 million annually (Breazeale, 2007). Economic losses due to disease are difficult to assess accurately because they are usually underreported due to self-diagnosis by the producer and lack of record keeping. Economic losses attributable to disease on individual farms can be devastating (Hawke and Khoo, 2004). Depending on the disease, 60% to 100% of fish can be lost in an individual pond or even on a single farm during a disease outbreak (Plumb, 1999; Hawke and Khoo, 2004).

Most infectious diseases, including those that affect fish, have a multifactorial etiology. For a disease eventto occur, simultaneous interactions among host, agent, and environmental factors must all occur. The existence of an infectious organism (agent) in a fish or the environment will not necessarily lead to clinical disease (Jarp*, et al.*, 1993). Some feel that environmental factors, such as deterioration of water quality, can be linked to the occurrence of fish disease. Catfish farming today is increasingly more intensive (Plumb, 1999; Hargreaves, 2002), with increased stocking densities, feeding rates, and multi-batch harvesting compared to previous years. These practices have resulted in poor water quality as defined by low dissolved oxygen, high nitrogenous compounds, and high stress, followed by low immune system function. The subsequent introductions of young immunologically naïve fish into this environment is cause for concern. Fish are very sensitive to environmental fluctuations, and adverse reactions can occur quickly due to fish being poikilotherms and constantly exchanging metabolites and gasses with their surroundings (Plumb, 1999). It is imperative to investigate the specific associations between environmental parameters and disease occurrences in catfish aquaculture as well as to devise prevention strategies using this knowledge.

The main goal in aquaculture is to produce a quality product efficiently and for a profit. Infectious disease hinders this process in numerous ways. Mortality causes loss of production and less pounds to market resulting in decreased income. Morbidity results in poorer feed conversion, slower growth, delayed harvest, increased susceptibility to secondary pathogens or environmental stressors (Roberts and McKnight, 1976). Delayed harvest results in less efficient use of space which could have more productive with healthy fish (Rosenlund, 1977). Therefore, higher production costs are associated with disease outbreaks, and there are limited drug therapies currently available for use in food fish. Hence prevention of disease is essential.

The objectives of this study were to: 1) develop a catfish database for epidemiological studies, 2) determine pond level risk factors associated with columnaris disease and enteric septicemia of catfish related mortalities, 3) determine the economic cost of mortality on a per acre and per pond basis and 4) determine if production parameters reported by farm personnel can be used to predict the occurrence of disease events.

CHAPTER II

LITERATURE REVIEW

Development of the Farm raised catfish industry

The history of the channel catfish (*Ictalurus punctatus*) industry is over one hundred years old. In 1871 the U.S. Fish and Fisheries Commission was formed to increase the populations of different fish species for the stocking of lakes, farm ponds and rivers in the United States (Hargreaves and Tucker, 2004). Channel catfish was one of the species selected for this program. Initial research centered on spawning, hatcheries and fry production. By the 1920s channel catfish were propagated using hatchery ponds (Hargreaves and Tucker, 2004).

Many of the techniques developed during this time form the basis for the industry today. The addition of spawning containers to broodfish ponds was first introduced in 1917 (Shira, 1917). The incubation and aeration of eggs in shallow troughs with constant water flow and slowly rotating paddles was introduced in 1929 (Clapp, 1929; Fuqua and Topel, 1939).

In the 1950s Dr H. S. Swingle from Auburn led the research to develop increased production in pond raised adult channel catfish. He found that the yield on farm ponds could be increased by using inorganic fertilizer. Annual yields in fertilized ponds ranged from 90 to 180 pounds per acre (Swingle, 1954). He also found that using soybean cake as a feed source could increase yield up to 225 lbs per acre (Swingle, 1957). Yields in catfish ponds could be increased up to 1,250 pounds per acre if a dry powered diet formulated from minnows was used (Swingle, 1957). Swingle later found that fish could be stocked at 2000 fish per acre and if fed no more than 30 to 40 lbs. of feed per acre the fish population would thrive without causing oxygen depletion and fish kills (Swingle, 1959).

The birth of modern channel catfish production took place in the 1950s and 1960s. Farmers in Arkansas seeking an alternative for rice and cotton started growing buffalofish. Channel catfish were introduced and grown in the same pond with the buffalofish (polyculture) and soon the demand for the channel catfish exceeded the buffalofish. By 1966 Arkansas had 9,750 acres of catfish ponds in production (Meyer*, et al.*, 1967). The first commercial production of catfish in Mississippi began around 1965 in the Delta region of the state. Most catfish were raised by independent producers and sold locally. Processing of catfish was seasonal with peak demand in the spring while peak harvest occurred in the fall. No quality control programs were in place so flavor varied greatly (Hargreaves and Tucker, 2004).

In 1967 eleven catfish producers in the Morgan City, Mississippi area formed a corporation to build a small processing plant (Hargreaves and Tucker, 2004). For the processing plant to operate efficiently it needed a year round supply of fish. To meet this demand, producers used a multiple-batch system, with different size and ages of catfish in the same pond, which allowed year round harvesting and processing.

In 1971 ten catfish farmers formed a cooperative to build a feed mill in Isola, Mississippi. The mill, which began operating in 1974, allowed vertical integration of the catfish industry. The mill also led to the development of support industries for catfish production such as pond construction, equipment manufacturing and transportation (Hargreaves and Tucker, 2004). The industry rapidly expanded in the early 1970s but then consolidated as inefficient producers failed to survive. The number of catfish farms peaked in 1973 at 563 but fell to just 199 by 1977 (Wellborn and Tucker, 1985). The farm size during this same time frame almost doubled in size from 44 acres to 86 acres. By 1983 the average farm size had increased to 173 acres (Hargreaves and Tucker, 2004).

As farms increased in size farmers were able to realize economies of scale. This also led some farms to specialize in different phases of catfish production such as fry or fingerling production. This led to the reduced variability of fingerlings and a more uniform product at processing, which enhanced marketing. Continued feed mill construction and the development of feed specially designed for catfish were important developments.

In the 1980s production of catfish pounds per acre rapidly increased. From 1982 to 2002 pond acreage doubled but the quantity of catfish processed increased by more than six times (Tucker and Hargreaves, 2004). The electric paddlewheel for aeration allowed for increased stocking rates (Hargreaves and Tucker, 2004).

The Catfish Institute (TCI) was established in 1986 funded by adding $6.00 per ton of catfish feed. It had the responsibility to develop a generic marketing program to promote catfish as a food service item. Its goal was to take catfish from a regional to a national product (Hargreaves and Tucker, 2004).

Economic State of the Catfish Industry

The current state of the catfish industry is tenuous at best. Pressures from increasing feed prices and reduced market prices have forced producers to reevaluate their place in the industry. A reduction in catfish water acres has taken place over the last several years (Hanson and Sites, 2012; Hanson and Sites, 2013; Hason and Sites, 2014).

All data used to construct Figures 2.1 through 2.10 were obtained from the U.S. Catfish Database produced by David Sites of Mississippi State University, Department of Agricultural Economics and Dr. Terry Hanson of Auburn University School of Fisheries Aquaculture and Aquatic Sciences. These reports are a summary of data obtained from various reports from USDA-NASS (National Agricultural Statistics Service) and MASS (Mississippi Agricultural Statistics Service) as well as self-collected feed price data. These figures contain data from the 2011, 2012 and 2013 Catfish Databases (Hanson and Sites, 2012; Hanson and Sites, 2013; Hanson and Sites, 2014).

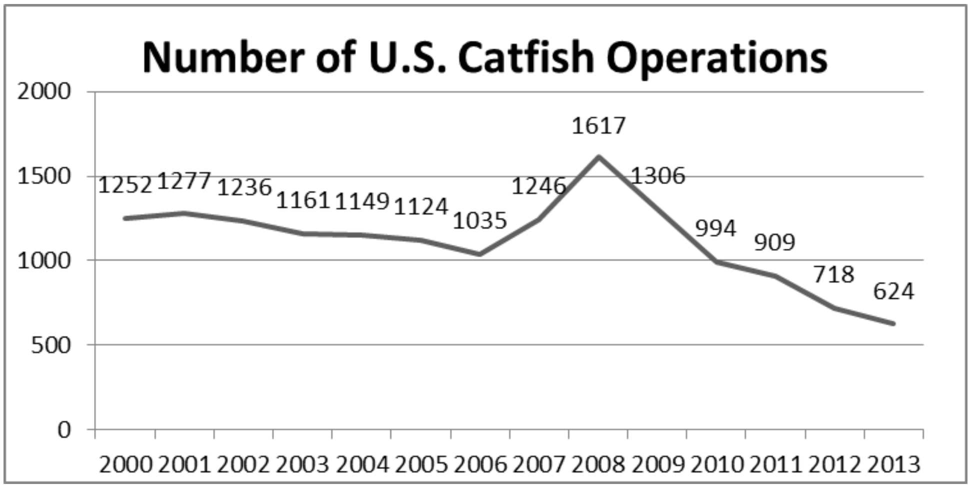


Figure 2.1 Number of U.S. Catfish Operations by year

(Hanson and Sites, 2012; Hanson and Sites, 2013; Hanson and Sites, 2014)

The USDA-National Agriculture Statistics Service found that the total operations in January 2008 were 1617 compared to 1306 in January 2009 a decrease of 311 operations. This trend continued through 2012 with 718 total operations remaining in the U.S., a 55.6% reduction in operations compared to the 2007 peak (Figure 2.1).

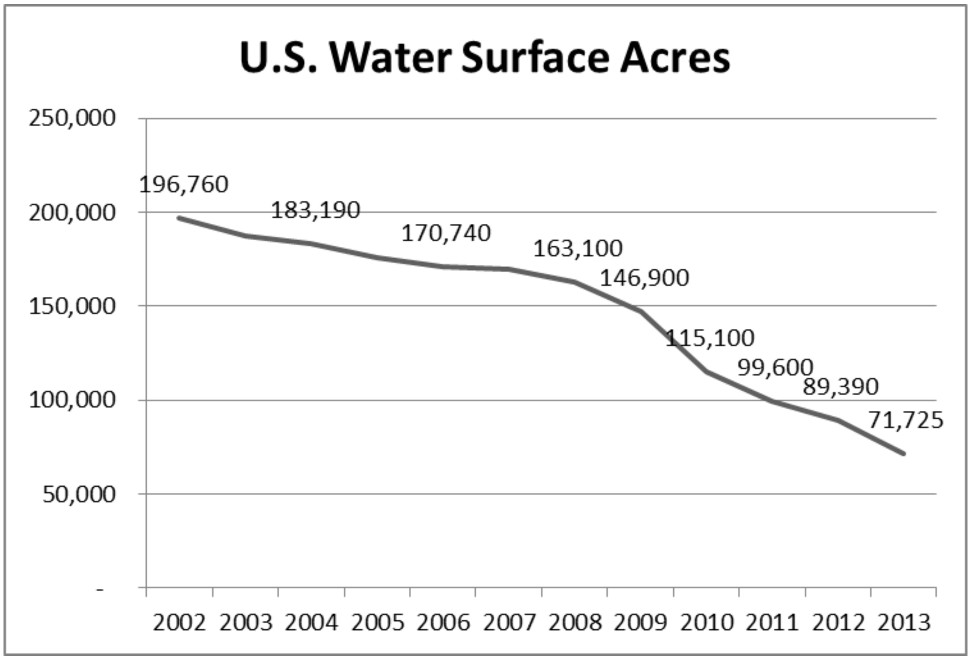


Figure 2.2 U.S. Water Surface Acres in Catfish Operations by year (Hanson and Sites, 2012; Hanson and Sites, 2013; Hanson and Sites, 2014)

Nationally the total acreage dedicated to catfish production peaked in 2001 at 196,760 acres. Since that time the U.S. acreage has been reduced each year. The total acreage remaining in production on January 1, 2013 was 71,725 acres. Compared to the peak in 2001 this is a 63.5 % reduction in the total water surface acreage dedicated to catfish production (Figure 2.2).

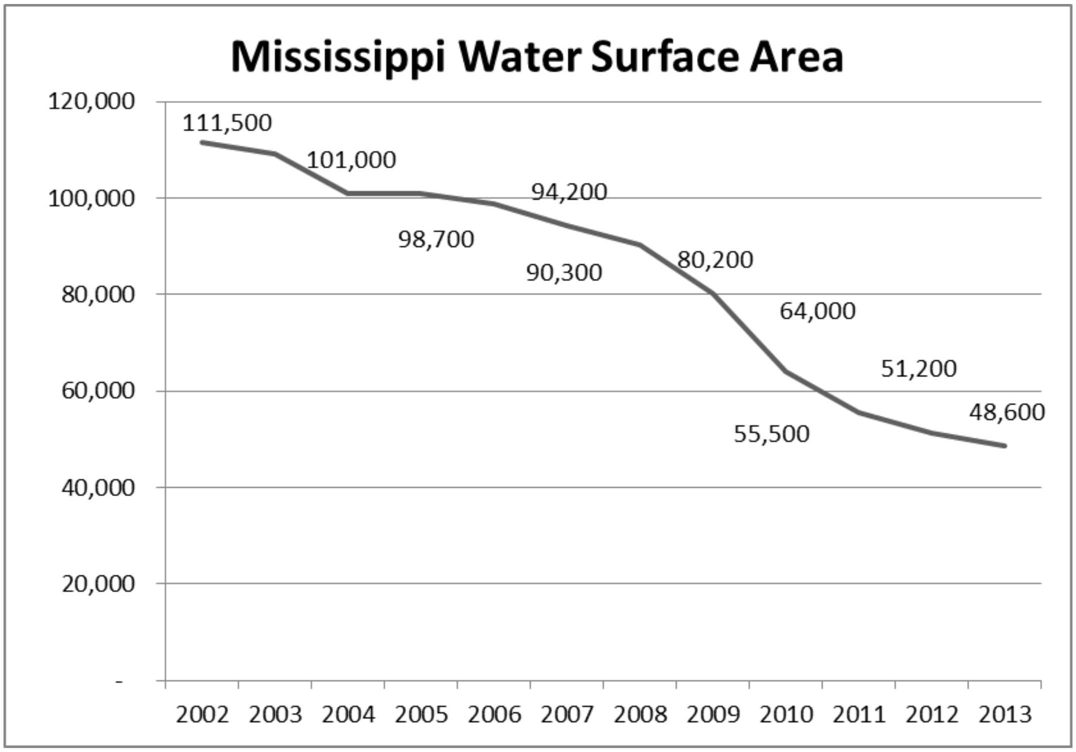


Figure 2.3 Mississippi Water Surface Acres in Catfish Operations by year (Hanson and Sites, 2013; Hanson and Sites, 2014)

Mississippi water acres peaked in January 2002 with 111,500 acres. In the January 1, 2012 inventory Mississippi reported 51,200 water surface acres, by January 2013 there were 48,600 water acres in production in the state of Mississippi. This represents a reduction of 64,100 acres or a decrease of 56.9% in water acres (Figure 2.3).

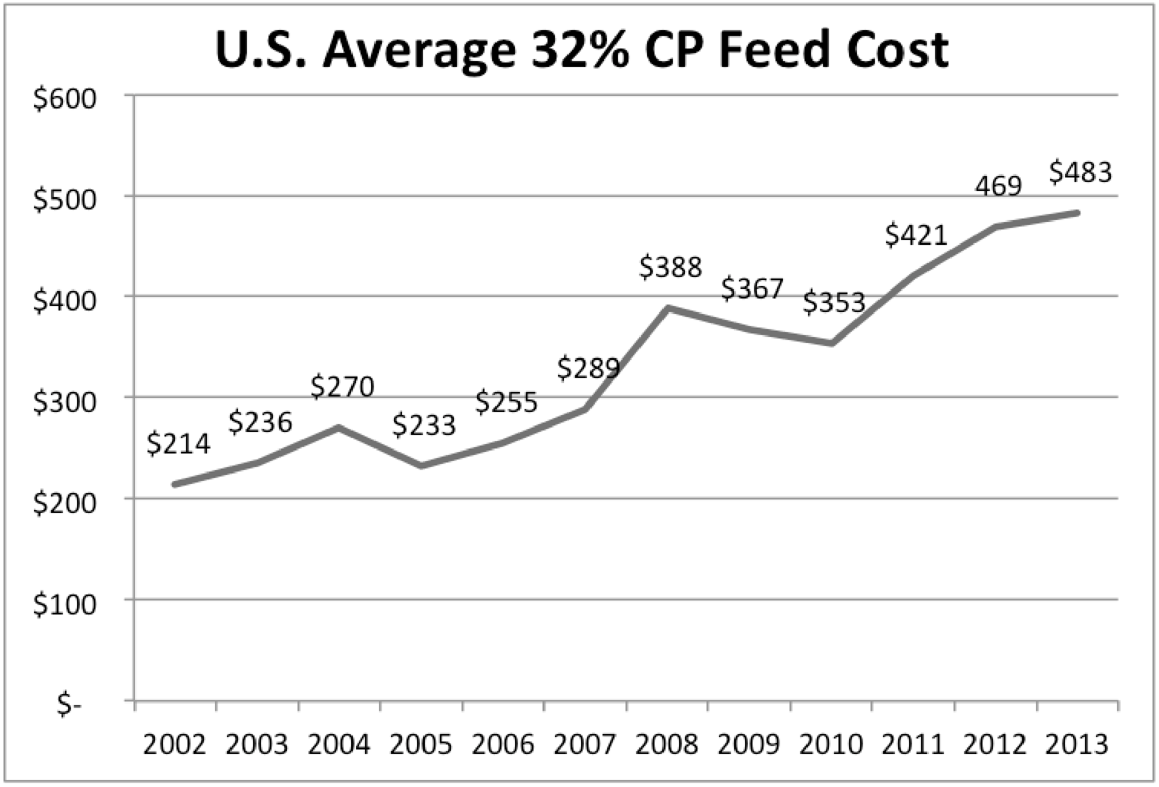


Figure 2.4 U.S. Average 32% Crude Protein Feed Cost by year

(Hanson and Sites, 2012; Hanson and Sites, 2013; Hanson and Sites, 2014)

One of the main reasons for the Catfish industry contraction is the increase in input cost. The cost per ton for 32% crude protein feed increased from $214 in 2002 to $483 in 2013 (Figure 2.4).

This large percentage increase in feed prices did not result in a similar increase in price per pound farmers received either in the U.S. (Figure 2.5) or Mississippi (Figure 2.6).

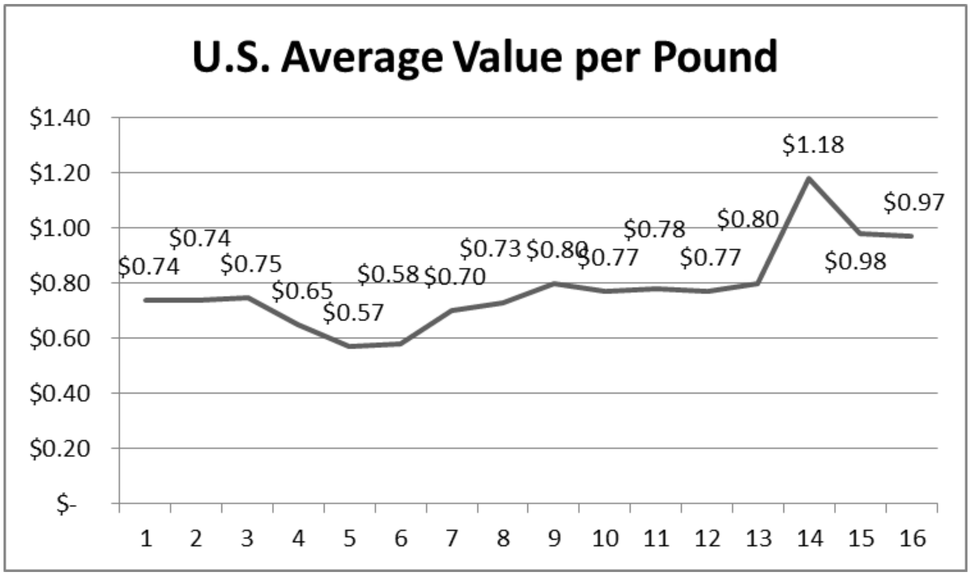


Figure 2.5 U.S. Average 32% Crude Protein Feed Cost by year

(Hanson and Sites, 2012; Hanson and Sites, 2013; Hanson and Sites, 2014)

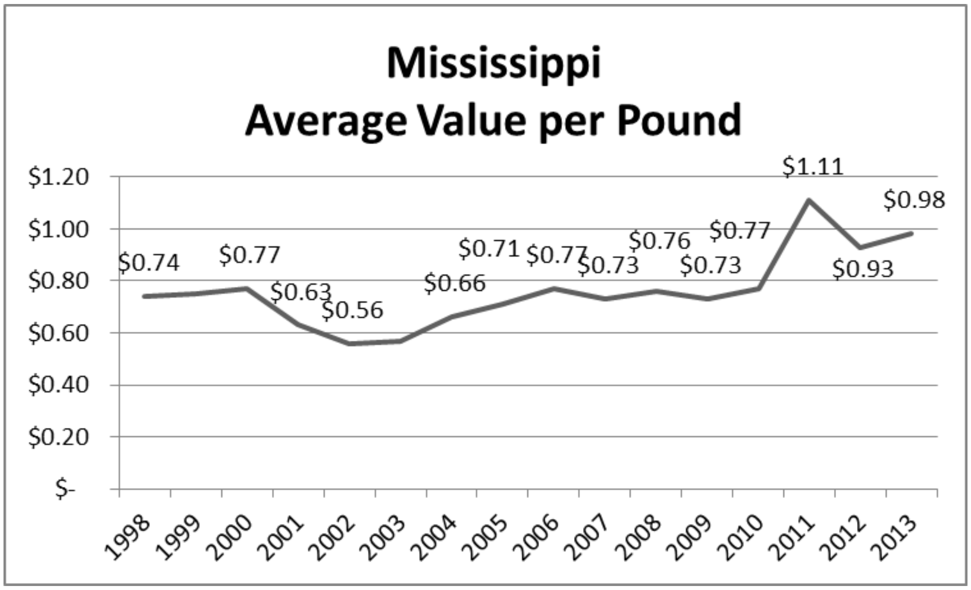


Figure 2.6 Mississippi Average Value per Pound by year

(Hanson and Sites, 2012; Hanson and Sites, 2013; Hanson and Sites, 2014)

The price per pound in the U.S. has fluctuated between a low of $0.57 in 2002 to $0.80 in 2010 before the price spiked to $1.18 in 2011. A similar trend was observed in Mississippi with a low price per pound of $0.56 in 2002 to a high of $1.11 in 2011.

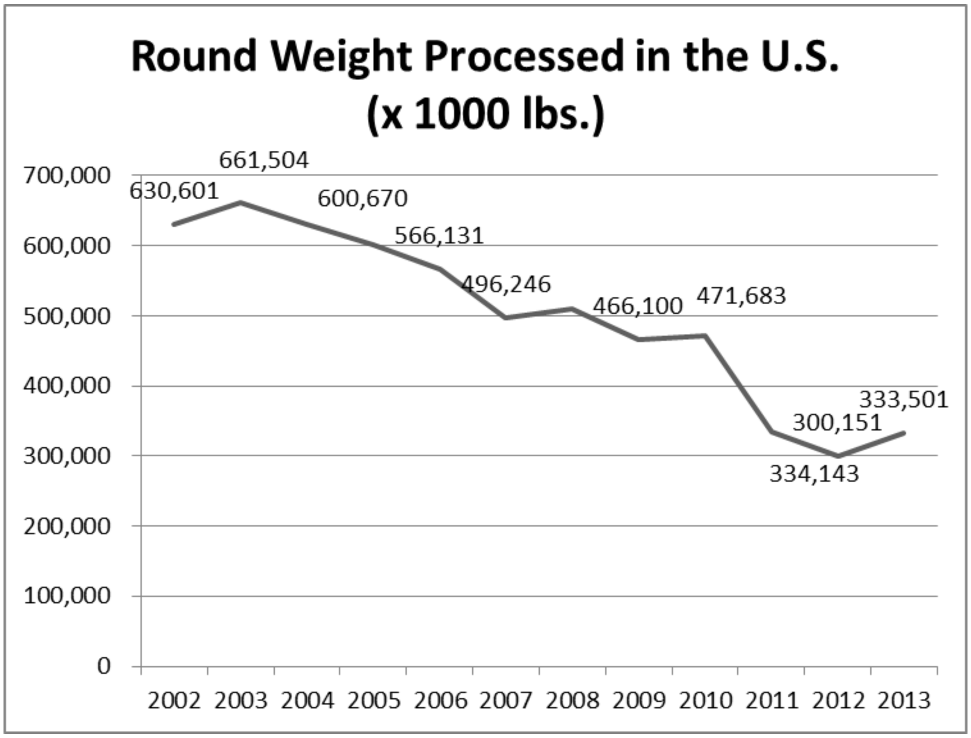


Figure 2.7 Total U.S. Round Weight Processed by year

(X 1,000lbs.)
(Hanson and Sites, 2012; Hanson and Sites, 2013; Hanson and Sites, 2014)

The round weight (live weight) processed by U.S. Catfish Processors, peaked in 2003 at 661.5 million pounds. In 2013 only 333.5 million pounds were processed (Figure 2.7).This is a 47% reduction from the peak round weight processed in 2003. During this same period imported frozen boneless catfish fillets increased from 10.2 million pounds in 2002 to 281.0 million pounds in 2013, a 2,654% increase (Figure 2.8).

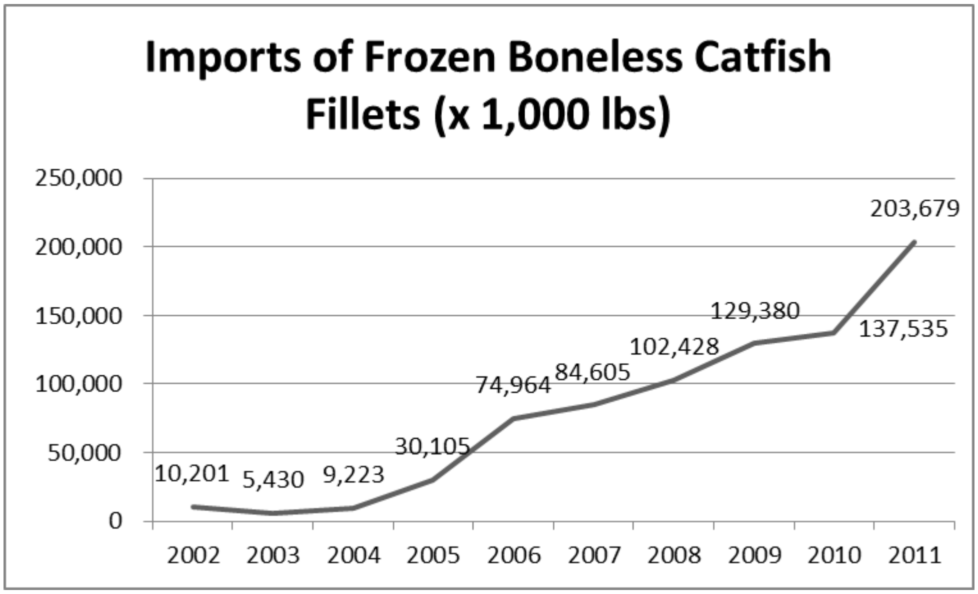


Figure 2.8 Imports of Frozen, Boneless Catfish Fillets by year

(X 1,000 lbs.)
(Hanson and Sites, 2012; Hanson and Sites, 2013; Hanson and Sites, 2014)

During this same period imported frozen boneless catfish fillets increased from 10.2 million pounds in 2002 to 281.0 million pounds in 2013, a 2,654% increase (Figure 2.8). Total U.S. catfish sales peaked in 2000 with sales of $501.4 million and reached a low in 2012 with sales of $340.6 million. In 2013 there has been a small increase in total catfish sales value reaching $342.4 million (Figure 2.9).

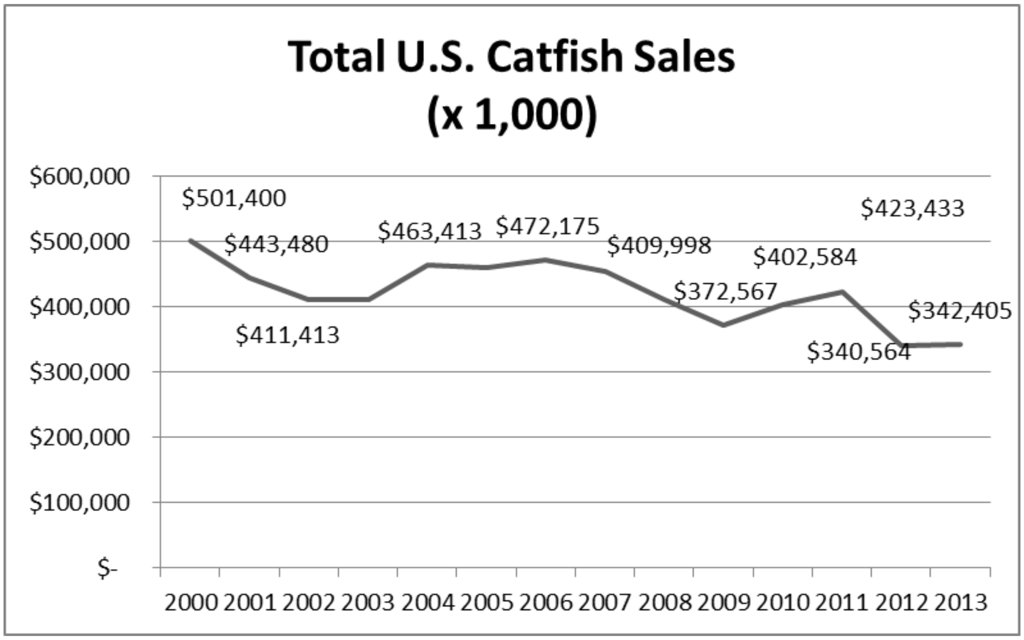


Figure 2.9 Total U.S. Catfish Sales by year

(X 1,000 lbs.)
(Hanson and Sites, 2012; Hanson and Sites, 2013; Hanson and Sites, 2014)

Total U.S. catfish (including fingerlings, stockers, food and brood fish) sales peaked in 2000 with sales of $501.4 million and reached a low in 2012 with sales of $340.6 million. In 2013 there has been a small increase in total catfish sales value reaching $342.4 million (Figure 2.9).

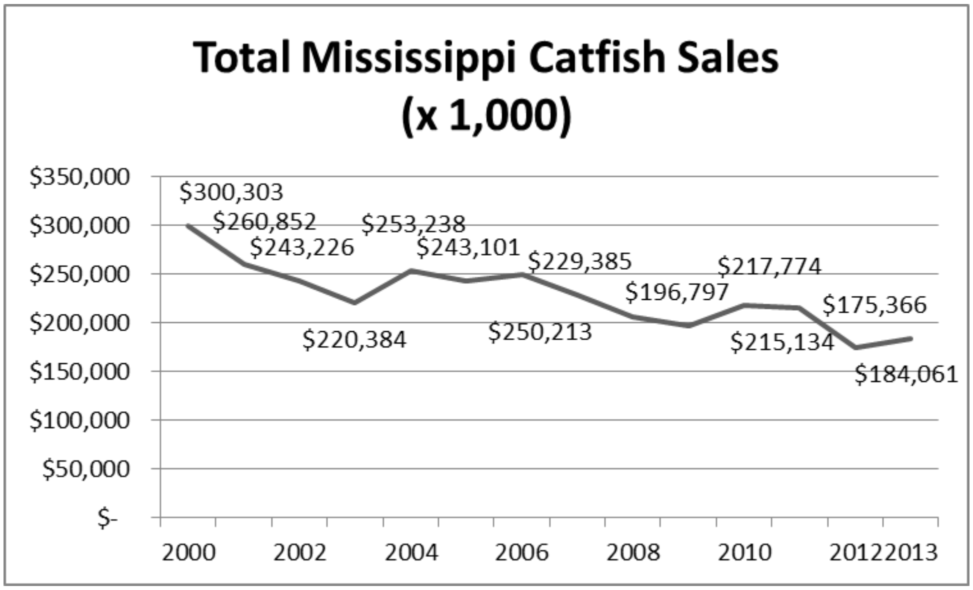


Figure 2.10 Total Mississippi Catfish Sales by year

(X 1,000 lbs.)
(Hanson and Sites, 2012; Hanson and Sites, 2013; Hanson and Sites, 2014)

Total Mississippi catfish (including fingerlings, stockers, food and brood fish) sales peaked in 2000 with sales of $303.3 million and reached a low in 2012 with sales of $175.4 million. In 2013 there was a small increase in total catfish sales value reaching $184.1 million (Figure 2.10). Mississippi Catfish foodfish sales peaked in 1998 with a value of 288.6 million dollars. That year Mississippi sold 390 million pounds of foodfish at an average price of $0.74 and at an average weight of 1.36 pounds. In 2013 Mississippi sold 172.8 million pounds of food fish at an average price of $0.98 and at an average weight of 1.70 pounds. The total value of Mississippi foodfish sales was 169.2 million dollars, a reduction of 116.2 million dollars from the peak.

This same trend was seen in stocker fish sales, with a peak in 2002 with sales of approximately 9.20 million dollars reduced to 6.83 million in 2013. This was due to a reduction in the number of head sold of 22.2 million head. Fingerling sales peaked in

2005 at 19.18 million dollars and were 7.83 million dollars in 2013 (Hanson and Sites 2012; Hanson and Sites 2013; Hanson and Sites 2014). Brood fish sales peaked in value at 1.52 million dollars in 1999 and are no longer reported yearly to avoid disclosing data from individual operations. In 2008 brood fish sales were $75,000.

Role of Imported fish

Imports play a key role in the reduction of Mississippi catfish production. Import of frozen, boneless Ictalurus, Pangasius and Siluiformes catfish fillets increased from 9.22 million pounds to 281.03 million pounds, an increase of 271.81 million pounds annually or 2948 % from 2004 to 2013 (Hanson and Sites 2012; Hanson and Sites 2013; Hanson and Sites 2014).

The continued pressure of the increase in imports of substitute “catfish-like” products and frozen catfish fillets has reduced producer prices. Data from February 2002 to July 2004 does not include imports of Vietnamese basa and tra, due to federal legislation forbidding non-Ictaluridae families of fish from being called “catfish” causing these years to be underreported. In August 2004 separate species are reported and aggregated in the data. Imports have increased from 30.1 million pounds in 2005 to 84.6 million pounds in 2007, an increase of 181.1 %. Imported frozen catfish and catfish-like substitutes now account for 45% of all U.S. sales of this product form (Hanson, *et al.*, 2008). When comparing the prices for frozen catfish or catfish-like fillets it is easy to see why imports are increasing so rapidly. In 2006 a frozen fillet from China cost $1.86 per pound compared to $2.92 per pound for fillets produced in the United States. In 2007 the fillet price spread between the China and the United States grew wider as China’s price dropped \$0.14 per pound to \$1.72 per pound. The United States produced fillet price held steady at \$2.92 per pound.

Infectious Diseases

Infectious disease has become one of the main concerns in aquatic animal production. Numerous investigators have identified infectious disease as the foremost constraint on further development of the aquaculture industry (Plumb, 1999; Georgiadis, *et al.*, 2001). Enteric Septicemia of Catfish (ESC) reportedly costs the catfish aquaculture industry \$50 to \$60 million annually (Breazeale, 2007). Economic losses due to disease are difficult to assess accurately because they are usually underreported due to self-diagnosis by the producer and poor record keeping. Economic losses attributable to disease on individual farms can be devastating (Hawke and Khoo, 2004). Depending on the disease, 60% to 100% of fish can be lost in an individual pond or even on a single farm during a disease outbreak (Plumb, 1999; Hawke and Khoo, 2004).

Most infectious diseases, including those that affect fish, have a multifactorial etiology. For a disease to occur, simultaneous interactions among host, agent, and environmental factors must all occur. The existence of an infectious organism (agent) in a fish or the environment only will not necessarily lead to clinical disease (Jarp*, et al.*, 1993). However, deterioration of water quality such as elevated nitrite concentration is linked to the occurrence of fish disease (Tucker and Hargreaves, 2004). Catfish farming today is increasingly more intensive (Plumb, 1999; Hargreaves, 2002), with increased stocking densities, feeding rates, and multi-batch harvesting over previous years. These practices have resulted in poor water quality as defined by low dissolved oxygen, high nitrogenous compounds, and high stress, followed by low immune system function. The subsequent introductions of young immunologically naïve fish into this environment is cause for concern. Fish are very sensitive to environmental fluctuations, and adverse reactions can occur quickly due to fish being poikilotherms and constantly exchanging metabolites and gasses with their surroundings (Plumb, 1999). It is imperative to investigate the specific associations between environmental parameters and disease occurrences in catfish aquaculture as well as to devise prevention strategies using this knowledge.

The USDA/APHIS (2003a) survey indicated that the survival rate during the fry to fingerling stage (nursery) averages 70% across the industry. Records from several large farms in the southeast indicate that the survival of catfish from fingerling to food fish averages between 70 and 80 percent. In a recent study survival from fingerling to stocker was 47.7%. This reduction was attributed to ESC infections and columnaris epizootics (D'Abramo*, et al.*, 2012). In 1996 producers indicated that infectious disease accounted for 45% of food fish losses (USDA/APHIS, 1997a). According to the USDA NAHMS study (USDA/APHIS, 2003a) bacterial diseases account for approximately 70% of all diseases affecting catfish in the southeast USA. Bacterial diseases are more common for a number of reasons. Because catfish are currently reared with multiple age fish in one pond there is always a susceptible population of naive fish to keep bacteria circulating. Many bacteria exist in the environment and are opportunistic waiting for fish to become stressed to express themselves. Stress conditions such as temperature extremes, crowding, injury, harvesting, stocking, poor water quality or low oxygen can contribute to bacterial disease outbreaks. Many bacterial diseases can be reduced through management. Proper stocking densities, good oxygen concentration and water quality will all help. If the water is contaminated with pathogenic bacteria then stress must be at a minimum to prevent outbreaks.

Age Segregation

Producers of other species have learned to control some bacterial diseases through age segregation. Animals of one age are kept together and not mixed with older, potentially infected animals. Facilities are all in – all out and cleaned between each group of animals so that each group can start clean. This is not possible in the catfish industry as it would be impractical to drain each pond after each group of fish. It is possible that modular production, which is now being adopted by a small segment of the catfish industry, will help with this problem. It is similar to all in – all out, three site production in the swine industry. The fry would be raised to stocker size and then harvested, re-sorted and placed at a different stocking rate in a food fish pond. Because they are entering at a much larger size the time in the food fish pond is reduced. There is only one age of fish in the pond at one time. In a recent study other advantages of modular production included reduced turnover time to final market weight, reducing risk of bird predation in the fingerling to stocker ponds due to larger size as greater than 98% of fish were longer than 20 cm. which is the length they are no longer susceptible predation (Glahn*, et al.*, 1995), disease treatment due to fish being of similar size and inventory control (D'Abramo*, et al.*, 2012).

Continued development of effective vaccines can help to reduce the effect of bacterial diseases. Most progress will have to come from management changes, as described above. If modular production has similar results in the catfish industry as it has had in other industries one could expect a reduction in disease incidence, improved growth rates, improved feed conversions and a lower cost of production when compared to multiage ponds.

Baseline data for many of the biological and epidemiological characteristics of major catfish diseases does not exist. On-farm monitoring and surveillance programs, as a means of defining progress in the prevention and control of diseases, are crucial to the sustainability of health programs. No systems are currently in place for the systematic collection of both diagnostic and field data for detecting disease through surveillance and monitoring.

Epidemiology can play a key role in understanding disease in aquaculture through such tools as risk-factor studies, risk analysis, and disease modeling (Georgiadis*, et al.*, 2001). Previous epidemiologic and scientific studies have identified operation size, stocking density and feeding rate as risk factors for disease (Wagner*, et al.*, 2002).

Diseases of Interest

Columnaris disease

A gram-negative bacterium, *Flavobacteriun columnare* is the cause of columnaris disease. It is considered the second most important disease in the catfish industry. It is often part of a mixed infection. Approximately 86% of the cases from Louisiana involving columnaris were mixed with other bacteria such as *Edwardsiella ictaluri*, *E tarda and Aeromonas spp*. (Hawke and Thune, 1992). Determining which bacteria is primary and which is secondary is very difficult. This makes determination of the economic impact of columnaris disease difficult. Khoo (2012) found that columnaris disease was the leading cause of mortality on Mississippi catfish farms in 2000. Over 70% of the catfish farmers polled considered columnaris disease or mixed infections including columnaris as causing the greatest economic loss on catfish farms in the four leading catfish producing states (USDA/APHIS, 1997b).

Epidemiology

Hawke and Khoo (2004) speculated that stressful conditions and columnaris disease outbreaks are related and that some strains are more pathogenic than other strains. Columnaris disease is usually an external infection of the skin, fins and gills but has been isolated from clinically normal channel catfish (Hawke and Thune, 1992). *Flavobacterium columnare* can infect catfish at any age, during all seasons and under a host of water conditions (Griffin, 1987). Bacterial infection causes damage to the mucosa, gills, fins fraying and skin depigmentation. External clinical signs include a grayish white spot on the body, head, lips or fins (Bullock*, et al.*, 1986). Lesions on the fins may progress to a shallow ulcer that may exhibit slight yellow discoloration (Hawke and Khoo, 2004). A lesion that appears along the dorsal fin and later extends laterally down both sides of the abdomen is called a “saddleback lesion” (Griffin, 1987). Gill necrosis may be observed and appear brown or muddy from clay particles trapped in the slime secreted by the bacteria (Hawke and Khoo, 2004). Flexing rods in a typical haystack formation are evident in microscopic examination of necrotic tissue scrapings (Durborow*, et al.*, 1997). Mucoid material may cover the mouth and inner oral cavity. Secondary infection of skin lesions by *Aeromonas spp*. is common and results in deeper, liquefactive lesions in the muscle (Hawke and Khoo, 2004).

Flavobacterium columnare is difficult to culture from contaminated external sites and may be part of a mixed infection internally. Definitive identification of isolates is difficult and antibiotic susceptibility results are lacking. *Flavobacterium columnare* can be identified using PCR or by five biochemical characteristics that separate it from other yellow pigment producing, gram negative aquatic bacteria: 1) the ability to grow in the presence of neomycin sulfate and polymyxin B, 2) colonies on cytophaga agar plates are typically rhizoid and pigmented pale yellow, 3) production of gelatin degrading enzymes, 4) binding of congo red dye to the colony, and 5) production of chondroitin sulfate A degrading enzymes. (Griffin, 1992)

Columnaris can occur as a primary cause of mortality with mortalities as high as 50% (Plumb, 1999). More commonly it is considered a secondary infection following periods of stress or infection by other parasitic or microbial agents (Hawke and Khoo, 2004). At the Louisiana Aquatic Diagnostic Laboratory, columnaris disease was diagnosed in 54% of the submissions but only 7% of the cases identified *F. columnare* as the sole agent. In 47 % of the cases it was present in mixed infections with other pathogens, such as *Aeromonas spp., Edwardsiella ictaluri, and E. tarda* (Hawke and Thune, 1992).

Columnaris disease is usually transmitted from fish to fish via the water. Stress from poor water quality and handling can also play a part. Very low water salinity (< 1 ppt.) improves the ability of columnaris disease to establish and progress (Altinok and Grizzle, 2001). Water salinity of 1 part per thousand (ppt) reduced the mortality of channel catfish challenged with virulent *F. columnare* when compared to fresh water and no mortality occured at salinities of 3 ppt or above (Hawke and Khoo, 2004). Increased salinities reduced the ability of the bacterium to bind to gill and skin tissues (Altinok and Grizzle, 2001).

Treatment

The bacterium is considered ubiquitous in most waters but movement of infected stocks of fish should be minimized to prevent spread of the disease within the infected stock. Treatment of systemic columnaris in hatcheries is dependent on chloramine T treatements in water once daily for up to four consecutive days. . Terramycin is not approved for the treatment of columnaris disease but is effective in controlling losses.

AquaFlor® (florfenicol) is a Type A Medicated Article was approved for the treatment of columnaris in catfish in 2012. In order to use AquaFlor® the producer must obtain a Veterinary Feed Directive from a licensed veterinarian with a valid client-patient relationship. The feed mill, which will mix the producers feed, will have to have a valid Medicated Feed Mill License. The dosage for AquaFlor® is 10-15 mg/ kg of body weight for 10 consecutive days. It is important to know the total fish biomass weight of the pond so that an accurate treatment can be calculated. Extra-label use, such as treatment for non-labeled diseases is strictly prohibited. There is a 15-day withdrawal for food fish.

Enteric Septicemia of Catfish (ESC)

Enteric septicemia of catfish (ESC) is caused by a gram-negative bacterium *Edwardsiella ictaluri*. Outbreaks usually occur in the spring and fall months when water temperatures are 20-28 C degrees (USDA/APHIS, 2011).

Hawke and Khoo (2004) describe ESC with mortality rates of up to 100% in susceptible catfish and clinical signs of reduced feed consumption, erratic swimming or swimming in circles. Clinical signs include hemorrhagic areas around the mouth and on the undersides of fish. Small white ulcers may also be present on skin surfaces. The presence of an ulcer on the top of the head, between the eyes is considered the most characteristic clinical sign of the disease and gives ESC its common name, “hole-in-the – head disease”. Infected fish can have exophthalmia and distended abdomens (Hawke and Khoo, 2004). Surviving catfish have reduced growth rate and weight gains.

Epidemiology

Stress plays a key role in outbreaks. Stress factors such as handling, poor diet, poor water quality, overcrowding and water temperature fluctuations can lead to an outbreak (Wise*, et al.*, 1993). Multiple age cultures or under stocking (stocking multiple age classes of fish) also plays a key role in spread of the disease to healthy fish. Surviving fish can carry the disease for up to 200 days in their kidney, liver or brain. Stress may increase susceptibility to infection and losses but it is not a prerequisite for the disease. Immune status of the individual fish may also determine the outcome (Hawke and Khoo, 2004).

Enteric septicemia of catfish is widespread throughout the industry. The spread of the disease is probably related to the shipment of infected but non-symptomatic fingerlings. These fingerlings may be non-clinical carriers outside of the temperature ranges where the disease usually occurs (Klesius, 1993). The bacteria may continue in a multi-batch culture environment with the introduction of naïve fingerlings to a pond containing older exposed catfish.

The primary mode of transmission is through fecal shedding from sick fish or the carcasses of dead fish (Earlix, 1995). The bacterium can cross the intestinal epithelium, enter the blood stream and migrate to the kidneys within 15 minutes of experimental intestinal infection (Baldwin and Newton, 1993). Vertical transmission from infected broodstock to fry has not been demonstrated (Hawke and Khoo, 2004). The presence of viable *E. ictaluri* in the intestinal contents of cormorants and herons suggest the fecal wastes from piscivorous birds are a potential source of infection (Taylor, 1992).

Channel catfish, white catfish *Ameiurus catus* , brown bullhead *Ameiurus nebulosus* and walking catfish *Clarias batrachus* are all susceptible to infection by *Edwardsiella ictaluri*, but channel catfish are the most susceptible (Hawke and Khoo, 2004). Blue catfish *Ictalurus furcatus* are somewhat resistant to experimental infection (Wolters and Johnson, 1994).

There is no good way to prevent ESC in catfish. Reducing stress, adding vitamin supplements to a balanced diet have been tried with little success (Hawke*, et al.*, 1998). Reducing stocking densities may decrease the efficiency of ESC transmission in a pond (Hawke*, et al.*, 1998). There are conflicting data on the effects of winter feeding on subsequent spring ESC outbreaks (Hawke*, et al.*, 1998). A commercially produced live attenuated ESC vaccine provided lower cumulative mortality when compared to non-vaccinated fish in both laboratory and field studies (Wise*, et al.*, 2000).

Treatment

Treatment of ESC is limited. Romet 30 (sulfadimethoxine and ormetoprim) is approved for ESC treatment. In 2005 Aquaflor® was approved for the control of mortality associated with *E. ictaluri* in catfish. In order to use AquaFlor® the producer must obtain a Veterinary Feed Directive from a licensed veterinarian with a valid client-patient relationship. The feed mill, which will mix the producers feed, will have to have a valid Medicated Feed Mill License. Cumulative mortality rate was significantly reduced when compared to the control group when fed feed containing Aquaflor® (florfenicol) giving catfish farmers another option (Gaunt*, et al.*, 2006).

Aquaflor ® is approved for the use in channel catfish for controlling mortality due to enteric septicemia (ESC) associated with *Edwardsiella ictaluri*. The decision to prescribe AquaFlor® is based on a clinical diagnosis of a labeled disease, such as enteric septicemia of catfish, on the farm and in a particular pond. The onsite clinical diagnosis should be confirmed by laboratory diagnosis, either by clinical signs, lesions, culture or other diagnostic tests or histopatholgy. Since ESC can have high mortality rates it is important to treat this disease aggressively.. Because it is a feed grade antibiotic it is important that the decision to treat be made while the majority of fish are still eating.

Recent research has shown that withholding feed for a period of time can lead to reduced mortality. This seems to be effective because the disease is readily transmitted orally during feeding by the ingestion of bacteria contaminated water. Withholding feed early in an outbreak will lessen the transmission efficiency of the disease and reduce losses (Hawke, *et al.*, 1998). As with all treatments, economics play a key role. The producer must balance the cost of the medicated feed versus the lack of growth in the catfish while withholding feed.

CHAPTER III

CATFISH DATABASE DEVELOPMENT

Database Development

A database was developed to facilitate the collection of data for epidemiological studies to determine risk factors associated with catfish production at the farm/pond level, and to determine the association between disease, mortality and these risk factors and to determine the economic cost of these risk factors and associations.

Infectious diseases cost producers many millions of dollars in direct fish losses each year. Infectious diseases also influence profitability by increasing treatment costs, reducing food consumption by fish, increasing feed conversion ratios and causing harvesting delays. (Wagner, *et al.*, 2002) In general, progress in the area of disease control is limited by a poor understanding of the pathogenesis of the major disease entities inadequate knowledge of the relationships between management practices and other risk factors associated with disease outbreaks. Bacterial diseases in catfish tend to be most important. There is not a clear understanding of how risk factors affect bacterial diseases. Operation size, stocking density and feeding rate were shown to be associated with the ESC/columnaris disease breaks (Wagner, *et al.*, 2002).

In order to gather and organize data to define risk factors associated with catfish disease the Catfish Management Database was developed using the Microsoft Access® platform. A large integrated catfish producer shared production records. The farm's record keeping system contained large amounts of data on Microsoft Excel® spreadsheets. Additionally feeding records were kept in a catfish management program developed at Mississippi State University called Fishy®. With two different record keeping systems some data had to be entered twice. One person in the organization was capable of manipulating the data to obtain any analysis and management reports including feed rates, mortalities, harvest events and feed conversion ratio.

The Catfish Management Database was developed to incorporate the production data that is currently being kept by the catfish farmer. Health and disease information including mortalities were collected on a pond basis. Diagnostic results from the Mississippi State University College of Veterinary Medicine Diagnostic Laboratory located in Stoneville, Mississippi were coded to the farm and pond.

The Catfish Management Database contains the feeding records in terms of total pounds of feed fed, for each pond on a daily basis. Whenever a mortality event occurs the date, pond identification (id), presumptive diagnosis, pounds and number of dead fish were recorded. When samples were submitted to the CVM Diagnostic laboratory in Stoneville it was noted and a presumptive diagnosis was compared to laboratory diagnosis.

Since water quality plays such an important role in catfish production a separate database for Water Quality was constructed for the farm. Ponds were tested weekly during the growing season for nitrite, ammonia and potentially chloride levels. Additionally the database was designed to automatically report ponds that exceed a user-defined nitrite to ammonia ratio. Other important parameters that may have been important factors in disease events are stocking events in which the source, date, number of head stocked, size of the fish and weight of the fish stocked were recorded. Harvesting events including the date of the harvest, the pounds, size and number of fish harvested were recorded. Off flavor data were collected and included the date tested the degree and type of off flavor.

Many agricultural industries use production databases to help improve production. For many years the dairy industry has used the Dairy Herd Improvement Association (DHIA)[a] database. Data collected are used for: 1) making farm management decisions; 2) educational programs and research, including the genetic evaluation of cows and sires; and 3) promoting and selling of animals. In 2008, over 4.5 million dairy cows were on DHIA programs. The swine industry has used a similar database called PigChamp[b]. Swine producers can track and analyze herd production and benchmark it against other herds. This database has allowed rapid improvement through selection of superior animals and to highlight areas of concern in production.

The catfish industry is similar to the swine industry with key economic drivers, growth rate and fed efficiency. Feed costs are the largest expense in catfish production. Catfish are fed daily as much as they will eat during warm months. Catfish are fed to maximize growth and minimize waste because overfeeding can have a negative effect on water quality. Monitoring feed intake is an important management tool. Some catfish producers use a database, FISHY®[c] (Killcreas, 2002), developed by the Mississippi State University Agricultural Economics Department by Wallace Kilcrease. FISHY®[c] was designed to help catfish producers improve their production management decision-making. The FISHY®[c] database concentrates on feeding and projecting fish growth. The Catfish Management database developed for this research allows the farm to manage not only feed but also other factors such as stocking, harvesting, and mortality. The Catfish Management database allows the farm to generate user-defined reports on each pond's efficiency and cost of production.

Sampling/Data Collection

A large commercial catfish enterprise agreed to share producer production records. The farm was comprised of over five hundred ponds on 5 sites covering multiple counties in the Mississippi Delta, dedicated to food fish production was available for analysis.

This database was designed to: 1) to incorporate production data already being recorded for generating reports for use at weekly managerial meetings focused on feeding rates, feed conversion ratios, mortalities and harvesting events; 2) be easily used by a catfish farmer to collect management data in order to analyze production efficiency through a series of farmer defined management reports and 3) provide the farm with easy access to management reports. Additional customized reports can be generated as requested by the farm management.

The database was programmed in Microsoft Access.[d] Permanent unique pond identifications (id) were assigned to each pond. Data were recorded by the producer from 2004 to 2007 and was imported into the newly constructed database.

A separate water quality database was developed and located in the water quality testing laboratory on the farm. Pond water was tested and values recorded for total ammonia nitrogen (TAN), nitrites and potentially chlorides. Chlorides were measured if the TAN level was considered high (>6mg/L). The database was designed to automatically generate a report of ponds that exceeded the management defined ammonia to nitrite ratio. The water quality database was constructed in 2005 so data from 2005-2007 were included in the analysis. Water quality data were collected on a weekly or biweekly basis during the growing season (March-November) and monthly during the non-growing season.

Database Management Reports

The Catfish Management Database (CMD) opens up to a main menu (Figure 3.1) that is split into 5 main sections. The first section is labeled Enter Farm Data. In this section the information of the farm enterprise such as name, address, phone, fax and email address is entered. Also included in this section is the individual site information. The name of the site along with the total acres is entered here. If any of the ponds were being rebuilt or taken out of production an adjust acreage entry was recorded and the new acreage was then used in calculations for the database.

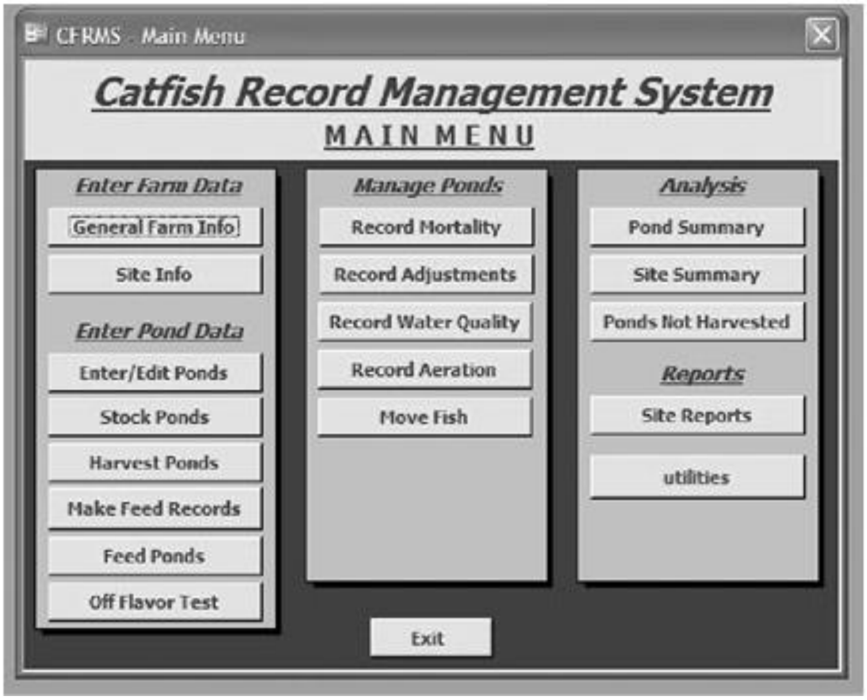
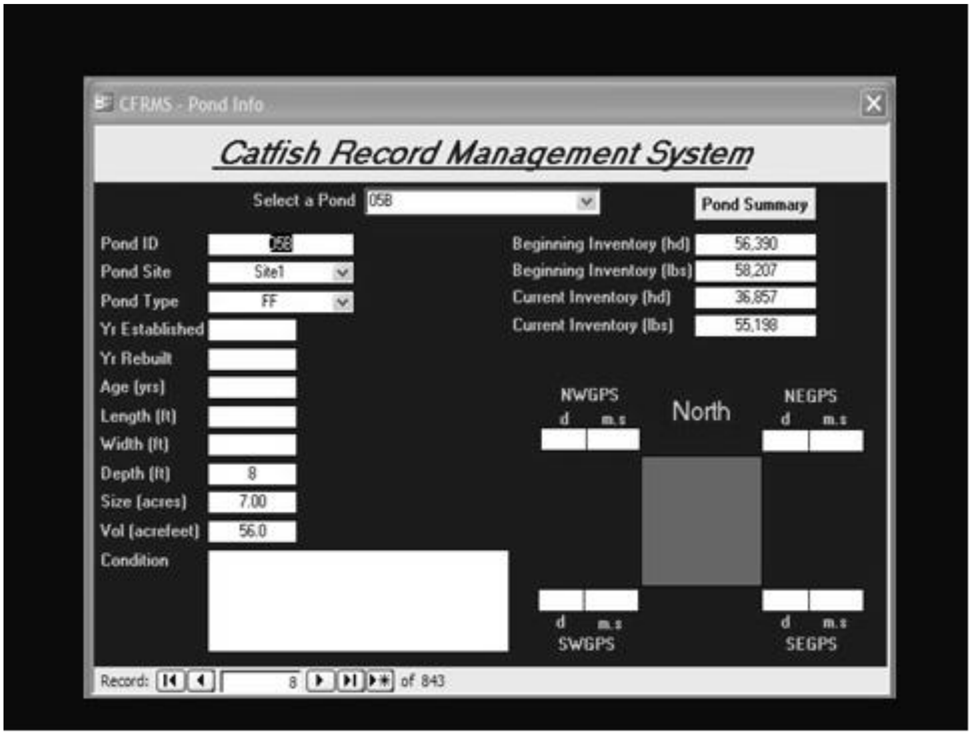


Figure 3.1 Catfish Database Main Menu

The second section on the main menu is the Enter Pond Data section (Figure 3.2). This is the place to enter new ponds or edit the information on existing ponds. The pond information sheet allows the user to select the pond of interest from a drop down menu. It will then automatically fill in the Pond Site and Pond Type. Pond types include foodfish, fingerling and broodfish. The pond information sheet also contains the year the pond was established or built, the year it was rebuilt, the length, width and depth of the pond. Size of the pond in acres and volume of the pond in acre-feet are also included. Information from the database is used to give the beginning and current inventory in terms of pounds and number of head. The pond information sheet also includes a place for the GPS coordinates. The most useful part of the pond information sheet is the button labeled

"Pond Summary" (Figure 3.3). A click on this button will generate a summary report of the biomass activity of the particular selected pond.



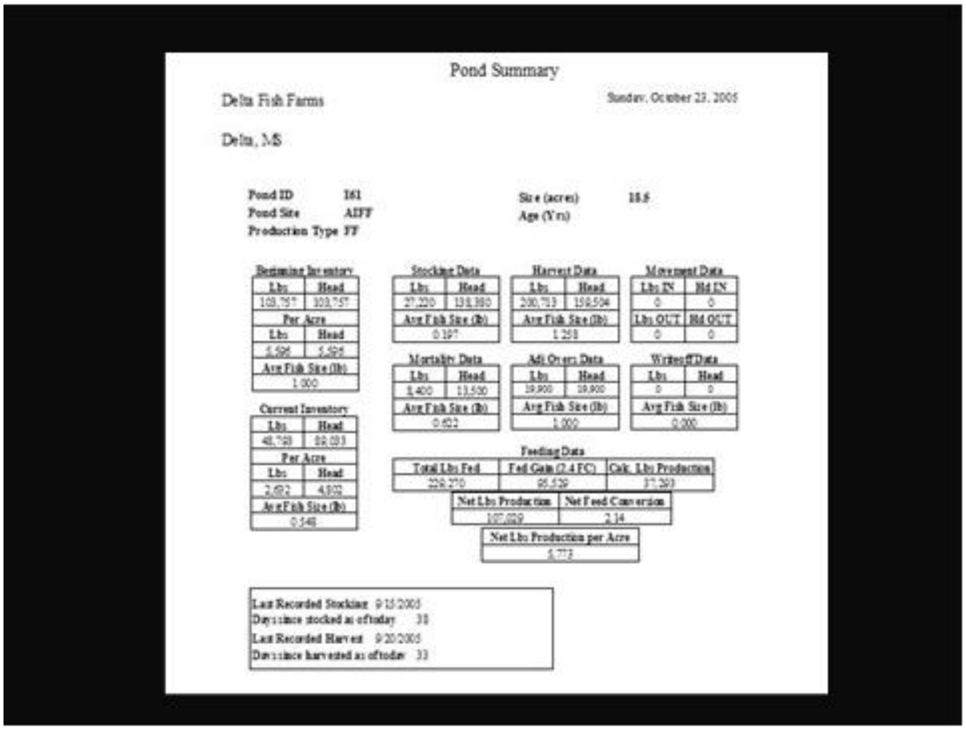
Select a Pond 058

Pond ID 058
Pond Site Site1
Pond Type FF
Yr Established
Yr Rebuilt
Age (yrs)
Length (ft)
Width (ft)
Depth (ft) 8
Size (acres) 7.00
Vol (acrefeet) 56.0
Condition

Beginning Inventory (hd) 56,390
Beginning Inventory (lbs) 58,207
Current Inventory (hd) 36,857
Current Inventory (lbs) 55,198

Record: 8 of 843

Figure 3.2 Enter Pond Data



Pond Summary

Delta Fish Farms — Sunday, October 23, 2005

Delta, MS

Pond ID 161
Pond Site AIFF
Production Type FF
Size (acres) 18.5
Age (Yrs)

Beginning Inventory

Lbs	Head
103,757	103,757
Per Acre	
Lbs	Head
5,596	5,596
Avg Fish Size (lb)	
1.000	

Stocking Data

Lbs	Head
27,220	138,380
Avg Fish Size (lb)	
0.197	

Harvest Data

Lbs	Head
200,713	159,504
Avg Fish Size (lb)	
1.258	

Movement Data

Lbs IN	Hd IN
0	0
Lbs OUT	Hd OUT
0	0

Mortality Data

Lbs	Head
8,400	13,500
Avg Fish Size (lb)	
0.622	

Adj Overs Data

Lbs	Head
19,900	19,900
Avg Fish Size (lb)	
1.000	

WriteoffData

Lbs	Head
0	0
Avg Fish Size (lb)	
0.000	

Current Inventory

Lbs	Head
48,750	89,033
Per Acre	
Lbs	Head
2,692	4,802
Avg Fish Size (lb)	
0.546	

Feeding Data

Total Lbs Fed	Fed Gain (2.4 FC)	Calc. Lbs Production
229,270	95,529	37,293

Net Lbs Production	Net Feed Conversion
107,029	2.14

Net Lbs Production per Acre
5,773

Last Recorded Stocking 9/15/2005
Days since stocked as of today 38
Last Recorded Harvest 9/20/2005
Days since harvested as of today 33

Figure 3.3 Pond Summary

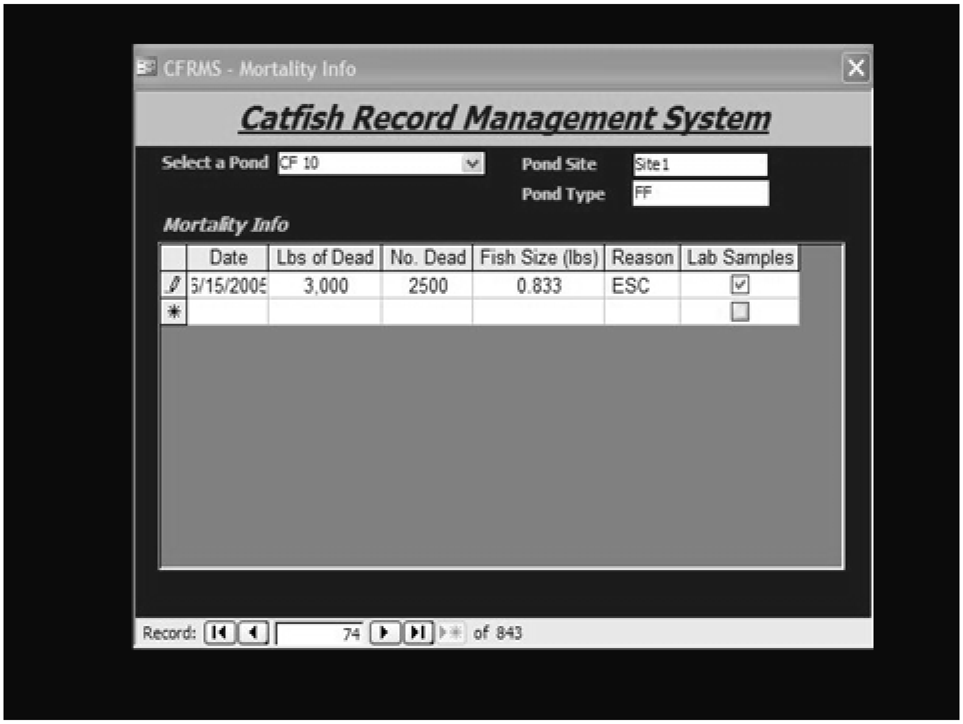
Besides the pond id, site, production type, size (acres) and pond production age (years in production or since it was last rebuilt) the pond summary report will give the producer the beginning and current inventory in total pounds and number of head as well pounds and number of head per acre. The average fish size is also calculated. All stocking, harvest, movement, mortality, adjustment and write off data are summarized and reported. The feeding data are reported as “total pounds fed” and using a standard of a 2.4 feed conversion ratio, the amount of gain expected is calculated and reported as “fed gain”. The Net Feed Conversion is calculated along with a Net Pounds Production per Acre. The last recorded stocking and harvesting event are reported as well as the days since this event took place. This report is important in that it gives the farm a snapshot of how a pond is performing at any point in time. It can be used to isolate under-performing ponds that would require a higher level of management.

The other areas of the “enter pond data” section consist of entering stocking, harvest, feed and off flavor information. Feed is entered as pounds fed daily by pond.

The next section of the Catfish Database is Manage Ponds (Figure 3.4). In this section one can enter Mortalities, Adjustments, Record Movements and Water Quality. A separate Water Quality database was developed for recording` basic water quality parameters.

Figure 3.4 Manage Ponds

The Record Mortality (Figure 3.5) of the Manage Ponds section records the pounds of dead fish, which is usually an estimate based on the farm managers experience`, number of dead fish and the average fish size. A list of reasons (Figure 3.6) is built into a drop down menu and can be edited by the producer. The producer also can check if fish were submitted to the diagnostic laboratory for a confirmatory diagnosis.



CFRMS - Mortality Info

Catfish Record Management System

Select a Pond CF 10

Pond Site Site1

Pond Type FF

Mortality Info

	Date	Lbs of Dead	No. Dead	Fish Size (lbs)	Reason	Lab Samples
✎	5/15/2005	3,000	2500	0.833	ESC	☑
✱						☐

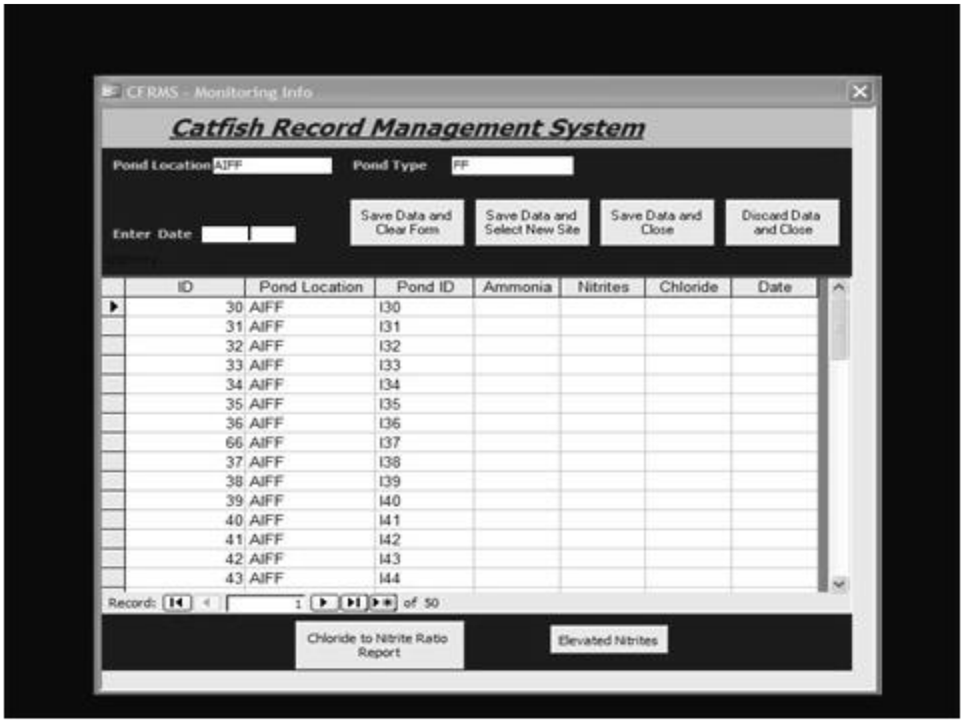
Record: 74 of 843

Figure 3.5 Record Mortality Events

Code	Reason
ADJ	INVENTORY ADJUSTMENTS
CAA	ANEMIA
CCV	CHANNEL CATFISH VIRUS
COM	COLUMNARIS
ESC	ENTERIC SEPTICEMIA
GON	ESCAPED
ICH	ICH
OXY	OXYGEN LOSS
PAR	PARASITES
PGD	PROLIFERATIVE GILL DISEASE
TRE	TREMATODES
UKN	UNKOWN
VTC	VISCERAL TOXICOSIS
WKL	WINTER KILL

Figure 3.6 Mortality Codes

The water quality section gives the producer the option of entering water quality information by pond or by individual site (Figure 3.7). There were multiple sites under this farm enterprise. There is a drop down menu to select the site to enter the data. The data recorded on a weekly basis during the growing season include the nitrite and ammonia level. Chloride levels are tested on an as needed basis.



Pond Location AIFF
Pond Type FF
Enter Date

ID	Pond Location	Pond ID	Ammonia	Nitrites	Chloride	Date
30	AIFF	I30				
31	AIFF	I31				
32	AIFF	I32				
33	AIFF	I33				
34	AIFF	I34				
35	AIFF	I35				
36	AIFF	I36				
66	AIFF	I37				
37	AIFF	I38				
38	AIFF	I39				
39	AIFF	I40				
40	AIFF	I41				
41	AIFF	I42				
42	AIFF	I43				
43	AIFF	I44				

Figure 3.7 Water Quality Entries by Pond or Farm

The producer can generate a user defined chloride to nitrite ratio report and an Elevated Nitrite Report. A weekly chart is can be generated that graphs the concentration of nitrites, ammonia and chlorides (Figure 3.8).

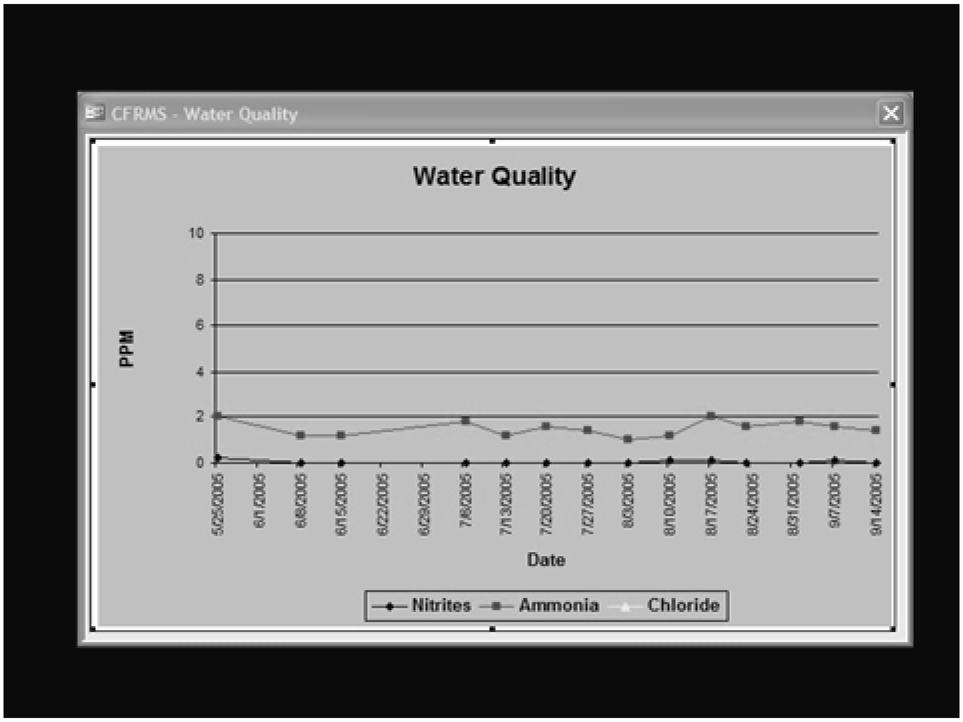


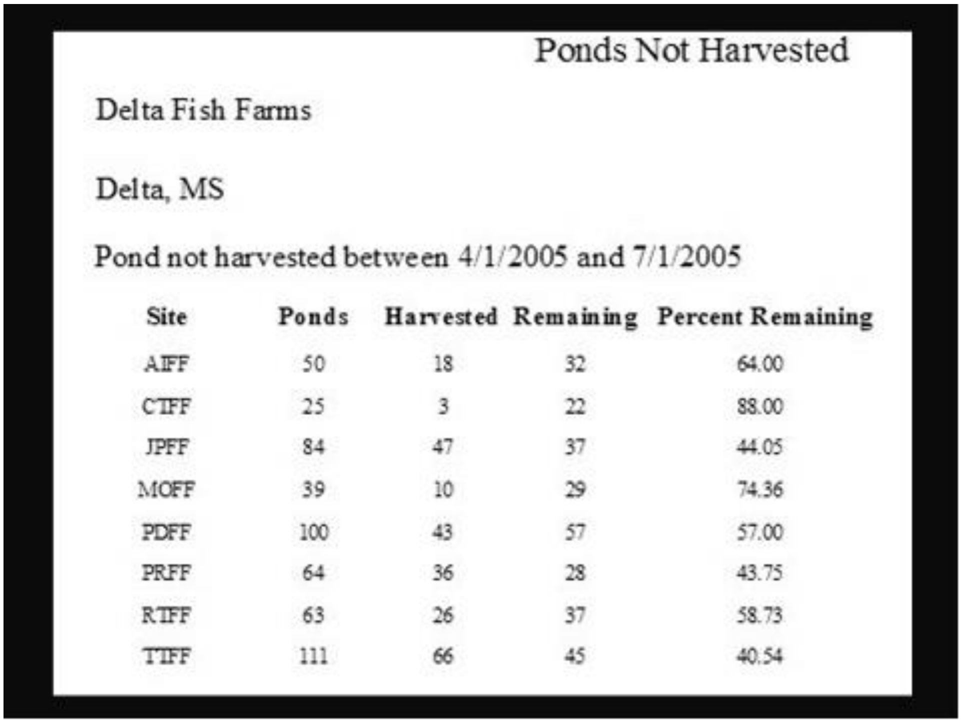
Figure 3.8 Weekly Nitrite, Ammonia and Chloride Levels Graph

The next section in the Catfish Management Database is the Analysis section. This includes an analysis of individual ponds, sites and a series of reports representing the ponds not harvested. The General Size Analysis Report includes the Pond ID, Beginning Inventory in number of head and pounds, stocking events in number of head and pounds, Current Inventory in number of head and pounds as well as the average fish size. The total surface acres of the pond are included in the report along with calculations of the number of head and pounds on a per acre basis. The report also calculates the total amount of feed fed to the pond. The Site Summary report includes all of the ponds on a site and reports the totals for Beginning and Current Inventory along with the feed fed and weight gain. Total Harvesting, Stocking and Mortality events are also calculated. The

Net movements of fish in and out of the ponds of the site as well as any adjustments are calculated. All of this information is then used to calculate the Total Pounds on the site as well as the Net Pounds produced. This report is an excellent way to compare individual sites or the entire farm.

The Ponds Not Harvested reports (Figure 3.9) have user defined dates and can get a summary by the site (Figure 3.10). It is also possible to get a listing on the individual ponds that have not been harvested and the days since the last harvest in 60 days intervals (Figure 3.11). Figure 3.12 calculates the percentage of ponds not harvested in each of the 60 day intervals.

Figure 3.9 Ponds Not Harvested-Select Dates



Ponds Not Harvested

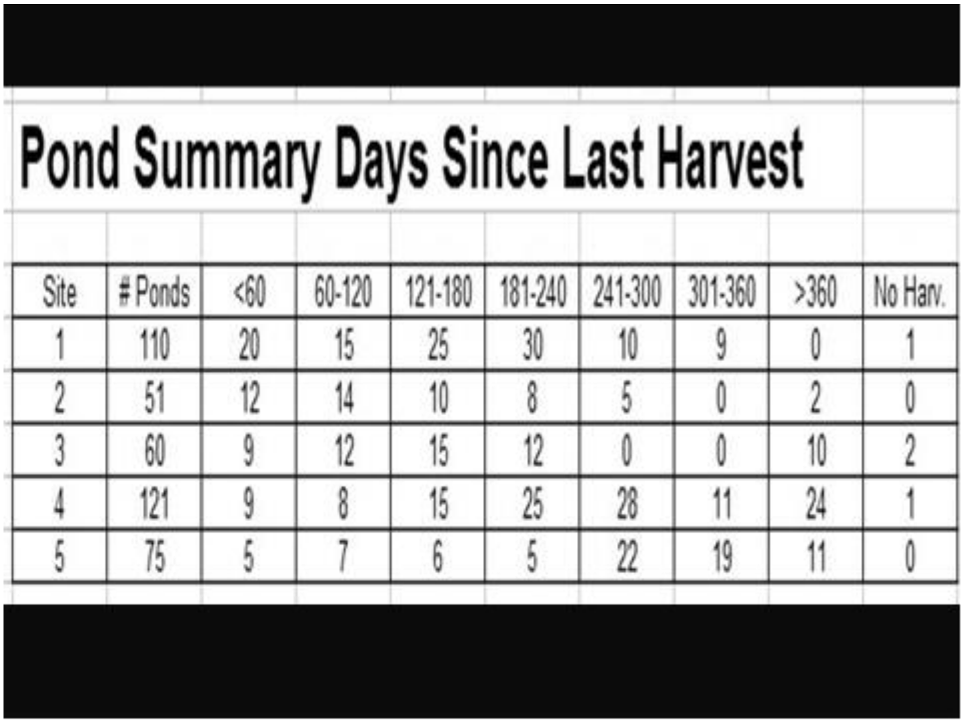
Delta Fish Farms

Delta, MS

Pond not harvested between 4/1/2005 and 7/1/2005

Site	Ponds	Harvested	Remaining	Percent Remaining
AIFF	50	18	32	64.00
CTIFF	25	3	22	88.00
JPFF	84	47	37	44.05
MOFF	39	10	29	74.36
PDFF	100	43	57	57.00
PRFF	64	36	28	43.75
RTIFF	63	26	37	58.73
TTIFF	111	66	45	40.54

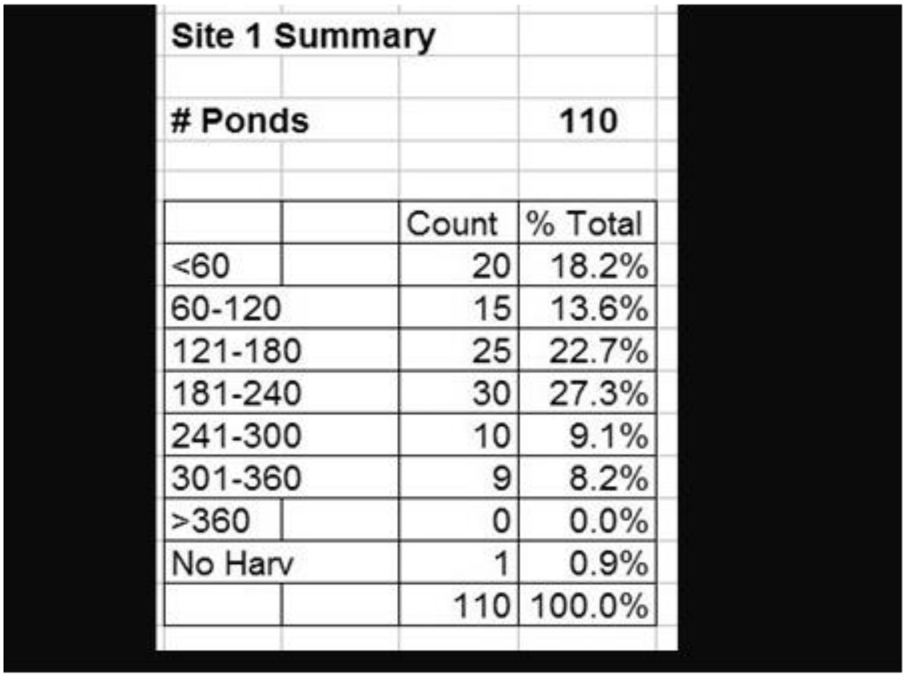
Figure 3.10 Ponds Not Harvested by Site



Pond Summary Days Since Last Harvest

Site	# Ponds	<60	60-120	121-180	181-240	241-300	301-360	>360	No Harv.
1	110	20	15	25	30	10	9	0	1
2	51	12	14	10	8	5	0	2	0
3	60	9	12	15	12	0	0	10	2
4	121	9	8	15	25	28	11	24	1
5	75	5	7	6	5	22	19	11	0

Figure 3.11 Ponds Summary-Days Since Last Harvest by Site

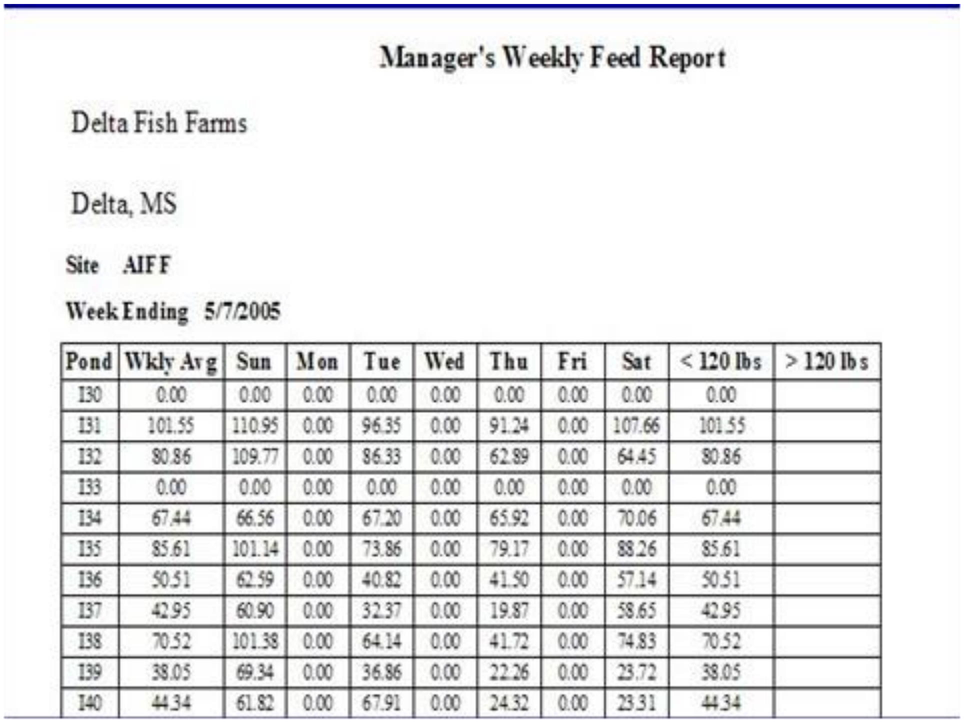


Site 1 Summary

 # Ponds **110**

	Count	% Total
<60	20	18.2%
60-120	15	13.6%
121-180	25	22.7%
181-240	30	27.3%
241-300	10	9.1%
301-360	9	8.2%
>360	0	0.0%
No Harv	1	0.9%
	110	100.0%

Figure 3.12 Site Summary for Count and Percentage of Ponds not Harvested for Site



Manager's Weekly Feed Report

Delta Fish Farms

Delta, MS

Site AIFF

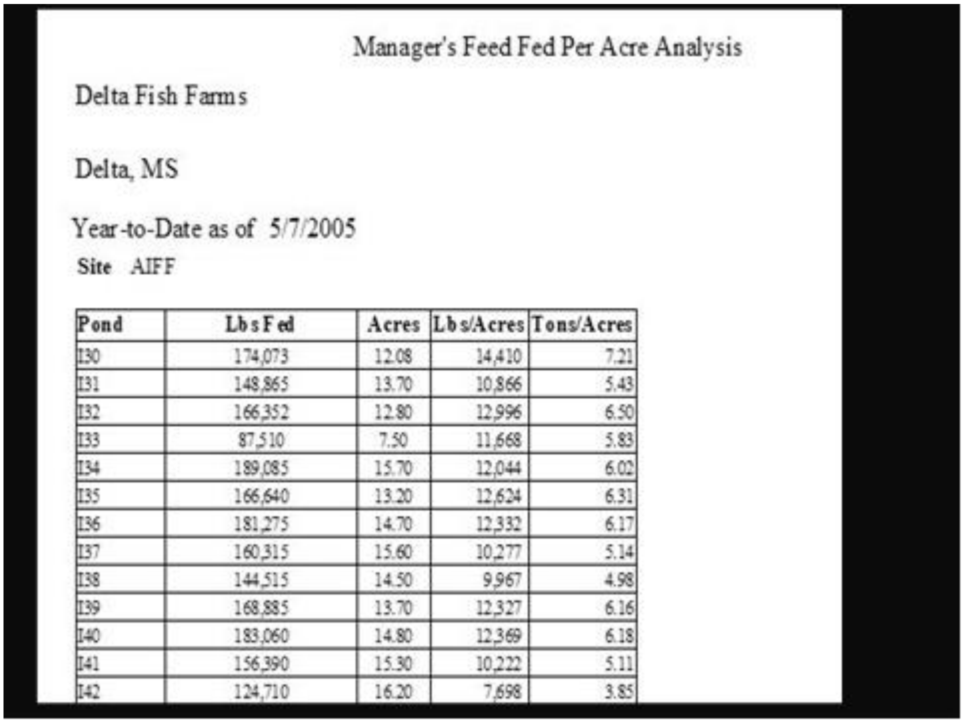
Week Ending 5/7/2005

Pond	Wkly Avg	Sun	Mon	Tue	Wed	Thu	Fri	Sat	< 120 lbs	> 120 lbs
I30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
I31	101.55	110.95	0.00	96.35	0.00	91.24	0.00	107.66	101.55	
I32	80.86	109.77	0.00	86.33	0.00	62.89	0.00	64.45	80.86	
I33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
I34	67.44	66.56	0.00	67.20	0.00	65.92	0.00	70.06	67.44	
I35	85.61	101.14	0.00	73.86	0.00	79.17	0.00	88.26	85.61	
I36	50.51	62.59	0.00	40.82	0.00	41.50	0.00	57.14	50.51	
I37	42.95	60.90	0.00	32.37	0.00	19.87	0.00	58.65	42.95	
I38	70.52	101.38	0.00	64.14	0.00	41.72	0.00	74.83	70.52	
I39	38.05	69.34	0.00	36.86	0.00	22.26	0.00	23.72	38.05	
I40	44.34	61.82	0.00	67.91	0.00	24.32	0.00	23.31	44.34	

Figure 3.13 Manager's Weekly Feed Report

(Columns 2-10 represent quantity of feed in pounds)

The Reports section is the last part of the Catfish Database. It includes the Site Reports and utilities. The Site Reports focus on the analysis of the amount of feed fed and include a Weekly Feed Report (Figure 3.13), Year-To-Date Feed Report, Year-To-Date Feed Fed by Week Chart and a Year-To-Date Feed Fed Per Week Analysis. The Producer can select the Site to analyze and the week ending date. The Weekly Feed Report includes the daily feed fed, a weekly average on a per pond basis and if the pond averaged more or less than 120 lbs. of feed per day. This level can be producer defined to reflect desired feeding goals.



Manager's Feed Fed Per Acre Analysis

Delta Fish Farms

Delta, MS

Year-to-Date as of 5/7/2005

Site AIFF

Pond	Lbs Fed	Acres	Lbs/Acres	Tons/Acres
I30	174,073	12.08	14,410	7.21
I31	148,865	13.70	10,866	5.43
I32	166,352	12.80	12,996	6.50
I33	87,510	7.50	11,668	5.83
I34	189,085	15.70	12,044	6.02
I35	166,640	13.20	12,624	6.31
I36	181,275	14.70	12,332	6.17
I37	160,315	15.60	10,277	5.14
I38	144,515	14.50	9,967	4.98
I39	168,885	13.70	12,327	6.16
I40	183,060	14.80	12,369	6.18
I41	156,390	15.30	10,222	5.11
I42	124,710	16.20	7,698	3.85

Figure 3.14 Year to Date Feed Fed per Acre Analysis

The Year to Date Feed Report (Figure 3.14) includes the pond id along with the total pounds of feed fed, acres of pond and average pounds per acre and tons per acre. The Year to Date Feed Fed per Week Analysis includes by each site or farm the total pounds of feed fed, the total adjusted acres and then calculates the pounds of feed per acre, tons of feed per acre and the average tons for all sites. The tons per acre by site are compared to the average tons for all sites. Each site is either above or below the average for all sites. This gives management a way to compare how each site is being fed and may provide information as to why production varies from site to site.

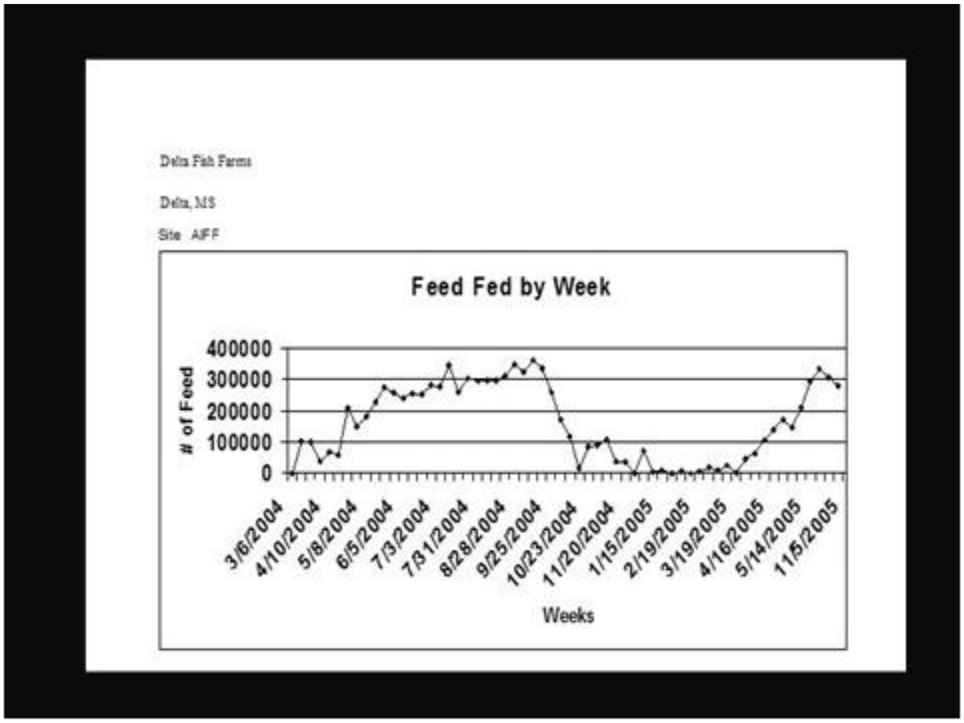


Figure 3.15 Weekly Feed Chart by Site

The Year to Date weekly feed chart (Figure 3.15) is useful to visualize any unusual changes in the feeding pattern of the pond. It is a good visual summary of the farm’s feeding for spring, summer, fall and winter feeding.

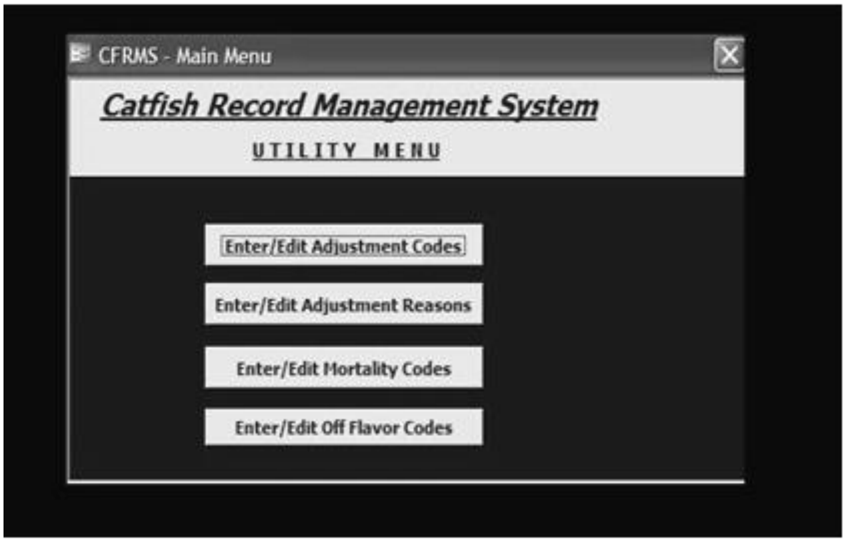


Figure 3.16 Utility Menu

The final section of the Catfish Database is the Utility Menu (Figure 3.16). This is an important section as it allows the producer to customize the database to their needs. The Adjustment codes and Reasons as well as the Mortality and Off Flavor codes can be entered or edited.

While the Catfish Management Database is fully functional there is still additional development that has to take place in order to make it more commercially viable. Currently its main usefulness is as a way to organize data for further analysis. It holds great promise as a management tool for Catfish producers. An obstacle facing the Catfish Management Database is the tendency for producers to change the function of ponds from fingerlings to food fish or brood fish. The database depends on a permanent ID for each pond. Some larger producers have multiple ponds with the same ID on different sites. None of these problems are insurmountable but they do make it difficult for producer use and further development is needed to circumvent these problems.

CHAPTER IV

POND LEVEL RISK FACTORS ASSOCIATED WITH COLUMNARIS DISEASE ON MISSISSIPPI COMMERCIAL CATFISH FARMS

Content in this chapter previously published: Cunningham, F., S. Jack, D. Hardin and R. Wills 2012. Pond level risk factors associated with Columnaris disease on Mississippi commercial catfish farms. Journal of Aquatic Animal Health 00:1-7, 2012

Introduction

A gram negative bacterium, *Flavobacterium columnare* is the cause of columnaris disease, the second most prevalent bacterial disease in the farm raised catfish (USDA/APHIS, 2003b). Determination of the economic impact of columnaris disease is difficult as it is often part of a mixed infection. Approximately 86% of the cases from Louisiana involving columnaris were mixed with other bacteria [e.g. *Edwardsiella ictaluri*, *E tarda and / or Aeromonas spp*.] (Hawke and Thune, 1992). Determining which bacteria is primary and which is secondary is very difficult. Columnaris disease was the leading cause of mortality on Mississippi catfish farms in 2012 (Khoo, 2012). Over 70 % of the catfish farmers polled considered columnaris disease or mixed infections including columnaris as causing the greatest economic loss on catfish farms in the four leading catfish producing states (Khoo, 2001). Often pond bank diagnosis of columnaris disease is performed by farm management with confirmation from a diagnostic laboratory.

The bacterium is present in most waters and movement of infected stocks of fish should be minimized to prevent spread of the disease (Wise*, et al.*, 2004). Columnaris disease is usually an external infection of the skin, fins and gills but *F. columnare* has been isolated from clinically normal channel catfish (Hawke and Thune, 1992). Catfish at any age, during all seasons and under a host of water conditions can be infected (Griffin, 1987). Columnaris disease is usually transmitted from fish to fish via the water but is usually associated with stressful conditions such as poor water quality, and fish handling such as stocking or harvesting (Hawke and Khoo, 2004). Increasing the salinity of water reduces mortality of channel catfish challenged with *F. columnare* (Altinok and Grizzle, 2001). Mortality of channel catfish challenged with *F. columnare* is significantly lower at 1 gram per liter (g/L), salinity than in fresh water and no mortality occurs at salinities of 3 g/L or above (Hawke and Khoo, 2004). The bacterium may be less able to bind to gill and skin tissues of the channel catfish at increased levels of salinity (Altinok and Grizzle, 2001).

Many agricultural industries use databases to help improve production. For many years the dairy industry has used the Dairy Herd Improvement Association (DHIA)[a] database. Data collected are used for: 1) making farm management decisions; 2) educational programs and research, including the genetic evaluation of cows and sires; and 3) the promotion and sale of animals. In 2008, over 4.5 million dairy cows were on DHIA programs. The swine industry has used a similar database called PigChamp[b]. Swine producers can track and analyze herd production and benchmark it against other herds.[b] This database has allowed rapid improvement through selection of superior animals and to highlight areas of concern in production.

The catfish industry is similar to the swine industry with key economic drivers, growth rate and feed efficiency. Feed costs are the largest expense in catfish production. Catfish are fed daily to satiation during warm months. Catfish are fed to maximize growth and minimize waste because overfeeding can have a negative effect on water quality. Monitoring feed intake is an important management tool. Some catfish producers use a database, FISHY[c], developed by the Mississippi State University Agricultural Economics Department. FISHY® can help catfish producers improve their production management decision-making. The FISHY® database concentrates on feeding and projecting fish growth. The Catfish Management database developed for this research allows the farm to manage not only feed but also other factors such as stocking, harvesting, and mortality. The Catfish Management database allows the farm to generate user defined reports on each pond's efficiency and cost of production.

The objective of this study was to determine pond level risk factors associated with columnaris disease mortalities. Of particular interest was determining if production parameters reported by farm personnel could be used to predict the occurrence of disease events

Materials and Methods

Sampling/Data Collection

A large commercial catfish enterprise agreed to share their production records. Over five hundred ponds from 5 farms covering multiple counties in the Mississippi Delta, dedicated to foodfish production were included in this analysis. These ponds had an average size of 5.00±1.66 hectares.

Database Development

To identify risk factors a Catfish Management database was developed. This database was designed to: 1) incorporate production data already being recorded for generating reports for use at weekly managerial meetings focused on feeding rates, feed conversion ratios, mortalities and harvesting events; 2) be easily used by a catfish farmer to collect management data in order to analyze production efficiency through a series of farmer defined management reports and 3) provide the farm with easy access to management reports. Additional customized reports were generated as requested by the farm management.

The database was programmed in Microsoft Access.[d] Permanent unique pond identifications (id) were assigned to each pond. Data recorded by the producer from 2004 to 2007 were imported into the newly constructed database. Briefly, when a mortality event occurred, the date, pond id, reason or cause of the mortality event as well as pounds, average size and number of fish lost were recorded. When the mortality cause could not be determined, affected fish were submitted to the Mississippi State University College of Veterinary Medicine Diagnostic Laboratory located in Stoneville Mississippi, for laboratory confirmation of columnaris disease.

Statistical Analysis: Variable selection and definition

Pond and production information, later used as explanatory variables in statistical models, were recorded or constructed into four main groups, i.e. 1) physical characteristics of the ponds, 2) interval from fish handling to mortality event, 3) daily feed consumption and 4) water quality. Physical characteristics of each pond included the surface area (hectares), average depth (meters) in order to calculate the volume (hectare-meter). Surface area was determined from Geographical Information Systems (GIS)[e] files while pond depth was recorded as a single point measurement supplied by farm management. Disease Pond Age was defined as the age of the pond at the time of a mortality event and was calculated from the time of original construction or from when the pond was rebuilt.

A second group of variables included two calculated variables. Disease Stocking Interval was defined as the interval from the time fish were stocked into the pond until a mortality event occurred. Stocking event information was recorded and included the source of the fish stocked, date the pond was stocked and the number, size and weight of fish stocked. Disease Harvest Interval was defined as the time from a harvesting event until a mortality event occurred. Harvesting event information was recorded and included the date of the harvest, the weight and number of fish harvested.

The third group of variables dealt with feed consumption. The Catfish Management Database contained the feeding records in terms of total kilograms of feed fed, for each pond on a daily basis. The total feed, was then aggregated for periods of 7, 14, 21, and 30 days prior to the columnaris-related mortality event. These values did not take into account the varying sizes of the ponds. In order to compare feed usage the aggregate totals were divided by pond area to calculate feed per hectare, divided by pond depth to calculate feed per meter of depth and divided by pond volume to calculate feed per hectare-meter. These calculations allowed comparisons between ponds of differing sizes, depth and volumes.

The fourth group of variables involved water quality measurements. A separate water quality database was developed and located in the water quality testing laboratory on the farm. Pond water was tested and values recorded for total ammonia nitrogen (TAN), nitrites and chlorides. Chlorides were measured if the TAN level was considered high (>6mg/L). The database was designed to automatically generate a report of ponds that exceeded the management defined ammonia to nitrite ratio. The water quality database was constructed in 2005 so data from 2005-2007 was included in the analysis. Water quality data were collected on a weekly or biweekly basis during the growing season (March-November) and monthly during the non-growing season.

Statistical Procedures: risk factor modeling

Logistic regression was used to assess the strength of association between the dichotomous outcome of interest, columnaris occurrence in ponds, and various independent variables that represented potential risk factors for the disease. The data in the study was hierarchically structured, which calls for multilevel modeling (Guo and Zhao, 2000) with ponds (level 1) nested in farms (level 2) which are nested in the catfish enterprise (level 3). Biases in parameter estimates could result from ignoring observations that are more highly correlated and within clusters or levels. Linear and binary models underestimate standard errors when clustering is not taken into account and the assumption of independence is violated. Multilevel modeling provides more accurate standard errors, confidence intervals and significance tests by correcting these biases (Guo and Zhao, 2000).

Univariable Model

Generalized linear mixed models designating a binomial distribution with a logit link function were fitted using the GLIMMIX procedure in SAS^{f}® 9.2 software for

Windows[f] to conduct the logistic regression analysis. Random effects were incorporated to account for the repeated measures of ponds and variability among the participating farms and possible intra-farm correlation. In the screening process, each risk factor was evaluated in the basic model as a single fixed effects factor, and if associated with the outcome ($p \leq 0.20$) was retained for further analysis. In the second step, all risk factors retained from the screening step were investigated for pair wise collinearity using the CORR procedure in SAS[f] ® 9.2 software for Windows. Each case of collinearity detected was treated separately.

Multivariable Model

To build the final multivariable model, the fixed effects risk factors retained from the screening and collinearity investigations were offered to the basic model all at once as fixed effects factors. After each model run, the fixed effects factor with the highest *p-value* was removed until a final model with all the fixed effects variables significant at $p \leq 0.050$ was developed. Further refinement of the developed full final model was pursued to obtain the most parsimonious model while preserving its explanatory ability. A limited number of tools are available to evaluate the performance of generalized linear mixed models with different set of predictors for a given outcome. There is no best way to estimate goodness of fit for multilevel models. In non-multilevel logistic regressions, the chi-square goodness of fit tests is appropriate when an assumption of independence of observations is met and data are not very sparse (Schukken, *et al.*, 2003). These assumptions are not met in multilevel modeling with clustering so the chi-square goodness of fit test is not appropriate.

The full model and candidate reduced models were compared using the Akaike Information Criterion (AIC) score. The model that had the smallest AIC score was selected. (Burnham and Anderson, 2001).

Results

In columnaris related mortality events, mean losses were 3,155 ± 228 head, 0.53±0.015 kg per fish for a total weight of 1,612 ±127 kg per mortality event. Columnaris accounted for 18.33% of the observed mortalities from 2004-2007. On a monthly basis, farm recorded columnaris mortalities peaked in April and again October (Figure 4.1).

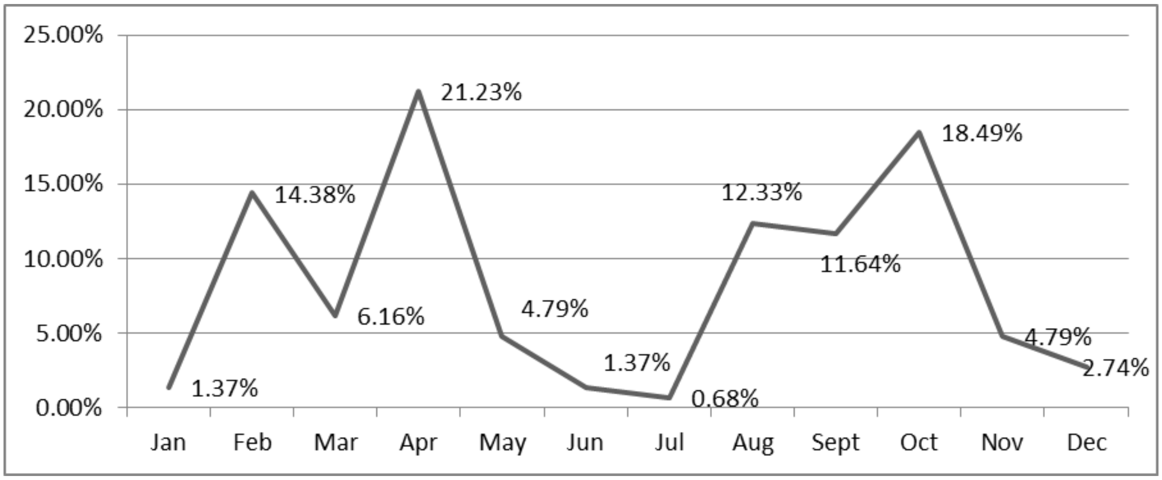


Figure 4.1 Farm reported percent columnaris mortalities (cases/month 2004-2007)

Mean pond surface area was 5.1± 0.12 hectares with a range from 2.0 hectares to 8.9 hectares. Mean pond depth was 1.99 ± 0.028 meters with a range from 1.1 to 2.7 meters. These farms had undergone an aggressive pond rebuilding program from 2005 to 2007 with newer rebuilt ponds being deeper (Figure 4.2). Mean pond volume was 10.19±

0.271 hectare-meter with a range in volume from 3.16 hectare-meter to 21.91 hectare-meter.

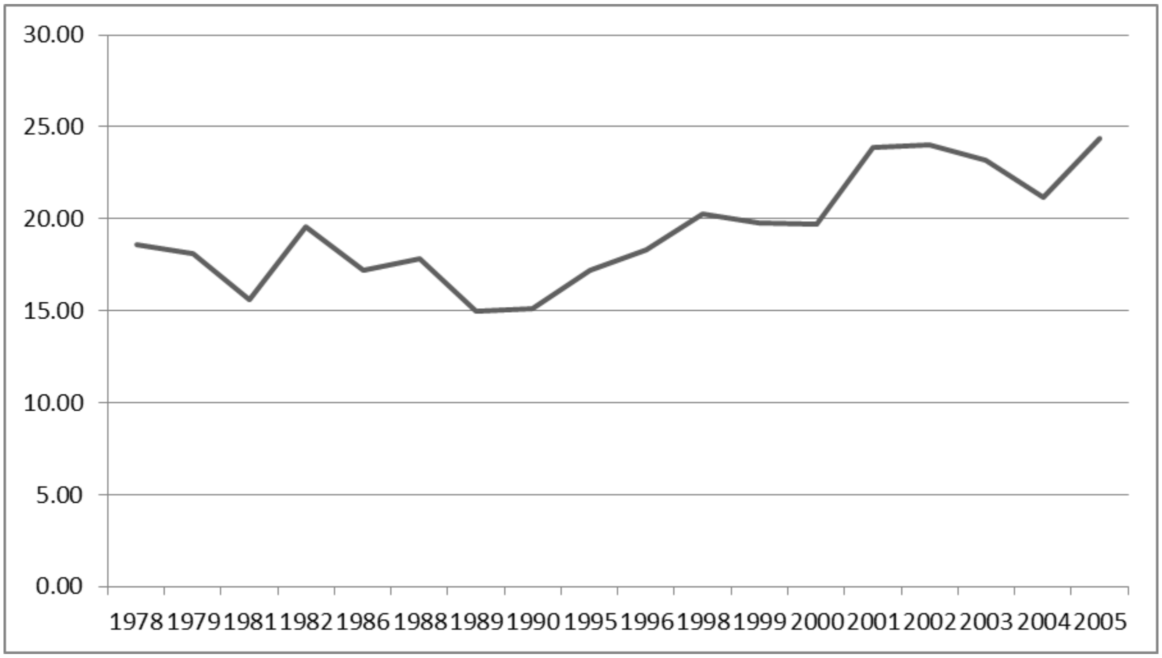


Figure 4.2 Average farm pond depth (decimeters) by year of construction

The screening process identified 16 variables with an association ($P \leq 0.2$) with the occurrence of columnaris and were considered as candidates in a multivariable model (Table 4.1).

Table 4.1 Logistic regression results for variables associated with the occurrence of columnaris

Variable	Measured Unit	N	Odds Ratio	Confidence Interval	P-value
Depth	Decimeters	10,325	1.10	1.03,1.18	.003
Volume	Hectare-meter	10,326	1.08	1.01,1.14	.017
Size	Hectare	10,326	1.13	0.98,1.30	.103
Disease Harvest Interval	30 days	10,315	1.00	1.00,1.00	.105
Nitrites 8-14 days	mg/L	3,341	0.19	0.04,0.93	.041
Ammonia 0-7 days	mg/L	3,607	1.47	1.06,2.03	.020
Ammonia 8-14 days	mg/L	3,343	1.34	1.01,1.79	.045
Ammonia 15-21 days	mg/L	2,937	2.44	1.89,3.15	<.0001
Feed 0-7 days/Hectare	kg/ha	10,325	0.99	0.99,1.00	.076
Feed 0-14 days/Hectare	kg/ha	10,325	0.95	0.99,0.99	.025
Feed 0-21 days/Hectare	kg/ha	10,325	0.99	0.99,1.00	.133
Feed 0-7 days /Hectare meter	kg ha^{-1} m^{-1}	10,325	1.00	0.99,1.00	.039
Feed 0-14 days/Hectare meter	kg ha^{-1} m^{-1}	10,325	1.00	0.92,0.99	.008
Feed 0-21 days/Hectare meter	kg ha^{-1} m^{-1}	10,325	1.00	0.95,1.00	.045
Feed 0-30 days/Hectare meter	kg ha^{-1} m^{-1}	10,325	1.00	0.97,1.00	.112
Feed 0-14 days/meter	kg/m	10,325	1.00	0.99,1.00	.111

(p values < .0.20)

An observation was defined as a pond with a positive mortality event due to columnaris disease as defined by the farm. Ponds without a history of mortality events associated with columnaris were selected as negative ponds and served as controls. A negative pond was defined as a pond that did not have a mortality event 60 days prior and 60 days post the mortality event date being analyzed. During the variable screening process, it was observed that the number of observations was greatly reduced when water quality variables were considered. This occurred due to the water quality database not being constructed until 2005 and to the sampling frequency of the ponds. Consequently, two separate multivariable models were developed. The first analysis excluded water quality variables resulting in 10,711 potential observations. In the second analysis, water quality variables were included reducing the number of observations to 3,950.

In the analysis which excluded water quality variables, the most parsimonious multi-variable model included two effects in the final model: depth of the pond and feed fed for 14 days, on a per hectare basis, prior to the disease breaks (Table 4.2).

Table 4.2 Multivariable Model excluding water quality variables

Variables	Units	Odds Ratio	Confidence Interval	P
Pond Depth	dm	1.1	1.03, 1.18	0.003
Feed 14 Days Prior to	100kg/ha	0.99	0.991,0.999	0.025

As pond depth increased the odds of a mortality event associated with columnaris occurring in a pond increased. For each 100 kg/hectare increase in feed fed for the14 days prior to a disease outbreak the odds of a mortality event associated with columnaris occurring in a pond decreased. For the ponds included in the analysis excluding water quality variables, the mean pond surface area was 4.7± 0.02 hectares and mean pond depth was 18.3 ± 0.04 decimeters.

For the analysis which included water quality variables, the most parsimonious multi-variable model included four effects in the final model: depth of the pond, feed fed for 14 days prior to the disease breaks on a per hectare basis, TAN measured within 7 days of a mortality event and the interval from stocking of new fish to a mortality event (Table 4.3).

Table 4.3 Multivariable Model including water quality variables

Variables	Units	Odds Ratio	Confidence Interval	P
Pond Depth	dm	1.2	1.10,1.34	0.0001
Feed 14 days prior to disease	100kg/h	0.97	0.967,0.97	<0.0001
Total Ammonia Nitrogen (TAN) 7 days prior to disease	mg/L	1.77	1.26,2.48	0.0009
Stocking to Disease Interval	30 days	0.41	0.25,0.66	0.0003

As pond depth and TAN increased the odds of a mortality event associated with columnaris occurring in a pond increased. For each 100 kg/hectare increase in feed fed for the 14 days prior to a disease outbreak and the longer the interval from stocking of new fish in a pond until a mortality event, the odds of a mortality event associated with columnaris occurring in a pond was decreased. The mean of 30 day time periods from a stocking to a mortality event was 16.6 ± 0.13. For the ponds included in the analysis including water quality variables, mean pond surface area was 4.8± 0.03 hectares and mean pond depth was 18.5 ± 0.06 decimeters.

Discussion

The objective of this study was to identify potential risk factors associated with mortality events the farm managers attributed to columnaris disease. Pond depth was significantly associated with columnaris occurrence in analysis that both included and excluded water quality variables. Pond depth data was a single measurement reported by the farm. It is recognized that catfish ponds are sloped and are shallower at the margins and/or on one end and deeper on the opposite end. Pond depth can be influenced by the age of the pond and sediment accumulation. Mean sediment depth increased with pond age, although the rate of sediment accumulation was greatest in the first year (12.5cm/year) (Steeby*, et al.*, 2004). Rebuilt ponds are deeper on these farms (Figure 4.2).

A survey of catfish farmers found that the average pond depth in the southern region, including Alabama, Arkansas, Louisiana and Mississippi, was 5.5 feet or 1.67 meters (N=553) (Hanson*, et al.*, 2008). Mississippi Agriculture and Forestry Experiment Station researchers recommended that catfish ponds should have an average depth of 6 to 7 feet or 1.83 to 2.13 meters (Coblentz, 2003). Increased pond depth reduced non-specific disease related catfish losses (Hanson*, et al.*, 2008). In contrast this study found greater pond depth increased the odds of a mortality event associated with columnaris disease. Deeper ponds have a greater volume. Since aeration is based on pond size and not volume, deeper ponds may have reduced aeration levels and lower oxygen levels leading to greater stress. One clinical sign of columnaris disease is the necrosis of the gills which may look brown due to clay particles trapped by mucus secreted by the bacteria (Hawke and Khoo, 2004). This reduces the efficiency of the gills leading to reduce oxygen uptake. This stress may lead to increased odds of a columnaris related mortality event. We may also find that the odds of a mortality event related to pond depth differ with individual catfish diseases.

Reduced feed consumption for a 14 day period measured on a per hectare basis was significantly associated with columnaris occurrence in the analysis of both of these models. It is not surprising that ponds would have reduced feed consumption prior to a disease break. Past studies have found that sick fish have reduced feed consumption (Robinson*, et al.*, 2004). This study suggests that monitoring feed consumption in ponds using a 14 day rolling average would offer a way to identify ponds that have a higher risk of mortality associated with columnaris disease. These ponds could then be targeted for closer scrutiny to determine the status of the pond.

The analysis that included water quality data indicated that these variables appear to be important but limited data makes interpretation difficult. Water quality data was limited due to lack of recorded values prior to 2005 and to the sampling frequency of the ponds. Intermittent frequency of testing during the growing and non-growing season resulted in missing data. Water quality data, if available, was recorded 0-7, 8-14 and 15-21 days prior to each mortality event date but only the 0-7 day period for TAN remained in the model.

Elevated ammonia levels can cause physiological, biochemical, histological and behavioral effects (Hargreaves and Tomasso Jr, 2004). In channel catfish ammonia is carried in the blood and excreted as un-ionized ammonia (NH_3). Total ammonia nitrogen (NH_3 +NH_4^+) is partitioned between ionized and un-ionized forms depending on pH and temperature. The diffusion of NH_3 across the gill epithelium is a function of water pH, plasma pH and total ammonia concentration (Hargreaves and Tomasso Jr, 2004). Low dissolved oxygen levels can increase the effect of high ammonia levels. In commercial catfish ponds, ammonia rarely accumulates to concentrations that cause death; ammonia is much more likely to have sub-lethal effects that reduce growth or compromise immunocompetence and even low levels of total ammonia (0.43 mg/L) can reduce voluntary feed consumption by 68% (Hargreaves and Tomasso Jr, 2004). In this study, ponds that had higher total ammonia nitrogen (TAN) levels had increased odds of experiencing a columnaris associated mortality event. These higher ammonia levels may have led to reduced immunocompetence and feed consumption. Elevated ammonia decreases alpha-ketoglutarate need to run the Citric Acid Cycle resulting in the inhibition of the cycle, depletion of ATP and a buildup of lactic acid (Lieske and Volmer, 2004). This stress may have contributed to a columnaris disease mortality event. Elevated ammonia levels were observed within 7 days prior to the mortality event and could serve as an indicator that the pond should be carefully monitored.

Shorter intervals from stocking to disease were significantly associated with ponds that experienced a columnaris mortality event. These shorter intervals could have been due to the introduction of naive fish into a pond with infected fish. Fingerlings especially in their first fall are susceptible to columnaris even without predisposing stress factors (Wise*, et al.*, 2004). Introducing infected fish into a pond with a population of naïve fish may also cause columnaris disease. The bacterium is considered ubiquitous in most waters but movement of infected stocks of fish should be minimized to prevent spread of the disease (Wise*, et al.*, 2004). Stress from poor water quality or handling of fish, such as stocking and harvesting can play a part in a columnaris disease outbreak (Hawke and Khoo, 2004).

These data was used in the management of the catfish farm and assumed accurate. Compared to a prospective study a disadvantage of this retrospective study was that key variables such as pond dissolved oxygen levels and pH were not recorded. The variables described in this study are associated with columnaris mortality events but do not necessarily cause columnaris disease. They are however good variables to consider when designing controlled experiments to determine which farm level risk factors actually cause columnaris associated mortalities. The model and methodology developed for this study may well be useful for the investigation of additional economically important catfish diseases. This study showed some commonly recorded production variables (feed consumption, pond depth, ammonia levels and stocking events) were associated with columnaris disease outbreaks and if monitored could help identify “at risk” ponds prior to disease outbreaks.

CHAPTER V

RISK FACTORS ASSOCIATED WITH ENTERIC SEPTICEMIA OF CATFISH ON MISSISSIPPI COMMERCIAL CATFISH FARMS

Content in this chapter previous published**:** Cunningham, F., S. Jack, D. Hardin and R. Wills 2014. Risk factors associated with Enteric Septicemia of Catfish on Mississippi commercial catfish farms. Journal of Aquatic Animal Health 26:2 84-90, 1-7,

DOI: 10.1080/08997659.2014.886635

Introduction

Enteric septicemia of catfish (ESC) is one of the most prevalent bacterial diseases in commercial catfish production (USDA/APHIS, 2003b). It is caused by a gram negative bacteria *Edwardsiella ictaluri* (Hawke*, et al.*, 1981). The epidemiology of ESC can be multifactorial. Outbreaks usually occur in the spring (April-June) and fall (September-November) months when water temperatures are 70-85 F degrees (Tucker*, et al.*, 2004). ESC occurs in three forms, acute, sub-acute and chronic. In the acute phase catfish show few clinical signs but go off feed and swim listlessly or become motionless. Infected fish can have exophthalmia and distended abdomens. The sub-acute phase is characterized by a slower onset but cumulative mortalities may be high (Hawke and Khoo, 2004). Catfish will have petechial and ecchymotic cutaneous hemorrhage on the belly and around the head along with small shallow white or red ulcers. Fish will go off feed more slowly than in acute ESC. Chronic phase clinical signs may include hemorrhagic areas around the mouth and on the ventral sides of fish. Small white ulcers may be found on the fish's skin. Ulcers on the top of the head, between the eyes are considered pathognomonic for the disease and give it one of its common names, hole-in-the-head disease (Tucker, *et al.*, 2004). Fish suffer central nervous system involvement expressed as spinning, spiraling and tail chasing (Hawke and Khoo, 2004). Stress plays a key role in outbreaks. Stress factors such as handling, poor diet, poor water quality, and overcrowding and water temperature fluctuations can lead to an outbreak (Wise, *et al.*, 1993; Plumb and Shoemaker, 1995). Culturing fish in mixed age populations or under stocking also plays a key role in spread of the disease to healthy fish. Surviving fish can carry the pathogen for up to 200 days in their kidney, liver or brain. Stress may increase susceptibility to infection and losses but it is not a prerequisite for the disease. Immune status of the individual fish may also determine the outcome (Hawke and Khoo, 2004).

ESC is widespread throughout the industry. The spread of the disease may be related to the shipment of infected but asymptomatic fingerlings. These fingerlings may be asymptomatic carriers outside of the temperature ranges where the disease usually occurs (Klesius, 1993). Bacteria may be maintained in a multi-batch culture environment with the introduction of naïve fingerlings to a pond containing older exposed catfish.

ESC transmission between fish is from fecal shedding from sick fish or the carcasses of dead fish (Earlix, 1995). The bacterium can cross the intestinal epithelium, enter the blood stream and migrate to the kidneys within 15 minutes of experimental intestinal infection (Baldwin and Newton, 1993). Vertical transmission from infected broodstock to fry has not been demonstrated (Hawke and Khoo, 2004). The presence of viable *E. ictaluri* in the intestinal contents of cormorants and herons suggest the fecal wastes from piscivorous birds are a potential source of infection (Taylor, 1992). However, Waterstrat*, et al.* (1999) in experimentally infected great blue herons, (*Ardea Herodias*) found no viable *E. ictaluri* in feces, gastrointestinal tract or feathers and concluded that great blue herons do not play a role in the transmission of ESC between catfish ponds.

Many agricultural industries use production databases to help improve production. Feed costs are the largest expense in catfish production. Catfish are fed daily to satiation during warm months. Catfish are fed to maximize growth and minimize waste because overfeeding can have a negative effect on water quality. Monitoring feed intake is an important management tool. Some catfish producers use a database, FISHY[c], that was developed by the Mississippi State University Agricultural Economics Department to help catfish producers improve their production management decision-making. The FISHY® database concentrates on feeding and projecting fish growth. The Catfish Management Database developed for this research includes data from 2004-2007. The Catfish Management database allows the farmer to manage feed, stocking, harvesting, and mortality as well as the generation of user define reports designed to: 1) incorporate production data already being recorded for generating reports for use at weekly managerial meetings focused on feeding rates, feed conversion ratios, mortalities and harvesting events; 2) be easily used by a catfish farmer to collect management data in order to analyze production efficiency; 3) provide the farm with easy access to management reports and 4) calculate a pond's efficiency and cost of production. Additional customized reports were generated as requested by the farm management.

The objective of this study was to identify risk factors associated with ESC mortalities. Of particular interest was determining if the farm collected production parameters could be used to predict the occurrence of ESC mortality events.

Materials and Methods

Sampling/Data Collection

A large commercial catfish enterprise agreed to share their production records. Over five hundred ponds from 5 farms covering multiple counties in the Mississippi Delta, dedicated to foodfish production were included in this analysis. These ponds had an average size of 5.0±1.66 hectares.

The Catfish Management Database was programmed in Microsoft Access.[b] A permanent unique pond identification number greater than 1 , (id) was assigned to each pond. Data recorded by the producer from 2004 to 2007 was imported into the newly constructed database. Briefly, when a mortality event occurred, the date, pond id, reason or cause of the mortality event as well as pounds, average size and number of fish lost were recorded. Occasionally, affected fish were submitted to the Mississippi State University College of Veterinary Medicine Diagnostic Laboratory located in Stoneville Mississippi, for laboratory confirmation of ESC.

Pond and production information, later used as explanatory variables in statistical models, were recorded or classified into four main groups: 1) physical characteristics of the ponds, 2) interval from fish handling to mortality event, 3) daily feed consumption and 4) water quality. Physical characteristics of each pond included the surface area (hectares) and average depth (meters), which were used to calculate the volume (hectare-meter). Surface area was determined from Geographical Information Systems (GIS)[e] files while pond depth, was recorded as a single point measurement supplied by farm management. Disease pond age was defined as the age of the pond at the time of a mortality event and was calculated from the time of original construction or from when the pond was rebuilt.

A second group of variables included two calculated variables. Disease stocking interval was defined as the interval from the time fish were stocked into the pond until a mortality event occurred. Stocking event information was recorded and included the source of the fish stocked, date the pond was stocked and the number, size and weight of fish stocked. Disease harvest interval was defined as the time from a harvesting event until a mortality event occurred. Harvesting event information was recorded and included the date of the harvest, the weight and number of fish harvested.

The third group of variables dealt with feed consumption. The Catfish Management Database contained the feeding records in terms of total kilograms of feed fed, for each pond on a daily basis. The total feed was then aggregated for periods of 7, 14, 21, and 30 days prior to the ESC-related mortality event. These values did not take into account the varying sizes of the ponds. In order to compare feed usage the aggregate totals were divided by pond area to calculate feed per hectare, divided by pond depth to calculate feed per meter of depth and divided by pond volume to calculate feed per hectare-meter. These calculations allowed comparisons between ponds of differing sizes, depth and volumes.

The fourth group of variables involved water quality measurements. A separate water quality database was developed and located in a water quality testing laboratory on the farm. All testing for pond water quality parameters was performed in the central laboratory by one technician. Pond water was tested for total ammonia nitrogen (TAN), nitrite and chloride. Chloride was measured only if the TAN level was considered high (>6mg/L). The database was designed to automatically generate a report of ponds that exceeded the management defined total chloride to nitrite ratio. The water quality database was constructed in 2005 so data from 2005-2007 was included in the analysis. Water quality data were collected on a weekly or biweekly basis during the growing season (March-November) and monthly during the non-growing season.

An observation was defined as a pond with a positive mortality event due to ESC as defined by the farm management. Ponds without a history of mortality events associated with ESC were selected as negative ponds and served as controls. A negative pond was defined as a pond that did not have a mortality event 60 days prior and 60 days post the mortality event date being analyzed

Statistical Procedures: risk factor modeling, variable selection

Logistic regression was used to assess the strength of association between the dichotomous outcome of interest, ESC occurrence in ponds, and various independent variables that represented potential risk factors for the disease. The data in the study was hierarchically structured, which calls for multilevel modeling (Guo and Zhao, 2000) with ponds (level 1) nested in farms (level 2) which are nested in the catfish enterprise (level 3). Biases in parameter estimates could result from ignoring observations that are more highly correlated and within clusters or levels. Linear and binary models underestimate standard errors when clustering is not taken into account and the assumption of independence is violated. Multilevel modeling provides more accurate standard errors, confidence intervals and significance tests by correcting these biases (Guo and Zhao, 2000). Generalized linear mixed models designating a binomial distribution with a logit link function were fitted using the GLIMMIX procedure in SAS[f]® 9.2 software for Windows[d] to conduct the logistic regression analysis. Random effects were incorporated to account for the repeated measures of ponds and variability among the participating farms and possible intra-farm correlation. In the screening process, each risk factor was evaluated in the basic model as a single fixed effects factor, and if associated with the outcome ($p \leq 0.20$) was retained for further analysis.

In the second step, all continuous variables considered as risk factors were retained from the screening step and investigated for pair wise collinearity using the CORR procedure in SAS[f] for Windows® v 9.2. Each case of collinearity, defined at $R \geq 0.6$, detected was evaluated separately on the significance of the association with the occurrence of ESC and relationship with other explanatory variables.

To build the final multivariable model, the fixed effects risk factors retained from the screening and collinearity investigations were offered to the basic model all at once as fixed effects factors. After each model run, the fixed effects factor with the highest p-value was removed until a final model with all the fixed effects variables significant at $p \leq 0.050$ was developed. Further refinement of the developed full final model was pursued to obtain the most parsimonious model while preserving its explanatory ability. A limited number of tools are available to evaluate the performance of generalized linear mixed models with different set of predictors for a given outcome. There is no best way to estimate goodness of fit for multilevel models. In non-multilevel logistic regressions, chi-square goodness of fit tests is appropriate when an assumption of independence of observations and data is not very sparse (Schukken*, et al.*, 2003). These assumptions are not met in multilevel modeling with clustering so the chi-square goodness of fit test is not appropriate.

The models were compared using the Akaike Information Criterion (AIC) score. Models that had AIC score differences of greater than 2 from the model with the minimum AIC score were eliminated from the analysis (Burnham and Anderson, 2001). Models with the lowest AIC scores were selected as the final model.

In descriptive statistics, means were reported with their standard deviation. Strength of association between variables was reported as odds ratios.

Results

In ESC related mortality events, mean losses were 4,053 ± 224 head, 0.6±0.01 kg per fish for a total weight of 2,303 ±120 kg per mortality event. ESC accounted for 18.91% of the observed mortalities from 2004-2007. On a monthly basis, farm recorded ESC mortalities peaked in September and October (Figure 5.1).

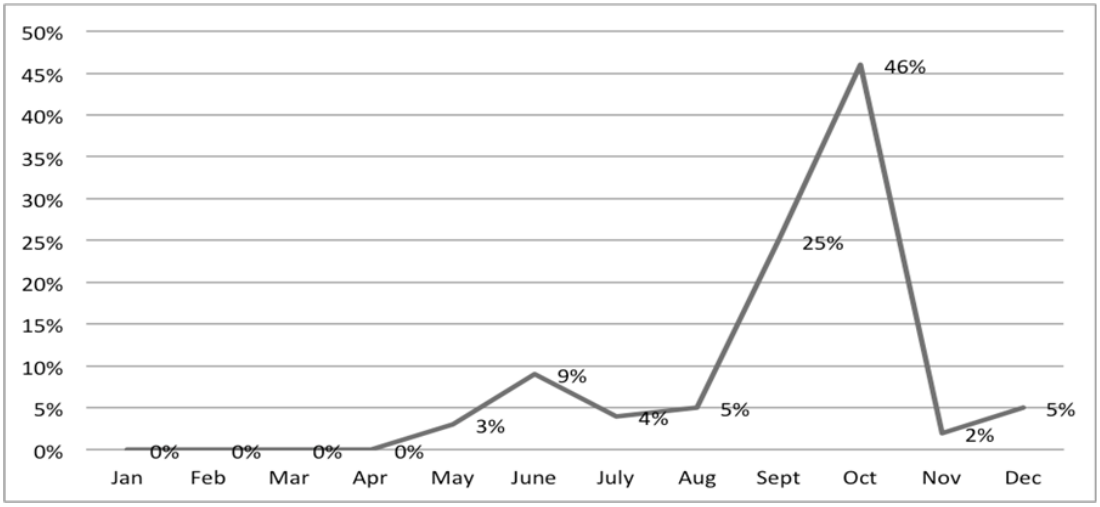


Figure 5.1 Farm reported percent enteric septicemia of catfish mortalities (cases/month 2004-2007)

Mean pond surface area was 4.6± 1.52 hectares (range 4.4 to 4.8 hectares). Mean pond depth was 1.8 ± 0.33 meters (range 1.71 to 1.81 meters). This farm has undergone a very aggressive pond rebuilding program 2005 through 2008 with newer rebuilt ponds being deeper. Mean pond volume was 8.5± 3.84 hectare-meters (range 7.9 to 9.1 hectare-meters).

The screening process for the data set identified 27 variables with an association ($P \leq 0.2$) to the occurrence of ESC and were considered as candidates in a multivariable model (Table 5.1).

Table 5.1 Logistic regression analysis results for variables associated with the occurrence of enteric septicemia of catfish

Variable	Measured Unit or Comparison	N	Odds Ratio	Confidence Interval	P-value
Depth	meters	1,215	0.11	0.03,0.47	0.0027
Volume	hectare-meter	1,215	0.78	0.66,0.91	0.0019
Size	hectare	1,216	0.68	0.51,0.92	0.0124
Year	year	1,216			<0.0001
	2005 vs 2007		0.02	0.01,0.05	
	2006 vs 2007		0.37	0.28,0.49	
Disease Pond Age	days	1,215	1.23	1.15,1.32	<.0001
Pre Disease Feed	kg	1,215	3.14	2.54,3.86	<.0001
Disease Harvest	days	1,215	1.47	1.40,1.53	<.0001
Disease Stock Interval	days	1,215	0.44	0.30,0.67	<.0001
Nitrites 8-14 days	mg/L	1,215	3.44	2.06,5.74	<.0001
Ammonia 8-14 days	mg/L	1,215	7.41	4.13,13.28	<.0001
Nitrites 14-21 days	mg/L	192	7.48	0.95,58.82	0.056
Feed 0-7	kg	1,215	1.00	1.00,1.00	0.1058
Feed 0-14 days	kg	1,215	1.00	1.00,1.00	0.0127
Feed 0-21 days	kg	1,215	1.00	1.00,1.00	<.0001
Feed 0-30 days	kg	1,215	1.00	1.00,1.001	<.0001
Feed 0-7 days per	kg/ha	1,215	1.00	0.99,1.00	0.1230
Feed 0-14 days per	kg/ha	1,215	1.00	1.00,1.001	0.0167
Feed 0-21 days per	kg/ha	1,215	1.00	1.00,1.00	<.0001
Feed 0-30 days per	kg/ha	1,215	1.001	1.001,1.001	<.0001
Feed 0-7 days per Hectare meter	kg/ha-m	1,215	0.999	0.998,1.000	0.1297
Feed 0-14 days per Hectare meter	kg/ha-m	1,215	1.001	1.000,1.001	0.0058
Feed 0-21 days per Hectare meter	kg/ha-m	1,215	1.001	1.000,1.001	<.0001
Feed 0-30 days per Hectare meter	kg/ha-m	1,215	1.002	1.002,1.002	<.0001
Feed 0-7 days per meter	kg/m	1,215	1.000	1.000,1.000	0.1606

(p values < 0.20)

During the variable screening process 1,215 observations were identified. The most parsimonious multi-variable model included six effects in the final model: 1) pond volume, 2) interval from stocking until a mortality event, 3) interval from harvest until a mortality event, 4) nitrite measured within 14 days of a mortality event, 5) TAN measured within 14 days of a mortality event and 6) sum of feed fed for 14 days prior to the disease outbreak. As pond volume and the interval from stocking to a mortality event increased, the odds of a mortality event associated with ESC occurring decreased. As the interval from harvest to a mortality event, nitrite and ammonia levels within 14 days and sum of feed fed for 14 days prior to a mortality event increased the odds of a mortality event associated with ESC occurring in a pond increased (Table 5.2).

Table 5.2 Odds Ratio (OR) of the final logistic regression model

Variables	Measured Unit	Odds Ratio	Confidence Interval	P-value
Volume	hectare-meter	0.56	0.42,0.74	<.0001
Disease Stocking Interval	days	0.52	0.34,0.81	0.0035
Disease to Harvest Interval	days	1.49	1.41,1.57	<.0001
Nitrites 14 days	mg/L	3.49	1.66,7.33	0.0010
Total Ammonia 14 days	mg/L	20.48	9.96,42.11	<.0001
Feed 0-14 days	100 kg	1.02	1.01,1.03	<.0001

Note: For the ponds included in this analysis, the mean pond and standard deviation of surface area was 4.8± 1.60 hectares and mean pond depth was 1.84 ± 0.364 meters

Discussion

The objective of this study was to identify potential risk factors associated with mortality events the farm managers attributed to ESC. Wagner*, et al.* (2002) using the 1997 National Animal Health Monitoring System (NAHMS) survey of catfish farmers found that the most frequently reported (35.7%) average loss per outbreak of ESC and columnaris combined was 200-2000 pounds per outbreak. Only 18.3% of the operations reported losses classified as severe (> 2000 lbs.). In contrast, the ESC related mortality events in this study resulted in mean losses (mean, standard deviation) of 3,156 ± 3317 fish, 0.5±0.02 kg per fish for a total weight of 1,615±1835 kg per mortality event. ESC accounted for 18.91% of the observed mortalities from 2004-2007. Wagner,, *et al.* (2002), found that 78.1% of the farms surveyed and 42.1% of all ponds experienced ESC/columnaris problems.

In the model, pond volume was significantly associated with ESC occurrence. Ponds with more volume had reduced odds of a mortality event associated with ESC. Since depth is a key component of volume (area X depth) this result in not unexpected. Hanson*, et al.* (2008) found that as pond depth increased, catfish losses from weather related causes decreased, because the deeper ponds were not as sensitive to windstorms, droughts and freezing. In contrast, Cunningham*, et al.* (2012) found that the incidence of columnaris increased with greater pond depth. Greater pond depth offers more living space for the catfish; shallower ponds or older ponds that have filled in (Steeby*, et al.*, 2004) provide less space and may lead to crowding and increased stress on the catfish. Pond depth data was a single measurement reported by the farm. It is recognized that catfish ponds are sloped and are shallower at the margins and/or on one end and deeper on the opposite end. Pond depth can be influenced by the age of the pond and sediment accumulation. Increased stress can lead to greater chance of disease occurring, deeper ponds may reduce this stress, leading to reduced odds of a disease occurring.

As the stocking to disease interval increased, the odds of a disease break associated with ESC decreased. Therefore, a decreased stocking to disease interval would be associated with increased odds of ESC, suggesting that contaminated equipment used in stocking or stress due to the stocking event could have contributed to disease occurrence. The odds of a mortality event due to ESC increased as the harvest to disease interval increased. This could be caused by less fish in the pond after harvest leading to decreased fish density which would lower the odds of an ESC break. As the pond is restocked and the fish density is increased, stress will also increase, increasing the risk of an ESC break. These intervals could be used as indirect indicators of fish handling stress or the use of contaminated equipment.

Increased total feed fed increased the odds of a disease break associated with ESC. Catfish ponds have a finite capacity to process waste without affecting water quality. Water quality problems including low dissolved oxygen (DO) will increase in severity and frequency if feed exceeds the waste processing capacity of a pond. Catfish ponds fed at a high rate, defined as a maximum of 78 kg/ha, had lower DO levels at dawn, reduced growth rate, poorer feed conversion and increased mortality when compared to medium (56 kg/ha) and low (34 kg/ha) feeding rates (Tucker*, et al.*, 1979). In 50% of the ponds fed at the higher rate the mortality rate ranged from 7 to 32%. Cole and Boyd (1986) found that net fish production increased in proportion to feed fed up to 112 kg/ha/day but then decreased at higher feeding rates. Feed conversion (increased feed fed per unit of gain) was constant when feed fed was between 28-112 kg/ha but quickly increased at higher feeding levels (>112kg/ha/day) where fish did not consume all of their feed resulting in increased waste accumulation and decreased water quality.

The odds of a pond having an ESC outbreak were 3.49 times greater for each one unit (mg/L) increase in nitrite measured 14 days prior to a disease event and 20.48 times greater for each one unit increase in TAN levels measured for this same time period.

Water quality measures that potentially affect fish health include nitrite, ammonia, and oxygen levels. High nitrite can result from overfeeding and/or decomposition of organic materials. Therefore, routine monitoring of nitrite levels in ponds is considered to be an essential Best Management Practice (BMP) towards the prevention of mortalities due to toxic levels.

Water quality data were collected on a weekly or biweekly basis during the growing season (March-November) and monthly during the non-growing season. Weekly measurements give the farm time to identify at risk ponds. The addition of salt to ponds is a common management practice aimed towards the treatment and prevention of disease. Elevated ammonia levels can cause physiological, biochemical, histological and behavioral effects. Un-ionized ammonia (NH_3) is excreted by passive diffusion from the gills of channel catfish. The pH of plasma and water and total ammonia concentration determine the total ammonia that is partitioned between ionized (NH_4^+) and un-ionized (NH_3) forms. Gill epithelium diffusion of NH_3 is a function of water pH, plasma pH and total ammonia concentration (Hargreaves and Tomasso Jr, 2004). High levels of NH_3 in water will cause decreased diffusion and an increase in plasma.

Low DO levels can increase the effect of high ammonia levels. Although ammonia concentrations that cause death are seldom observed in catfish ponds, sub-lethal effects such as compromised immune status and reduced growth rate are observed. As oxygen levels decrease even low levels of total ammonia (0.43 mg/L) can reduce voluntary feed consumption by 68% (Hargreaves and Tomasso Jr, 2004). The chloride to nitrite ratio is important to determine methemoglobin levels in catfish. Nitrite from the pond water is actively transported to the catfish circulatory system producing a life threatening condition known as brown blood disease or methemoglobinemia (Durborow, *et al.*, 1997). Ratios (chloride to nitrite) of 20:1 or greater are recommended. Lower ratios can result in brown blood disease (Hargreaves and Tomasso Jr, 2004). The database was designed to automatically generate a report of ponds that do not meet the management defined chloride to nitrite ratio. This ratio is important because the potential toxicity of nitrite is reduced by increasing the chloride concentration of the pond water by adding salt. Chloride to nitrite-nitrogen ratios of 30:1 allow little nitrite to enter the catfish blood stream but producers routinely maintain pond water chloride concentrations of 100 to 150 mg/L to maintain a safety margin (Tucker and Hargreaves, 2004).

The data were used in the management of the catfish farm and assumed accurate. Compared to a prospective study a disadvantage of this retrospective study was that key variables such as pond DO levels, temperature and pH were not recorded. The farm recorded DO content on each pond up to 8 times per night. They did not record these observations (>3,500 per night) due to the volume. They responded to any low DO (< 2ppm) by adding aeration. Pond water temperature was available from a nearby weather station but we did not use it because the water temperature would be the same in ponds with and without ESC outbreaks. The variables described in this study are associated with ESC mortality events but do not necessarily cause ESC. They are however good variables to consider when designing controlled experiments to determine which risk factors actually predispose a pond to ESC associated mortalities. The model and methodology developed for this study may well be useful for the investigation of additional economically important catfish diseases. This study showed some commonly recorded production variables (feed consumption, pond size and depth, nitrite levels and stocking events) were associated with ESC associated mortalities and if monitored could help identify “at risk” ponds prior to ESC outbreaks.

CHAPTER VI

ECONOMIC COST AND RISK FACTORS ASSOCIATED WITH MORTALITY ON MISSISSIPPI COMMERCIAL CATFISH FARMS

Introduction

Economic cost of Disease

In the late 1990's catfish aquaculture expanded but losses from events such as power outages (loss of aeration leading to loss from inadequate oxygen), bird depredation, and infectious disease outbreaks continued to hurt the industry. One of the main issues of concern is loss due to infectious diseases. To investigate this, well-designed epidemiological studies are needed.

Infectious disease has become one of the main concerns in aquatic animal production. Numerous investigators have identified infectious disease as the foremost constraint on further development of the aquaculture industry (Plumb, 1999; Georgiadis, *et al.*, 2001). Enteric septicemia of catfish reportedly costs the catfish aquaculture industry $50 to $60 million annually (Breazeale, 2007). Economic losses due to disease are difficult to assess accurately because they are usually underreported due to self-diagnosis by the producer, difficulty accounting for mortality and lack of record keeping. Economic losses attributable to disease on individual farms can be devastating (Hawke and Khoo, 2004). Depending on the disease, 60% to 100% of fish can be lost in an individual pond or even on a single farm during a disease outbreak (Plumb, 1999; Hawke and Khoo, 2004).

Most infectious diseases, including those that affect fish, have a multifactorial etiology including simultaneous interactions between host, agent, and environmental factors. The existence of an infectious organism (agent) in a fish or the environment will not necessarily lead to clinical disease (Jarp*, et al.*, 1993). Some feel that environmental factors, such as poor water quality, can be linked to the occurrence of fish disease. Catfish farming today is increasingly more intensive (Plumb, 1999; Hargreaves, 2002), with increased stocking densities, feeding rates, and multi-batch harvesting. These practices have resulted in poor water quality as defined by low dissolved oxygen, high nitrogenous compounds, and high stress, followed by low immune system function. The subsequent introductions of young immunologically naïve fish into this environment is cause for concern. Fish are very sensitive to environmental fluctuations, and adverse reactions can occur quickly due to fish being poikilotherms and constantly exchanging metabolites and gasses with their surroundings (Plumb, 1999). It is imperative to investigate the specific associations between environmental parameters and disease occurrences in catfish aquaculture as well as to devise prevention strategies using this knowledge.

Infectious diseases cost producers many millions of dollars in direct fish losses each year. Infectious diseases also influence profitability by increasing treatment costs, reducing food consumption by fish, increasing feed conversion ratios and causing harvesting delays (Wagner*, et al.*, 2002). In general, progress in the area of disease control is limited by a poor understanding of the pathogenesis of the major disease entities, inadequate knowledge of the relationships between management practices and other risk factors associated with disease outbreaks. Bacterial diseases in catfish tend to be most important. There is not a clear understanding of how risk factors affect bacterial diseases. Extreme temperature, overcrowding, normal management such as harvesting, stocking and poor water quality or low oxygen may be risk factors in bacterial disease outbreaks (USDA/APHIS, 2000).

The main goal in aquaculture is to produce a quality product efficiently and profitably. Infectious disease hinders this process in numerous ways. Mortality causes loss of production and less pounds to market resulting in decreased income. Morbidity results in poorer feed efficiency, slower growth, delayed harvest, increased susceptibility to secondary pathogens or environmental stressors (Roberts and McKnight, 1976). Delayed harvest causes lost space which could have been used for healthy fish (Rosenlund, 1977). Therefore, higher production costs are associated with disease outbreaks, and there are limited drug therapies currently available for use in food fish so prevention of disease is essential.

The USDA/APHIS (2003a) survey indicated that the survival rate during the fry to fingerling stage (nursery) averages 70% across the industry. Records from several large farms in the southeast indicate that the survival of catfish from fingerling to food fish averages between 70 and 80 percent. In 1996, producers indicated that infectious disease accounted for 45% of food fish losses (USDA/APHIS, 1997a). According to the USDA NAHMS study (USDA/APHIS, 2003a) bacterial diseases account for approximately 70% of all diseases affecting catfish in the southeast USA. Bacterial diseases are more common for a number of reasons. Due to the way catfish are currently raised with multiple age fish in one pond there is always a susceptible population of naive fish to keep the bacteria circulating. Many of the bacterial agents exist in the environment and are opportunistic waiting for fish to become stressed to express themselves. Stress conditions such as temperature extremes, crowding, injury, harvesting, stocking, poor water quality or low oxygen can contribute to bacterial disease outbreaks. Many bacterial diseases can be reduced through management. Proper stocking densities, good oxygen levels and water quality will all help. If the water is contaminated then stress must be at a minimum to prevent outbreaks.

Producers of other species have learned to control some bacterial diseases through age segregation. Animals of one age are kept together and not mixed with older, potentially infected animals. Facilities are all in – all out and cleaned between each group of animals so that each group can start clean. This is not possible in the catfish industry as it would be impractical to drain each pond after each group of fish. It is possible that modular, split pond or in pond raceway production which is now being adopted by some farmers in the catfish industry will help with this problem. In the modular system, fish fry would be raised to stocker size and then harvested, resorted and placed at a different stocking rate in a food fish pond. Because they are entering at a much larger size the time in the food fish pond is reduced. There is only one age of fish in the pond at one time. In a recent study other advantages of modular production included reduced turnover time to final market weight, reducing risk of bird predation in the fingerling to stocker ponds due to larger size as greater than 98% of fish were longer than 20cm. which is the length they are no longer susceptible to predation (Glahn*, et al.*, 1995), disease treatment due to fish being of similar size and inventory control (D'Abramo*, et al.*, 2012).

Baseline data for many of the biological and epidemiological characteristics of major catfish diseases does not exist. On-farm monitoring and surveillance programs, as a means of defining progress in the prevention and control of diseases, are crucial to the sustainability of health programs. No systems are currently in place for the systematic collection of both diagnostic and field data for defining disease through surveillance and monitoring.

Epidemiology can play a key role in understanding disease in aquaculture through such tools as risk-factor studies, risk analysis, and disease modeling (Georgiadis*, et al.*, 2001). An increased understanding of disease can lead to better control and prevention leading to increased profitability. We have previously identified the risk factors associated with two important diseases in catfish we will now examine the economic cost of these diseases based on farm production records.

Columnaris

A gram negative bacterium, *Flavobacterium columnare* is the cause of columnaris disease, the second most prevalent bacterial disease in the farm raised catfish (USDA/APHIS, 2003b). Determination of the economic impact of columnaris disease is difficult as it is often part of a mixed infection. Approximately 86% of the cases from Louisiana involving columnaris were mixed with other bacteria [e.g. *Edwardsiella ictaluri*, *E tarda and / or Aeromonas spp*.] (Hawke and Thune, 1992). Determining which bacteria is primary and which is secondary is very difficult. columnaris disease was the leading cause of mortality on Mississippi catfish farms in 2012 (Khoo, 2001).

Over 70 % of the catfish farmers polled considered columnaris disease or mixed infections including columnaris as causing the greatest economic loss on catfish farms in the four leading catfish producing states (Khoo, 2001). Often pond bank diagnosis of columnaris disease is performed by farm management with confirmation from a diagnostic laboratory.

Enteric Septicemia of Catfish

Enteric septicemia of catfish (ESC) is one of the most prevalent bacterial diseases in commercial catfish production (USDA/APHIS, 2003b). It is caused by a gram negative bacteria *Edwardsiella ictaluri* (Hawke*, et al.*, 1981). The epidemiology of ESC can be multifactorial. Outbreaks usually occur in the spring (April-June) and fall (September-November) months when water temperatures are 70-85 F degrees (Tucker*, et al.*, 2004). Stress plays a key role in outbreaks. Stress factors such as handling, poor diet, poor water quality, and overcrowding and water temperature fluctuations can lead to an outbreak (Wise*, et al.*, 1993; Plumb and Shoemaker, 1995). Culturing fish in mixed age populations or under stocking also plays a key role in spread of the disease to healthy fish. Surviving fish can carry the pathogen for up to 200 days in their kidney, liver or brain. Stress may increase susceptibility to infection and losses but it is not a prerequisite for the disease. Immune status of the individual fish may also determine the outcome (Hawke and Khoo, 2004).

Many agricultural industries use production databases to help improve production. Feed costs are the largest expense in catfish production. Catfish are fed daily as much as they will eat during warm months. Catfish are fed to maximize growth and minimize waste because overfeeding can have a negative effect on water quality. Monitoring feed intake is an important management tool. Some catfish producers use a database, FISHY[c], that was developed by the Mississippi State University Department of Agricultural Economics to help catfish producers improve their production management decision-making. The FISHY® database concentrates on feeding and projecting fish growth. A previously described database (Chapter III) was developed to facilitate the collection and utilization of production and health data. The objective of this study was to analyze these data to assess the economic cost of two important catfish diseases, columnaris and ESC.

Materials and Methods

Data collection

A large commercial catfish enterprise agreed to share their production and health records. Over five hundred ponds from 5 farms covering multiple counties in the Mississippi Delta, dedicated to foodfish production were included in this analysis.

The Catfish Management database was programmed in Microsoft Access[d] and allows farmers to better manage feed, stocking, harvesting, and mortality as well as the generation of user defined reports. The database was designed to: 1) incorporate production data already being recorded for generating reports for use at weekly managerial meetings focused on feeding rates, feed conversion ratios, mortalities and harvesting events; 2) be easily used by a catfish farmer to collect management data in order to analyze production efficiency; 3) provide the farm with easy access to management reports; and 4) aid in assessing a pond's efficiency and cost of production. Additional customized reports were generated as requested by the farm management. The Catfish Management database developed for this research includes data from 2004-2007. It has been used to study pond level risk factors associated with the occurrence of mortalities due to columnaris disease (Cunningham*, et al.*, 2012) and ESC (Cunningham*, et al.*, 2014). An observation was defined as a pond with a positive mortality event due to columnaris or ESC disease as defined by the farm. Ponds without a history of mortality events associated with columnaris or ESC were selected as negative ponds and served as controls. A negative pond was defined as a pond that did not have a mortality event 60 days prior and 60 days post the mortality event date being analyzed. The cost of the disease was calculated considering both direct cost and opportunity cost. The prices used in this calculation were $450 per metric ton of feed, $ 2.11 per kg of foodfish, marketed, adjusted or died. Fingerlings' price was $7.11 per kg.

Results

Disease Cost Columnaris

Ponds negative for columnaris were compared to ponds positive for columnaris. There was a difference in means for production parameters feed, harvest, stocking, farm inventory adjustments and mortality. Compared to negative ponds, ponds positive for columnaris disease were fed more feed, had a reduced harvest, had increased stocking, required more farm inventory adjustments and had increased mortality. All parameters were compared on a per hectare basis. To put that in perspective the cost of the disease was calculated considering both direct cost (actual money spent) and indirect cost (potential income that is not realized) (Table 6.1).

Table 6.1 Direct and Indirect Costs for Ponds with Mortality Events caused by Columnaris Disease

Parameter	Per ha	Unit	Price	Direct Cost $/ha	Opportunity Cost $/ha	Total Cost $/ha
More feed/ha	4393	Kg	$0.45	$1,976.85		$1,976.85
Reduced harvest/ha	-48	Kg	$2.11		$101.28	$101.28
Increased stocking/ha	626	Kg	$7.15	$4,475.90		$4,475.9
Increased adjustments	249	Kg	$2.11		$525.39	$525.39
Increased mortality/ha	480	Kg	$2.11		$1,012.80	$1,012.80
Total Cost $/ha				$6,452.75	$1,639.47	$8,092.22

For ponds with mortality events associated with columnaris disease when considering increased feed and fingerling stocking the direct cost was $6,452.75. Opportunity costs due to reduced harvest and increased adjustments and mortality were calculated at $1,639.47 for a total cost of $8,092.22 per hectare or about $3,274.81 per acre.

ESC Disease Cost

Ponds positive for ESC were compared to ponds negative for ESC. There was a difference in means for production parameters feed, harvest, stocking, farm inventory adjustments and mortality. Compared to negative ponds, ponds positive for ESC were fed more feed, had a reduced harvest, had reduced stocking, required more farm inventory adjustments and had increased mortality. All parameters were compared on a per hectare basis.

The cost of the disease was calculated considering both direct cost and indirect cost (Table 6.2).

Table 6.2 Direct and Indirect Costs for Ponds with Mortality Events caused by ESC

Parameter	per ha	Unit	Price	Direct Cost $/ha	Opportunity Cost $/ha	Total Cost $/ha
More feed/ha	4450	Kg	$0.45	$2,002.50		$2,002.5
Reduced	630	Kg	$2.11		$1,329.30	$1,329.30
Reduced	-304	Kg	$7.15	$(2,173.60)		$(2,173.60)
Increased	303	Kg	$2.11		$639.33	$639.33
Increased	795	kg	$2.11		$1,677.45	$1,677.45
Total Cost $/ha				$(171.10)	$3,646.08	$3,474.98

For ponds with mortality events associated with ESC when considering increased feed and reduced fingerling stocking the direct cost was a negative $ 171.10. The negative value was due to reduced stocking cost outweighing the cost of additional feed. Opportunity costs due to reduced harvest and increased adjustments and mortality were calculated at $ 3,646.08 or a total cost of $3,474.98 per hectare or about $1,406.28 per acre (Table 6.2).

Columnaris and ESC Disease Cost

Some ponds had mortality events associated with columnaris and/or ESC over the 4 year study period. An observation was defined as a pond with a positive mortality event due to either columnaris or ESC as defined by the farm management. Ponds without a history of mortality events associated with columnaris or ESC were selected as negative ponds and served as controls. A negative pond was defined as a pond that did not have a mortality event 60 days prior and 60 days post the mortality event date being analyzed.

The difference in means for production parameters included feed, harvest, stocking, farm inventory adjustments and mortality. Compared to negative ponds, ponds positive for columnaris and/or ESC were feed more feed, had a reduced harvest, had increased stocking, required more farm inventory adjustments and had increased mortality. All parameters were compared on a per hectare basis.

The costs of the diseases were calculated considering both direct and indirect costs. When these ponds were considered they had increased feed and fingerling stocking the direct cost was $6,035.10. Indirect costs due to reduced harvest and increased adjustments and mortality were calculated at $ 3,186.10 or a total cost of $9,221.20 per hectare or about $3,731.69 per acre (Table 6.3).

Table 6.3 Direct and Indirect Costs for Ponds with Mortality Events caused by either columnaris disease or ESC

Parameter	Per ha	Units	Price	Direct Cost $/ha	Opportunity Cost $/ha	Total Cost
More feed/ha	4500	Kg	$0.45	$2,002.50		$2,002.5
Reduced harvest/ha	-304	Kg	$2.11		$641.44	$641.44
Increased stocking/ha	564	Kg	$7.15	$4,032.60		$4,032.6
Increased	347	Kg	$2.11		$732.17	$732.17
Increased	859	Kg	$2.11		$1,812.49	$1,812.4
Total Cost per ha				$6,035.10	$3,186.10	$9,221.2

Columnaris and ESC Disease Cost

Influence of Pond Age

Feed cost represent approximately 60% of variable operating costs in commercial catfish production (Robinson and Li, personal communication). The pounds of feed per pound of gain, known as Feed Conversion ratio (FCR) is a key component in determining the cost of production or profitability of a Catfish farm. Catfish can potentially have FCR of 1.8 or less in research ponds (Robinson and Li, In Press). Industry wide the FCR are much higher and can be influenced by multiple factors, including disease, fish size, genetics, and pond environment including water quality. One factor that has a dramatic influence on FCR is pond age. For analysis of FCR, the ponds were grouped by 1 to 3 years, 4 to 6 years and 7 to 9 years. A feed cost of $400/ton and production rate of 4,500 fish per acre was used to calculate relative cost differentials (Table 6.4).

Table 6.4 Influence of Pond Age on Feed conversion/Costs

Feed = $400 per ton

N	FCR	Pond Age	Per Fish	Per Hectare	Per 8 hectare pond
13	2.58	1 to 3 yrs	$ 0.77	$ 1,393	$ 27,864
13	2.78	4 to 6 yrs	$ 0.83	$ 1,512	$ 30,240
4	3.38	7 to 9 yrs	$ 1.02	$ 1,836	$ 36,720
Additional Cost 4-6 years			$ 0.06	$ 119	$ 2,376
Additional Cost 7-9 years			$ 0.24	$ 443	$ 8,856

Ponds that had been rebuilt or were newly constructed and were 3 years old or less had a FCR of 2.58. FCR for ponds 4 to 6 years old increased by 0.20 when compared to ponds 3 years or less. The oldest ponds had a FCR of 3.38 or 0.60 more pounds of feed per pound of gain, greater than 4 to 6 years old and 0.80 greater than ponds 3 years or less. Older ponds increased the cost to produce a 1.5 lb. fish by $0.06 and $0.24 for ponds 4 to 6 years and 7 to 9 years respectively, when compared to the youngest ponds. Compared on a per hectare or a per 8 hectare pond basis the feed cost differential for 4 to 6 year old ponds increased by $119 per hectare and $2,376 per 8 hectare pond. Ponds 7 to

9 years old increase feed cost by $ 443 per hectare or $ 8,856 per 8 hectare pond when compared to 1 to 3 year old ponds. Table 6.5 demonstrates this variation based on feeding one fish at various feed costs and feed conversion ratios.

Feed Conversion and Feed Cost Interaction

Table 6.5 Influence of Feed Conversion and Feed Cost on Feed Costs/Fish at various feed costs and feed conversion ratios

Fish Market Weight 1.5 lbs

Feed Cost per ton

FCR	$ 350	$ 360	$ 370	$ 380	$ 390	$ 400	$ 410	$ 420	$ 430	$ 440	$ 450
2.20	$ 0.58	$ 0.59	$ 0.61	$ 0.63	$ 0.64	$ 0.66	$ 0.68	$ 0.69	$ 0.71	$ 0.73	$ 0.74
2.25	$ 0.59	$ 0.61	$ 0.62	$ 0.64	$ 0.66	$ 0.68	$ 0.69	$ 0.71	$ 0.73	$ 0.74	$ 0.76
2.30	$ 0.60	$ 0.62	$ 0.64	$ 0.66	$ 0.67	$ 0.69	$ 0.71	$ 0.72	$ 0.74	$ 0.76	$ 0.78
2.35	$ 0.62	$ 0.63	$ 0.65	$ 0.67	$ 0.69	$ 0.71	$ 0.72	$ 0.74	$ 0.76	$ 0.78	$ 0.79
2.40	$ 0.63	$ 0.65	$ 0.67	$ 0.68	$ 0.70	$ 0.72	$ 0.74	$ 0.76	$ 0.77	$ 0.79	$ 0.81
2.45	$ 0.64	$ 0.66	$ 0.68	$ 0.70	$ 0.72	$ 0.74	$ 0.75	$ 0.77	$ 0.79	$ 0.81	$ 0.83
2.50	$ 0.66	$ 0.68	$ 0.69	$ 0.71	$ 0.73	$ 0.75	$ 0.77	$ 0.79	$ 0.81	$ 0.83	$ 0.84
2.55	$ 0.67	$ 0.69	$ 0.71	$ 0.73	$ 0.75	$ 0.77	$ 0.78	$ 0.80	$ 0.82	$ 0.84	$ 0.86
2.60	$ 0.68	$ 0.70	$ 0.72	$ 0.74	$ 0.76	$ 0.78	$ 0.80	$ 0.82	$ 0.84	$ 0.86	$ 0.88
2.65	$ 0.70	$ 0.72	$ 0.74	$ 0.76	$ 0.78	$ 0.80	$ 0.81	$ 0.83	$ 0.85	$ 0.87	$ 0.89
2.70	$ 0.71	$ 0.73	$ 0.75	$ 0.77	$ 0.79	$ 0.81	$ 0.83	$ 0.85	$ 0.87	$ 0.89	$ 0.91
2.75	$ 0.72	$ 0.74	$ 0.76	$ 0.78	$ 0.80	$ 0.83	$ 0.85	$ 0.87	$ 0.89	$ 0.91	$ 0.93
2.80	$ 0.74	$ 0.76	$ 0.78	$ 0.80	$ 0.82	$ 0.84	$ 0.86	$ 0.88	$ 0.90	$ 0.92	$ 0.95
2.85	$ 0.75	$ 0.77	$ 0.79	$ 0.81	$ 0.83	$ 0.85	$ 0.88	$ 0.90	$ 0.92	$ 0.94	$ 0.96
2.90	$ 0.76	$ 0.78	$ 0.80	$ 0.83	$ 0.85	$ 0.87	$ 0.89	$ 0.91	$ 0.94	$ 0.96	$ 0.98
2.95	$ 0.77	$ 0.80	$ 0.82	$ 0.84	$ 0.86	$ 0.88	$ 0.91	$ 0.93	$ 0.95	$ 0.97	$ 1.00
3.00	$ 0.79	$ 0.81	$ 0.83	$ 0.85	$ 0.88	$ 0.90	$ 0.92	$ 0.94	$ 0.97	$ 0.99	$ 1.01
3.05	$ 0.80	$ 0.82	$ 0.85	$ 0.87	$ 0.89	$ 0.91	$ 0.94	$ 0.96	$ 0.98	$ 1.01	$ 1.03
3.10	$ 0.81	$ 0.84	$ 0.86	$ 0.88	$ 0.91	$ 0.93	$ 0.95	$ 0.98	$ 1.00	$ 1.02	$ 1.05
3.15	$ 0.83	$ 0.85	$ 0.87	$ 0.90	$ 0.92	$ 0.94	$ 0.97	$ 0.99	$ 1.02	$ 1.04	$ 1.06
3.20	$ 0.84	$ 0.86	$ 0.89	$ 0.91	$ 0.94	$ 0.96	$ 0.98	$ 1.01	$ 1.03	$ 1.06	$ 1.08
3.25	$ 0.85	$ 0.88	$ 0.90	$ 0.93	$ 0.95	$ 0.97	$ 1.00	$ 1.02	$ 1.05	$ 1.07	$ 1.10
3.30	$ 0.87	$ 0.89	$ 0.92	$ 0.94	$ 0.97	$ 0.99	$ 1.01	$ 1.04	$ 1.06	$ 1.09	$ 1.11
3.35	$ 0.88	$ 0.90	$ 0.93	$ 0.95	$ 0.98	$ 1.01	$ 1.03	$ 1.06	$ 1.08	$ 1.11	$ 1.13
3.40	$ 0.89	$ 0.92	$ 0.94	$ 0.97	$ 0.99	$ 1.02	$ 1.05	$ 1.07	$ 1.10	$ 1.12	$ 1.15

The influence of FCR and feed cost per fish when compared to a base production are examined in Table 6.6. The base chosen for this calculation was FCR of 2.80 and a feed cost of $400 per ton. The positive numbers in the table represent reduced cost when compared to base production. The negative numbers represent the additional cost to feed the fish when compared to the base production. The results range from a savings of $0.26 to an additional $0.31 in feed cost per 1.5 lb. fish. It is interesting to note that for each 0.05 improvement in FCR, the cost to feed a 1.5 lb. fish is reduced by one or two cents. It takes a $10 per ton decrease in feed price to realize the same savings.

Table 6.6 Influence of Feed Conversion and Feed Cost on Feed Cost/fish compared to Base Production

Base Production (Positive numbers are reduced feed cost per fish when compared to base, Negative numbers are additional feed costs)

Fish Weight	1.5 lbs
Base Feed Cost	400.0
Base Feed Conversion	2.8
Base cost of feed per fish	$ 0.84

Feed Cost per ton

FCR	$ 350	$ 360	$ 370	$ 380	$ 390	$ 400	$ 410	$ 420	$ 430	$ 440	$ 450
2.20	$ 0.26	$ 0.25	$ 0.23	$ 0.21	$ 0.20	$ 0.18	$ 0.16	$ 0.15	$ 0.13	$ 0.11	$ 0.10
2.25	$ 0.25	$ 0.23	$ 0.22	$ 0.20	$ 0.18	$ 0.16	$ 0.15	$ 0.13	$ 0.11	$ 0.10	$ 0.08
2.30	$ 0.24	$ 0.22	$ 0.20	$ 0.18	$ 0.17	$ 0.15	$ 0.13	$ 0.12	$ 0.10	$ 0.08	$ 0.06
2.35	$ 0.22	$ 0.21	$ 0.19	$ 0.17	$ 0.15	$ 0.14	$ 0.12	$ 0.10	$ 0.08	$ 0.06	$ 0.05
2.40	$ 0.21	$ 0.19	$ 0.17	$ 0.16	$ 0.14	$ 0.12	$ 0.10	$ 0.08	$ 0.07	$ 0.05	$ 0.03
2.45	$ 0.20	$ 0.18	$ 0.16	$ 0.14	$ 0.12	$ 0.11	$ 0.09	$ 0.07	$ 0.05	$ 0.03	$ 0.01
2.50	$ 0.18	$ 0.17	$ 0.15	$ 0.13	$ 0.11	$ 0.09	$ 0.07	$ 0.05	$ 0.03	$ 0.01	$ (0.00)
2.55	$ 0.17	$ 0.15	$ 0.13	$ 0.11	$ 0.09	$ 0.07	$ 0.06	$ 0.04	$ 0.02	$ (0.00)	$ (0.02)
2.60	$ 0.16	$ 0.14	$ 0.12	$ 0.10	$ 0.08	$ 0.06	$ 0.04	$ 0.02	$ 0.00	$ (0.02)	$ (0.04)
2.65	$ 0.14	$ 0.12	$ 0.10	$ 0.08	$ 0.06	$ 0.04	$ 0.03	$ 0.01	$ (0.01)	$ (0.03)	$ (0.05)
2.70	$ 0.13	$ 0.11	$ 0.09	$ 0.07	$ 0.05	$ 0.03	$ 0.01	$ (0.01)	$ (0.03)	$ (0.05)	$ (0.07)
2.75	$ 0.12	$ 0.10	$ 0.08	$ 0.06	$ 0.04	$ 0.02	$ (0.01)	$ (0.03)	$ (0.05)	$ (0.07)	$ (0.09)
2.80	$ 0.11	$ 0.08	$ 0.06	$ 0.04	$ 0.02	$ -	$ (0.02)	$ (0.04)	$ (0.06)	$ (0.08)	$ (0.11)
2.85	$ 0.09	$ 0.07	$ 0.05	$ 0.03	$ 0.01	$ (0.01)	$ (0.04)	$ (0.06)	$ (0.08)	$ (0.10)	$ (0.12)
2.90	$ 0.08	$ 0.06	$ 0.04	$ 0.01	$ (0.01)	$ (0.03)	$ (0.05)	$ (0.07)	$ (0.10)	$ (0.12)	$ (0.14)
2.95	$ 0.07	$ 0.04	$ 0.02	$ (0.00)	$ (0.02)	$ (0.04)	$ (0.07)	$ (0.09)	$ (0.11)	$ (0.13)	$ (0.16)
3.00	$ 0.05	$ 0.03	$ 0.01	$ (0.01)	$ (0.04)	$ (0.06)	$ (0.08)	$ (0.11)	$ (0.13)	$ (0.15)	$ (0.17)
3.05	$ 0.04	$ 0.02	$ (0.01)	$ (0.03)	$ (0.05)	$ (0.07)	$ (0.10)	$ (0.12)	$ (0.14)	$ (0.17)	$ (0.19)
3.10	$ 0.03	$ 0.00	$ (0.02)	$ (0.04)	$ (0.07)	$ (0.09)	$ (0.11)	$ (0.14)	$ (0.16)	$ (0.18)	$ (0.21)
3.15	$ 0.01	$ (0.01)	$ (0.03)	$ (0.06)	$ (0.08)	$ (0.11)	$ (0.13)	$ (0.15)	$ (0.18)	$ (0.20)	$ (0.22)
3.20	$ 0.00	$ (0.02)	$ (0.05)	$ (0.07)	$ (0.10)	$ (0.12)	$ (0.14)	$ (0.17)	$ (0.19)	$ (0.22)	$ (0.24)
3.25	$ (0.01)	$ (0.04)	$ (0.06)	$ (0.09)	$ (0.11)	$ (0.13)	$ (0.16)	$ (0.18)	$ (0.21)	$ (0.23)	$ (0.26)
3.30	$ (0.03)	$ (0.05)	$ (0.08)	$ (0.10)	$ (0.13)	$ (0.15)	$ (0.17)	$ (0.20)	$ (0.22)	$ (0.25)	$ (0.27)
3.35	$ (0.04)	$ (0.06)	$ (0.09)	$ (0.11)	$ (0.14)	$ (0.17)	$ (0.19)	$ (0.22)	$ (0.24)	$ (0.27)	$ (0.29)
3.40	$ (0.05)	$ (0.08)	$ (0.10)	$ (0.13)	$ (0.15)	$ (0.18)	$ (0.21)	$ (0.23)	$ (0.26)	$ (0.28)	$ (0.31)

The influence of Feed Conversion and feed cost were calculated at feed conversions ranging from 2.20 to 3.40 and feed cost from $350 to $450 per ton to examine how they affect the cost to feed one acre of fish (4,500 1.5 lb. fish) (Table 6.7). The cost differential between the best (2.2 FCR, $350/ton) and worse (3.4 FCR, $450/ton) is $2,565 per acre, $0.57 per pound or $0.86 per fish. When considering a feed cost per ton, an increase of $30 feed cost per ton ($430 vs. $400) increase feed cost per fish by $0.06. It would take an increase of 0.20 in FCR to equal the same costs.

Table 6.7 Influence of Feed Conversion and Feed Cost/ton on Feed Costs/acre at various production levels

Pounds of fish marketed per acre **4,500**
Average weight of fish marketed **1.5 lbs**

					Feed Cost per ton					
FCR	$ 350	$ 360	$ 370	$ 380	$ 390	$ 400	$ 410	$ 420	$ 430	$ 440	$ 450
2.20	$ 2,598.75	$ 2,673.00	$ 2,747.25	$ 2,821.50	$ 2,895.75	$ 2,970.00	$ 3,044.25	$ 3,118.50	$ 3,192.75	$ 3,267.00	$ 3,341.25
2.25	$ 2,657.81	$ 2,733.75	$ 2,809.69	$ 2,885.63	$ 2,961.56	$ 3,037.50	$ 3,113.44	$ 3,189.38	$ 3,265.31	$ 3,341.25	$ 3,417.19
2.30	$ 2,716.88	$ 2,794.50	$ 2,872.13	$ 2,949.75	$ 3,027.38	$ 3,105.00	$ 3,182.63	$ 3,260.25	$ 3,337.88	$ 3,415.50	$ 3,493.13
2.35	$ 2,775.94	$ 2,855.25	$ 2,934.56	$ 3,013.88	$ 3,093.19	$ 3,172.50	$ 3,251.81	$ 3,331.13	$ 3,410.44	$ 3,489.75	$ 3,569.06
2.40	$ 2,835.00	$ 2,916.00	$ 2,997.00	$ 3,078.00	$ 3,159.00	$ 3,240.00	$ 3,321.00	$ 3,402.00	$ 3,483.00	$ 3,564.00	$ 3,645.00
2.45	$ 2,894.06	$ 2,976.75	$ 3,059.44	$ 3,142.13	$ 3,224.81	$ 3,307.50	$ 3,390.19	$ 3,472.88	$ 3,555.56	$ 3,638.25	$ 3,720.94
2.50	$ 2,953.13	$ 3,037.50	$ 3,121.88	$ 3,206.25	$ 3,290.63	$ 3,375.00	$ 3,459.38	$ 3,543.75	$ 3,628.13	$ 3,712.50	$ 3,796.88
2.55	$ 3,012.19	$ 3,098.25	$ 3,184.31	$ 3,270.38	$ 3,356.44	$ 3,442.50	$ 3,528.56	$ 3,614.63	$ 3,700.69	$ 3,786.75	$ 3,872.81
2.60	$ 3,071.25	$ 3,159.00	$ 3,246.75	$ 3,334.50	$ 3,422.25	$ 3,510.00	$ 3,597.75	$ 3,685.50	$ 3,773.25	$ 3,861.00	$ 3,948.75
2.65	$ 3,130.31	$ 3,219.75	$ 3,309.19	$ 3,398.63	$ 3,488.06	$ 3,577.50	$ 3,666.94	$ 3,756.38	$ 3,845.81	$ 3,935.25	$ 4,024.69
2.70	$ 3,189.38	$ 3,280.50	$ 3,371.63	$ 3,462.75	$ 3,553.88	$ 3,645.00	$ 3,736.13	$ 3,827.25	$ 3,918.38	$ 4,009.50	$ 4,100.63
2.75	$ 3,248.44	$ 3,341.25	$ 3,434.06	$ 3,526.88	$ 3,619.69	$ 3,712.50	$ 3,805.31	$ 3,898.13	$ 3,990.94	$ 4,083.75	$ 4,176.56
2.80	$ 3,307.50	$ 3,402.00	$ 3,496.50	$ 3,591.00	$ 3,685.50	$ 3,780.00	$ 3,874.50	$ 3,969.00	$ 4,063.50	$ 4,158.00	$ 4,252.50
2.85	$ 3,366.56	$ 3,462.75	$ 3,558.94	$ 3,655.13	$ 3,751.31	$ 3,847.50	$ 3,943.69	$ 4,039.88	$ 4,136.06	$ 4,232.25	$ 4,328.44
2.90	$ 3,425.63	$ 3,523.50	$ 3,621.38	$ 3,719.25	$ 3,817.13	$ 3,915.00	$ 4,012.88	$ 4,110.75	$ 4,208.63	$ 4,306.50	$ 4,404.38
2.95	$ 3,484.69	$ 3,584.25	$ 3,683.81	$ 3,783.38	$ 3,882.94	$ 3,982.50	$ 4,082.06	$ 4,181.63	$ 4,281.19	$ 4,380.75	$ 4,480.31
3.00	$ 3,543.75	$ 3,645.00	$ 3,746.25	$ 3,847.50	$ 3,948.75	$ 4,050.00	$ 4,151.25	$ 4,252.50	$ 4,353.75	$ 4,455.00	$ 4,556.25
3.05	$ 3,602.81	$ 3,705.75	$ 3,808.69	$ 3,911.63	$ 4,014.56	$ 4,117.50	$ 4,220.44	$ 4,323.38	$ 4,426.31	$ 4,529.25	$ 4,632.19
3.10	$ 3,661.88	$ 3,766.50	$ 3,871.13	$ 3,975.75	$ 4,080.38	$ 4,185.00	$ 4,289.63	$ 4,394.25	$ 4,498.88	$ 4,603.50	$ 4,708.13
3.15	$ 3,720.94	$ 3,827.25	$ 3,933.56	$ 4,039.88	$ 4,146.19	$ 4,252.50	$ 4,358.81	$ 4,465.13	$ 4,571.44	$ 4,677.75	$ 4,784.06
3.20	$ 3,780.00	$ 3,888.00	$ 3,996.00	$ 4,104.00	$ 4,212.00	$ 4,320.00	$ 4,428.00	$ 4,536.00	$ 4,644.00	$ 4,752.00	$ 4,860.00
3.25	$ 3,839.06	$ 3,948.75	$ 4,058.44	$ 4,168.13	$ 4,277.81	$ 4,387.50	$ 4,497.19	$ 4,606.87	$ 4,716.56	$ 4,826.25	$ 4,935.94
3.30	$ 3,898.13	$ 4,009.50	$ 4,120.88	$ 4,232.25	$ 4,343.63	$ 4,455.00	$ 4,566.38	$ 4,677.75	$ 4,789.13	$ 4,900.50	$ 5,011.88
3.35	$ 3,957.19	$ 4,070.25	$ 4,183.31	$ 4,296.38	$ 4,409.44	$ 4,522.50	$ 4,635.56	$ 4,748.63	$ 4,861.69	$ 4,974.75	$ 5,087.81
3.40	$ 4,016.25	$ 4,131.00	$ 4,245.75	$ 4,360.50	$ 4,475.25	$ 4,590.00	$ 4,704.75	$ 4,819.50	$ 4,934.25	$ 5,049.00	$ 5,163.75

The influence of FCR and feed cost on a per acre basis when compared to a base production is presented in Table 6.8. The base chosen for this calculation was FCR of 2.80 and a feed cost of $400 per ton. The positive numbers in the table represent reduced cost when compared to base production. The negative numbers represent the additional cost to feed the fish on a per acre basis when compared to the base production. The results range from a savings of $1,181.25 to an additional $1,383.75 in feed cost per acre. It is interesting to note that for each 0.05 improvement in FCR the feed cost per acre decrease by $59.06. An improvement of $74.25 per acre in feed cost can be realized by a $10 per ton decrease in feed price.

Table 6.8 Influence of Feed Conversion and Feed Cost on Feed Cost/acre compared to Base Production

Base Production (Positive numbers are reduced feed cost per acre when compared to base, Negative numbers are additional feed costs)
Base production per surface acre of pond
Feed Conversion 2.8
Feed Cost per ton $ 400

					Feed Cost per ton					
FCR	$ 350	$ 360	$ 370	$ 380	$ 390	$ 400	$ 410	$ 420	$ 430	$ 440	$ 450
2.20	$ 1,181.25	$ 1,107.00	$ 1,032.75	$ 958.50	$ 884.25	$ 810.00	$ 735.75	$ 661.50	$ 587.25	$ 513.00	$ 438.75
2.25	$ 1,122.19	$ 1,046.25	$ 970.31	$ 894.37	$ 818.44	$ 742.50	$ 666.56	$ 590.62	$ 514.69	$ 438.75	$ 362.81
2.30	$ 1,063.13	$ 985.50	$ 907.87	$ 830.25	$ 752.62	$ 675.00	$ 597.37	$ 519.75	$ 442.12	$ 364.50	$ 286.87
2.35	$ 1,004.06	$ 924.75	$ 845.44	$ 766.12	$ 686.81	$ 607.50	$ 528.19	$ 448.87	$ 369.56	$ 290.25	$ 210.94
2.40	$ 945.00	$ 864.00	$ 783.00	$ 702.00	$ 621.00	$ 540.00	$ 459.00	$ 378.00	$ 297.00	$ 216.00	$ 135.00
2.45	$ 885.94	$ 803.25	$ 720.56	$ 637.87	$ 555.19	$ 472.50	$ 389.81	$ 307.12	$ 224.44	$ 141.75	$ 59.06
2.50	$ 826.88	$ 742.50	$ 658.13	$ 573.75	$ 489.38	$ 405.00	$ 320.63	$ 236.25	$ 151.88	$ 67.50	$ (16.88)
2.55	$ 767.81	$ 681.75	$ 595.69	$ 509.63	$ 423.56	$ 337.50	$ 251.44	$ 165.38	$ 79.31	$ (6.75)	$ (92.81)
2.60	$ 708.75	$ 621.00	$ 533.25	$ 445.50	$ 357.75	$ 270.00	$ 182.25	$ 94.50	$ 6.75	$ (81.00)	$ (168.75)
2.65	$ 649.69	$ 560.25	$ 470.81	$ 381.38	$ 291.94	$ 202.50	$ 113.06	$ 23.63	$ (65.81)	$ (155.25)	$ (244.69)
2.70	$ 590.63	$ 499.50	$ 408.38	$ 317.25	$ 226.13	$ 135.00	$ 43.88	$ (47.25)	$ (138.37)	$ (229.50)	$ (320.62)
2.75	$ 531.56	$ 438.75	$ 345.94	$ 253.13	$ 160.31	$ 67.50	$ (25.31)	$ (118.13)	$ (210.94)	$ (303.75)	$ (396.56)
2.80	$ 472.50	$ 378.00	$ 283.50	$ 189.00	$ 94.50	$ -	$ (94.50)	$ (189.00)	$ (283.50)	$ (378.00)	$ (472.50)
2.85	$ 413.44	$ 317.25	$ 221.06	$ 124.88	$ 28.69	$ (67.50)	$ (163.69)	$ (259.87)	$ (356.06)	$ (452.25)	$ (548.44)
2.90	$ 354.38	$ 256.50	$ 158.63	$ 60.75	$ (37.12)	$ (135.00)	$ (232.87)	$ (330.75)	$ (428.62)	$ (526.50)	$ (624.37)
2.95	$ 295.31	$ 195.75	$ 96.19	$ (3.37)	$ (102.94)	$ (202.50)	$ (302.06)	$ (401.62)	$ (501.19)	$ (600.75)	$ (700.31)
3.00	$ 236.25	$ 135.00	$ 33.75	$ (67.50)	$ (168.75)	$ (270.00)	$ (371.25)	$ (472.50)	$ (573.75)	$ (675.00)	$ (776.25)
3.05	$ 177.19	$ 74.25	$ (28.69)	$ (131.62)	$ (234.56)	$ (337.50)	$ (440.44)	$ (543.37)	$ (646.31)	$ (749.25)	$ (852.19)
3.10	$ 118.13	$ 13.50	$ (91.12)	$ (195.75)	$ (300.37)	$ (405.00)	$ (509.62)	$ (614.25)	$ (718.87)	$ (823.50)	$ (928.12)
3.15	$ 59.06	$ (47.25)	$ (153.56)	$ (259.87)	$ (366.19)	$ (472.50)	$ (578.81)	$ (685.12)	$ (791.44)	$ (897.75)	$ (1,004.06)
3.20	$ -	$ (108.00)	$ (216.00)	$ (324.00)	$ (432.00)	$ (540.00)	$ (648.00)	$ (756.00)	$ (864.00)	$ (972.00)	$ (1,080.00)
3.25	$ (59.06)	$ (168.75)	$ (278.44)	$ (388.12)	$ (497.81)	$ (607.50)	$ (717.19)	$ (826.87)	$ (936.56)	$ (1,046.25)	$ (1,155.94)
3.30	$ (118.13)	$ (229.50)	$ (340.88)	$ (452.25)	$ (563.63)	$ (675.00)	$ (786.38)	$ (897.75)	$ (1,009.13)	$ (1,120.50)	$ (1,231.88)
3.35	$ (177.19)	$ (290.25)	$ (403.31)	$ (516.38)	$ (629.44)	$ (742.50)	$ (855.56)	$ (968.63)	$ (1,081.69)	$ (1,194.75)	$ (1,307.81)
3.40	$ (236.25)	$ (351.00)	$ (465.75)	$ (580.50)	$ (695.25)	$ (810.00)	$ (924.75)	$ (1,039.50)	$ (1,154.25)	$ (1,269.00)	$ (1,383.75)

The influence of FCR and feed cost in a 20 acre pond were calculated at feed conversions ranging from 2.20 to 3.40 and feed cost from $350 to $450 per ton to examine how they affect the cost to feed a 1.5 lb. fish (Table 6.9). From best (2.2 FCR, $350/ton feed) to worst (3.4 FCR, $450/ton feed) the cost can increase by $51,300 per pond or $0.57 per fish.

Table 6.9 Influence of Feed Conversion and Feed Cost on Feed Cost/20 acre pond at various production levels

Base Production

Pounds of fish marketed per acre	4,500
Average weight of fish marketed	1.5 lbs
Pond size acres	20

	Feed Cost per ton										
Feed conv	$ 350	$ 360	$ 370	$ 380	$ 390	$ 400	$ 410	$ 420	$ 430	$ 440	$ 450
2.20	$ 51,975.00	$ 53,460.00	$ 54,945.00	$ 56,430.00	$ 57,915.00	$ 59,400.00	$ 60,885.00	$ 62,370.00	$ 63,855.00	$ 65,340.00	$ 66,825.00
2.25	$ 53,156.25	$ 54,675.00	$ 56,193.75	$ 57,712.50	$ 59,231.25	$ 60,750.00	$ 62,268.75	$ 63,787.50	$ 65,306.25	$ 66,825.00	$ 68,343.75
2.30	$ 54,337.50	$ 55,890.00	$ 57,442.50	$ 58,995.00	$ 60,547.50	$ 62,100.00	$ 63,652.50	$ 65,205.00	$ 66,757.50	$ 68,310.00	$ 69,862.50
2.35	$ 55,518.75	$ 57,105.00	$ 58,691.25	$ 60,277.50	$ 61,863.75	$ 63,450.00	$ 65,036.25	$ 66,622.50	$ 68,208.75	$ 69,795.00	$ 71,381.25
2.40	$ 56,700.00	$ 58,320.00	$ 59,940.00	$ 61,560.00	$ 63,180.00	$ 64,800.00	$ 66,420.00	$ 68,040.00	$ 69,660.00	$ 71,280.00	$ 72,900.00
2.45	$ 57,881.25	$ 59,535.00	$ 61,188.75	$ 62,842.50	$ 64,496.25	$ 66,150.00	$ 67,803.75	$ 69,457.50	$ 71,111.25	$ 72,765.00	$ 74,418.75
2.50	$ 59,062.50	$ 60,750.00	$ 62,437.50	$ 64,125.00	$ 65,812.50	$ 67,500.00	$ 69,187.50	$ 70,875.00	$ 72,562.50	$ 74,250.00	$ 75,937.50
2.55	$ 60,243.75	$ 61,965.00	$ 63,686.25	$ 65,407.50	$ 67,128.75	$ 68,850.00	$ 70,571.25	$ 72,292.50	$ 74,013.75	$ 75,735.00	$ 77,456.25
2.60	$ 61,425.00	$ 63,180.00	$ 64,935.00	$ 66,690.00	$ 68,445.00	$ 70,200.00	$ 71,955.00	$ 73,710.00	$ 75,465.00	$ 77,220.00	$ 78,975.00
2.65	$ 62,606.25	$ 64,395.00	$ 66,183.75	$ 67,972.50	$ 69,761.25	$ 71,550.00	$ 73,338.75	$ 75,127.50	$ 76,916.25	$ 78,705.00	$ 80,493.75
2.70	$ 63,787.50	$ 65,610.00	$ 67,432.50	$ 69,255.00	$ 71,077.50	$ 72,900.00	$ 74,722.50	$ 76,545.00	$ 78,367.50	$ 80,190.00	$ 82,012.50
2.75	$ 64,968.75	$ 66,825.00	$ 68,681.25	$ 70,537.50	$ 72,393.75	$ 74,250.00	$ 76,106.25	$ 77,962.50	$ 79,818.75	$ 81,675.00	$ 83,531.25
2.80	$ 66,150.00	$ 68,040.00	$ 69,930.00	$ 71,820.00	$ 73,710.00	$ 75,600.00	$ 77,490.00	$ 79,380.00	$ 81,270.00	$ 83,160.00	$ 85,050.00
2.85	$ 67,331.25	$ 69,255.00	$ 71,178.75	$ 73,102.50	$ 75,026.25	$ 76,950.00	$ 78,873.75	$ 80,797.50	$ 82,721.25	$ 84,645.00	$ 86,568.75
2.90	$ 68,512.50	$ 70,470.00	$ 72,427.50	$ 74,385.00	$ 76,342.50	$ 78,300.00	$ 80,257.50	$ 82,215.00	$ 84,172.50	$ 86,130.00	$ 88,087.50
2.95	$ 69,693.75	$ 71,685.00	$ 73,676.25	$ 75,667.50	$ 77,658.75	$ 79,650.00	$ 81,641.25	$ 83,632.50	$ 85,623.75	$ 87,615.00	$ 89,606.25
3.00	$ 70,875.00	$ 72,900.00	$ 74,925.00	$ 76,950.00	$ 78,975.00	$ 81,000.00	$ 83,025.00	$ 85,050.00	$ 87,075.00	$ 89,100.00	$ 91,125.00
3.05	$ 72,056.25	$ 74,115.00	$ 76,173.75	$ 78,232.50	$ 80,291.25	$ 82,350.00	$ 84,408.75	$ 86,467.50	$ 88,526.25	$ 90,585.00	$ 92,643.75
3.10	$ 73,237.50	$ 75,330.00	$ 77,422.50	$ 79,515.00	$ 81,607.50	$ 83,700.00	$ 85,792.50	$ 87,885.00	$ 89,977.50	$ 92,070.00	$ 94,162.50
3.15	$ 74,418.75	$ 76,545.00	$ 78,671.25	$ 80,797.50	$ 82,923.75	$ 85,050.00	$ 87,176.25	$ 89,302.50	$ 91,428.75	$ 93,555.00	$ 95,681.25
3.20	$ 75,600.00	$ 77,760.00	$ 79,920.00	$ 82,080.00	$ 84,240.00	$ 86,400.00	$ 88,560.00	$ 90,720.00	$ 92,880.00	$ 95,040.00	$ 97,200.00
3.25	$ 76,781.25	$ 78,975.00	$ 81,168.75	$ 83,362.50	$ 85,556.25	$ 87,750.00	$ 89,943.75	$ 92,137.50	$ 94,331.25	$ 96,525.00	$ 98,718.75
3.30	$ 77,962.50	$ 80,190.00	$ 82,417.50	$ 84,645.00	$ 86,872.50	$ 89,100.00	$ 91,327.50	$ 93,555.00	$ 95,782.50	$ 98,010.00	$100,237.50
3.35	$ 79,143.75	$ 81,405.00	$ 83,666.25	$ 85,927.50	$ 88,188.75	$ 90,450.00	$ 92,711.25	$ 94,972.50	$ 97,233.75	$ 99,495.00	$101,756.25
3.40	$ 80,325.00	$ 82,620.00	$ 84,915.00	$ 87,210.00	$ 89,505.00	$ 91,800.00	$ 94,095.00	$ 96,390.00	$ 98,685.00	$100,980.00	$103,275.00

The relative influence of FCR and feed cost per 20 acre pond basis when compared to a base production was examined (Table 6.10). The base chosen for this calculation was FCR of 2.80 and a feed cost of $400 per ton. When compared to the base production the additional costs (negative numbers) or cost savings (positive numbers) on a 20 acre pond are calculated (Table 6.10). It is interesting to note that either increasing feed cost per ton or increasing FCR ratio can be offset by each other. For example with a 2.8 FCR a $30 per ton increase in feed cost on a 20 acre pond will increase cost by $5,670 but this can be offset by a 0.21 improvement in FCR which will decrease cost by $5,670 if feed cost is held constant at $400/ton.

Table 6.10 Influence of Feed Conversion and Feed Cost on Feed Cost/20 acre pond compared to Base Production

Base Production (Positive numbers are reduced feed cost/20 acre pond when compared to base, Negative numbers are additional feed costs)
Base production per 20 acre pond
Feed Conversion 2.8
Feed Cost per ton $ 400

	Feed Cost per ton										
Feed conv	$ 350	$ 360	$ 370	$ 380	$ 390	$ 400	$ 410	$ 420	$ 430	$ 440	$ 450
2.20	$ 23,625.00	$ 22,140.00	$ 20,655.00	$ 19,170.00	$ 17,685.00	$ 16,200.00	$ 14,715.00	$ 13,230.00	$ 11,745.00	$ 10,260.00	$ 8,775.00
2.25	$ 22,443.75	$ 20,925.00	$ 19,406.25	$ 17,887.50	$ 16,368.75	$ 14,850.00	$ 13,331.25	$ 11,812.50	$ 10,293.75	$ 8,775.00	$ 7,256.25
2.30	$ 21,262.50	$ 19,710.00	$ 18,157.50	$ 16,605.00	$ 15,052.50	$ 13,500.00	$ 11,947.50	$ 10,395.00	$ 8,842.50	$ 7,290.00	$ 5,737.50
2.35	$ 20,081.25	$ 18,495.00	$ 16,908.75	$ 15,322.50	$ 13,736.25	$ 12,150.00	$ 10,563.75	$ 8,977.50	$ 7,391.25	$ 5,805.00	$ 4,218.75
2.40	$ 18,900.00	$ 17,280.00	$ 15,660.00	$ 14,040.00	$ 12,420.00	$ 10,800.00	$ 9,180.00	$ 7,560.00	$ 5,940.00	$ 4,320.00	$ 2,700.00
2.45	$ 17,718.75	$ 16,065.00	$ 14,411.25	$ 12,757.50	$ 11,103.75	$ 9,450.00	$ 7,796.25	$ 6,142.50	$ 4,488.75	$ 2,835.00	$ 1,181.25
2.50	$ 16,537.50	$ 14,850.00	$ 13,162.50	$ 11,475.00	$ 9,787.50	$ 8,100.00	$ 6,412.50	$ 4,725.00	$ 3,037.50	$ 1,350.00	$ (337.50)
2.55	$ 15,356.25	$ 13,635.00	$ 11,913.75	$ 10,192.50	$ 8,471.25	$ 6,750.00	$ 5,028.75	$ 3,307.50	$ 1,586.25	$ (135.00)	$ (1,856.25)
2.60	$ 14,175.00	$ 12,420.00	$ 10,665.00	$ 8,910.00	$ 7,155.00	$ 5,400.00	$ 3,645.00	$ 1,890.00	$ 135.00	$ (1,620.00)	$ (3,375.00)
2.65	$ 12,993.75	$ 11,205.00	$ 9,416.25	$ 7,627.50	$ 5,838.75	$ 4,050.00	$ 2,261.25	$ 472.50	$ (1,316.25)	$ (3,105.00)	$ (4,893.75)
2.70	$ 11,812.50	$ 9,990.00	$ 8,167.50	$ 6,345.00	$ 4,522.50	$ 2,700.00	$ 877.50	$ (945.00)	$ (2,767.50)	$ (4,590.00)	$ (6,412.50)
2.75	$ 10,631.25	$ 8,775.00	$ 6,918.75	$ 5,062.50	$ 3,206.25	$ 1,350.00	$ (506.25)	$ (2,362.50)	$ (4,218.75)	$ (6,075.00)	$ (7,931.25)
2.80	$ 9,450.00	$ 7,560.00	$ 5,670.00	$ 3,780.00	$ 1,890.00	$ -	$ (1,890.00)	$ (3,780.00)	$ (5,670.00)	$ (7,560.00)	$ (9,450.00)
2.85	$ 8,268.75	$ 6,345.00	$ 4,421.25	$ 2,497.50	$ 573.75	$ (1,350.00)	$ (3,273.75)	$ (5,197.50)	$ (7,121.25)	$ (9,045.00)	$ (10,968.75)
2.90	$ 7,087.50	$ 5,130.00	$ 3,172.50	$ 1,215.00	$ (742.50)	$ (2,700.00)	$ (4,657.50)	$ (6,615.00)	$ (8,572.50)	$ (10,530.00)	$ (12,487.50)
2.95	$ 5,906.25	$ 3,915.00	$ 1,923.75	$ (67.50)	$ (2,058.75)	$ (4,050.00)	$ (6,041.25)	$ (8,032.50)	$ (10,023.75)	$ (12,015.00)	$ (14,006.25)
3.00	$ 4,725.00	$ 2,700.00	$ 675.00	$ (1,350.00)	$ (3,375.00)	$ (5,400.00)	$ (7,425.00)	$ (9,450.00)	$ (11,475.00)	$ (13,500.00)	$ (15,525.00)
3.05	$ 3,543.75	$ 1,485.00	$ (573.75)	$ (2,632.50)	$ (4,691.25)	$ (6,750.00)	$ (8,808.75)	$ (10,867.50)	$ (12,926.25)	$ (14,985.00)	$ (17,043.75)
3.10	$ 2,362.50	$ 270.00	$ (1,822.50)	$ (3,915.00)	$ (6,007.50)	$ (8,100.00)	$ (10,192.50)	$ (12,285.00)	$ (14,377.50)	$ (16,470.00)	$ (18,562.50)
3.15	$ 1,181.25	$ (945.00)	$ (3,071.25)	$ (5,197.50)	$ (7,323.75)	$ (9,450.00)	$ (11,576.25)	$ (13,702.50)	$ (15,828.75)	$ (17,955.00)	$ (20,081.25)
3.20	$ 0.00	$ (2,160.00)	$ (4,320.00)	$ (6,480.00)	$ (8,640.00)	$ (10,800.00)	$ (12,960.00)	$ (15,120.00)	$ (17,280.00)	$ (19,440.00)	$ (21,600.00)
3.25	$ (1,181.25)	$ (3,375.00)	$ (5,568.75)	$ (7,762.50)	$ (9,956.25)	$ (12,150.00)	$ (14,343.75)	$ (16,537.50)	$ (18,731.25)	$ (20,925.00)	$ (23,118.75)
3.30	$ (2,362.50)	$ (4,590.00)	$ (6,817.50)	$ (9,045.00)	$ (11,272.50)	$ (13,500.00)	$ (15,727.50)	$ (17,955.00)	$ (20,182.50)	$ (22,410.00)	$ (24,637.50)
3.35	$ (3,543.75)	$ (5,805.00)	$ (8,066.25)	$ (10,327.50)	$ (12,588.75)	$ (14,850.00)	$ (17,111.25)	$ (19,372.50)	$ (21,633.75)	$ (23,895.00)	$ (26,156.25)
3.40	$ (4,725.00)	$ (7,020.00)	$ (9,315.00)	$ (11,610.00)	$ (13,905.00)	$ (16,200.00)	$ (18,495.00)	$ (20,790.00)	$ (23,085.00)	$ (25,380.00)	$ (27,675.00)

Discussion

Infectious diseases cost producers many millions of dollars in direct fish losses each year. Infectious diseases also influence profitability by increasing treatment costs, reducing food consumption by fish, increasing feed conversion ratios and causing harvesting delays (Wagner*, et al.*, 2002). This is evident from the data presented above.

Disease influenced cost in several ways in this study. Ponds with mortality events associated with columnaris disease had increased feed, fingerling stocking, decreased harvest, increased adjustments and increased mortality. Ponds with mortality events associated with ESC had increased feed, reduced fingerling stocking, decreased harvest, increased adjustments and increased mortality.

Over 70% of the catfish farmers polled considered columnaris disease or mixed infections including columnaris as causing the greatest economic loss on catfish farms in the four leading catfish producing states (USDA/APHIS, 1997b).

Enteric septicemia of catfish reportedly costs the catfish aquaculture industry $50 to $60 million annually (Breazeale, 2007). Economic losses due to disease are difficult to assess accurately because they are usually underreported due to self-diagnosis by the producer and lack of record keeping. Economic losses attributable to disease on individual farms can be devastating (Hawke and Khoo, 2004). Depending on the disease, 60% to 100% of fish can be lost in an individual pond or even on a single farm during a disease outbreak (Plumb, 1999; Hawke and Khoo, 2004).

The calculated cost of disease in this study was greater for ponds with mortality events associated with columnaris or with ponds with mortality events associated with either columnaris or ESC or both than ponds with mortality events associated with ESC. This was due to decreased fingerling stocking observed in the ESC ponds. The savings associated with the reduced fingerling purchases ($2,173.60) offset the increased feed cost observed ($2002.50). It should be noted even with these savings ESC ponds still had an overall increased cost of $3,474.98.

Ponds that experienced mortality events associated with either columnaris, ESC or in some cases both over the study period had the largest cost $9,221.20 due to disease.

Bacterial diseases such as columnaris disease and ESC continue to rob catfish farmers of profits. Wagner,, *et al.* (2002) found that 78.1% of the farms surveyed and 42.1% of all ponds experienced ESC/columnaris problems. These costs when taken on an industry wide basis are staggering. There were 89,390 water acres in 2012 in the

United States. This equates to 36,175 hectares, 42% would equal 15,193 ha. affected with ESC/columnaris problems. Using the calculated cost of ponds that experienced mortality events associated with either columnaris, ESC or in some cases both over the study period of $9,221.20 this equates to a potential production loss of $140,097,692 for the catfish industry.

The influence of pond age on FCR was examined. Feed costs were substantially reduced in ponds that were three years old or less when compared to ponds that had been in production 4 to 9 years. Wagner, *et al.* (2002) observed that ponds that were drained every 3 years or less, substantially reduced the risk of those ponds experiencing losses due to columnaris or ESC. D'Abramo, *et al.* (2012) found that feed cost made up 51% of fingerling to stocker production and 68% of stocker to harvest production. Feed cost increased up to $0.24 per fish in the oldest ponds. This increased cost has a dramatic effect on the profitability of the farm.

The relationship between FCR and feed cost was examined. It is no surprise that when FCR is increased (higher) the cost to feed a fish is also increased. A farm should always strive to have the most efficient FCR possible. Modular production may improve FCR. D'Abramo*, et al.* (2012) had a FCR of 3.18 in the fry to stocker phase including one pond with a 5.19 FCR. The pond with the highest FCR had the lowest harvest weight, total number harvested, survival and production while being fed the largest amount of feed. Low survivability, in this case, 38.7%, will cause lower production and higher feed costs. Stocker to grow out phase in this study had a FCR that ranged from 2.25 to 2.65 (2.43±.349).

Tables 6.5-6.10 examine the relationship between FCR and feed cost. These tables are designed to give the catfish farmer a quick way to determine projected feed cost when preparing a budget for the farm or pond. Increased feed cost can be somewhat offset by improvements in FCR. Poor FCR can be somewhat offset by reduce feed costs.

The extremes in the tables are considered best and worst case scenarios. Most farms will fall somewhere on the tables. The tables calculate this relationship for a fish, one acre and 20 acre pond. Farmers can set base production and judge how much money can be saved or lost for a fish, one acre or 20 acre pond. The tables are most useful when a farm is determining cost of production and what changes should be made to become more efficient. A farm that realized a .25 FCR (2.95 to 2.70) improvement with a change to modular production would reduce cost to feed a 20 acre pond, if feed cost were held constant at $400 per ton, by $6,750.

The opportunities for catfish farmers to stay competitive are related to how well they control disease, FCR and feed cost.

CHAPTER VII

GENERAL CONCLUSIONS

The objectives of this study were to: 1) develop a catfish database for epidemiological studies, 2) determine pond level risk factors associated with columnaris disease and enteric septicemia of catfish related mortalities, 3) determine the economic cost of mortality on a per acre and per pond basis and 4) determine if production parameters reported by farm personnel can be used to predict the occurrence of disease events.

To accomplish these objectives a new management tool, the Catfish Management Database was constructed for Mississippi catfish farmers using a Microsoft Access platform. The Catfish Management Database was developed to incorporate the production data that was being kept by the producer. Health and disease information including mortalities were collected on a per pond basis. Diagnostic results from the Mississippi State University College of Veterinary Medicine Diagnostic Laboratory located in Stoneville Mississippi were coded to the farm and pond as available.

The Catfish Management Database contained the feeding records in terms of total pounds of feed fed and for each pond on a daily basis. Whenever a mortality event occurs the date, pond id, reason, pounds of fish dead and number of fish dead was recorded. Since water quality played such an important role in catfish production a separate database for Water Quality was constructed for the farm. Ponds were tested weekly during the growing season for nitrite, ammonia and if necessary, chloride levels. Additionally the database was designed to automatically report ponds that exceed a user defined nitrite to ammonia ratio. Other parameters that may be important risk factors in disease events are stocking events. The source of the stocking fish, date the stocking occurred, number of head stocked, size of the fish and weight of the fish stocked were recorded. Harvesting events were recorded including the date of the harvest, the pounds, size and number of fish harvested.

The catfish industry is similar to the swine industry with key economic drivers, growth rate and feed efficiency. Feed costs are the largest expense in catfish production. Catfish are fed daily as much as they will eat during warm months. Catfish are fed to maximize growth and minimize waste because overfeeding can have a negative effect on water quality. Monitoring feed intake is an important management tool. The Catfish Management Database was developed to allow the farm to manage not only feed but also other factors such as stocking, harvesting, and mortality. The Catfish Management database allowed the farm to generate user defined reports on each pond's efficiency and cost of production. While the Catfish Management Database is fully functional there is still a great deal of development that has to take place in order to make it more user friendly and commercially viable. Currently its' main usefulness is as a way to organize data for further analysis. It holds great promise as a management tool for catfish producers. Some obstacles facing the Catfish Management Database were the tendency for producers to change the function of ponds from fingerlings to food fish or brood fish. The database depended on a permanent ID for each pond. Some larger producers had multiple ponds with the same ID on different sites. None of these problems were insurmountable but they did make it difficult for the producer to use and further development is needed to circumvent these problems.

The database was used to study the association of risk factors and the occurrence of columnaris disease. This disease is caused by a gram negative bacterium, *Flavobacterium columnare* and is considered the second most prevalent bacterial disease in farm raised catfish.

Logistic regression was used to model the relationships between probability of columnaris in ponds and risk factors examined. Pond depth and reduced feed consumption for a 14 day period prior to disease outbreaks measured on a per hectare basis were significantly ($p \leq 0.05$) associated with columnaris disease when not considering water quality variables. Water quality variables were considered and pond depth, reduced feed consumption, shorter intervals from stocking to disease outbreaks and total ammonia nitrogen were significantly ($p \leq 0.05$) associated with columnaris occurrence. The model and methodology developed for this study may well be useful for the investigation of additional economically important catfish diseases. This study showed some commonly recorded production variables (feed consumption, pond depth, ammonia levels and stocking events) were associated with columnaris disease outbreaks and if monitored could help identify "at risk" ponds prior to disease outbreaks.

The objective of a second study was to identify risk factors reported by farm personnel, which were associated with ESC mortalities. Caused by a gram negative bacterium, *Edwardsiella ictaluri,* ESC is one of the most prevalent bacterial diseases in farm raised catfish. Logistic regression was used to model the relationships between probability of ESC in ponds and risk factors examined. Increased pond volume reduced the risk of a mortality event associated with ESC. The pond interval from harvest until a mortality event, the interval from stocking until a mortality event, nitrite measured within 14 days of a mortality, total ammonia measured within 14 days of a mortality, and the sum of feed fed for 14 days prior to the disease outbreak event were significantly ($P \leq 0.05$) associated with ESC occurrence.

It is important to note that the variables described in this study were associated with columnaris and ESC mortality events but did not necessarily cause the diseases. They are however good variables to consider when designing controlled experiments to determine which risk factors actually predispose a pond to either columnaris or ESC associated mortalities. The model and methodology developed for this study may well be useful for the investigation of additional economically important catfish diseases. This study showed some commonly recorded production variables were associated with columnaris and ESC associated mortalities and if monitored could help identify "at risk" ponds prior to disease outbreaks.

Ponds with more volume had reduced odds of a mortality event associated with ESC. Depth is a key component of volume (area X depth) and this result in not unexpected. In multiple studies increased pond depth reduced catfish losses (Hanson, *et al.*, 2008) and losses from ESC (Cunningham, *et al.*, 2014). Greater pond depth offers more living space for the catfish; shallower ponds or older ponds that have filled in by sediment accumulation (Steeby, *et al.*, 2004) provide less space and may lead to crowding and increased stress on the catfish. Deeper ponds may reduce stress, leading to reduced odds of a disease occurring.

In contrast Cunningham, *et al.* (2012) found greater pond depth increased the odds of a mortality event associated with columnaris disease. Since aeration is based on pond size and not volume, deeper ponds may have reduced aeration levels and lower oxygen levels leading to greater stress. This stress may lead to increased odds of a columnaris related mortality event. Catfish farms should take pond volume into consideration when determining aeration rates.

A decreased stocking to disease interval was associated with increased odds of either a columnaris or ESC related mortality event occurring, suggesting that contaminated equipment used in stocking, stress due to the stocking event or the introduction of naive fish into a pond with infected fish could have contributed to disease occurrence. Fingerlings especially in their first fall are susceptible to columnaris even without predisposing stress factors (Wise, *et al.*, 2004). The bacterium is considered ubiquitous in most waters but movement of infected stocks of fish should be minimized to prevent spread of the disease (Wise, *et al.*, 2004). Stress from poor water quality or handling of fish, such as stocking and harvesting can play a part in a columnaris disease outbreak (Hawke and Khoo, 2004).

The odds of a mortality event due to ESC increased as the harvest to disease interval increased but did not differ in columnaris. This could be caused by less fish in the pond after harvest leading to decreased fish density which would decrease the odds of an ESC break. As the pond is restocked and the fish density is increased, stress also increased, increasing the risk of an ESC break. These intervals could be used as indirect indicators of fish handling stress or the use of contaminated equipment.

Monitoring feed consumption can be a key to monitoring fish health. Reduced feed consumption for a 14 day period measured on a per hectare basis was significantly associated with columnaris occurrence in the analysis. These results are in contrast to ESC results in which increased total feed fed increased the odds of a disease break associated with ESC. These results point to the difficulty of properly feeding a catfish pond and underfeeding or overfeeding can potentiate disease outbreaks.

In these studies, ponds that had higher ammonia levels had increased odds of experiencing a columnaris or ESC associated mortality event. In commercial catfish ponds, ammonia rarely accumulates to concentrations that cause death; ammonia is much more likely to have sub-lethal effects that reduce growth or compromise immunocompetence and even low levels of total ammonia (0.43 mg/L) can reduce voluntary feed consumption by 68% (Hargreaves and Tomasso Jr, 2004).

The odds of a pond having an ESC outbreak were greater with increased nitrite measured 14 days prior to a disease event. These higher ammonia levels may have led to reduced immunocompetence or interruption of the TCA cycle. This stress may have contributed to columnaris and ESC disease mortality events. Water quality measures that potentially affect fish health include nitrite, ammonia, and oxygen levels. High nitrite can result from overfeeding and/or decomposition of organic materials.

Disease Economics

Enteric septicemia of catfish reportedly costs the catfish aquaculture industry $50 to $60 million annually (Breazeale, 2007). Economic losses due to disease are difficult to assess accurately because they are usually underreported due to self-diagnosis by the producer and lack of record keeping. Economic losses attributable to disease on individual farms can be devastating (Hawke and Khoo, 2004). Depending on the disease, 60% to 100% of fish can be lost in an individual pond or even on a single farm during a disease outbreak (Plumb, 1999; Hawke and Khoo, 2004).

The calculated cost of disease in this study was greater for ponds with mortality events associated with columnaris or with ponds with mortality events associated with either columnaris or ESC or both than ponds with mortality events associated with ESC. This was due to decreased fingerling stocking observed in the ESC ponds. The savings associated with the reduced fingerling purchases ($2,173.60) offset the increased feed cost observed $2002.50. It should be noted even with these savings ESC ponds still had an overall increased cost of $3,474.98 per hectare.

Ponds that experienced mortality events associated with either columnaris, ESC or in some cases both over the study period had the largest cost $9,221.20 per hectare due to disease.

These studies have demonstrated the utility of a database for the catfish industry to: 1) manage catfish farms through data analysis and reports and 2) use their production records to identify ponds that are at risk for a mortality event associated with either columnaris or ESC prior to the event occurring so that management can intervene and possibly prevent the event from occurring.

The potential cost of each disease was determined on a per hectare basis. The relationship between feed cost and feed conversion ratio was examined and will help the industry identify ways to improve profitability by concentrating on these parameters. The effect of pond age on FCR was determined and younger ponds or ponds that have been rebuilt in the last three years had a better feed conversion ratio. The feed cost differential was substantial between different pond age classes and young ponds seem to have less disease indicating the farm should closely monitor pond age and production to maximize production and minimize costs.

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APPENDIX A

SOURCES

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b. PigCHAMP, 1531 Airport Road, Ames, IA 50010 http://www.pigchamp.com/

c. FISHY, Agriculture Economics, Mississippi State, MS 39762 http://msucares.com/

d. Microsoft Corporation, 1 Microsoft Way, Redmond, WA 98052 www.microsoft.com

e. Geographical Information Systems (GIS) (ESRI), 380 New York Street, Redland, CA 92373-8100

f. SAS Institute, Inc 100 SAS Campus Drive, Cary, NC 27513-2414 http://www.sas.com