Comparison of Ictalurid Hybrid Crosses (*Ictalurus punctatus x Ictalurus furcatus*) in Floating In-Pond Raceway Systems

by

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Abstract

With the US catfish industry facing higher feed costs and stiff international competition, producers are beginning to adopt intensive alternatives to traditional pond culture. Among these are split pond systems and in-pond raceways which offer the ability to produce higher fish biomasses in more stable environmental conditions. The selective pressures of intensive systems necessitate, however, increased attention to identification of genetic strains and crosses of catfish best suited for survival and growth in this dense, competitive environment. Hybrid catfish (*Ictalurus punctatus* ♀ x *Ictalurus furcatus* ♂) have demonstrated aggressive feeding behavior and disease resistance characteristics which recommend them for use in intensive systems. However, considerable variability exists in performance among hybrid crosses due to their differing domestication histories and selection strategies carried out on their parental lines. Therefore, here I examined the performance of three hybrid catfish crosses when raised from fry to stocker size fish in intensive systems. Eight hybrid catfish crosses were originally stocked as fry into recirculating aquaculture tanks (RAS) and raised to 6-inch fingerlings. Due to disease susceptibility and/or poor growth observed in five of the crosses, only three hybrid crosses, JSS x D&B, JS x D&B, and KSS x D&B, were then carried forward for the main part of the study.

For this study, floating in-pond raceways (FIPRS) were designed and built to improve upon traditional pond culture by offering reduced manpower, higher stocking densities, ease of feeding, grading and complete harvest, and precise disease treatment. The three hybrid crosses were stocked into 12 FIPRS with 4 replicate cells/cross. Fingerlings were grown to stocker size fish and production factors were compared including growth, weight gain, feed conversion ratio

(FCR), and survival. Length weight regressions were constructed for each of the three crosses for size and weight comparisons and to examine uniformity of growth. From these comparisons, it was determined that there were no significant differences among production per cell, FCR, or survival among the three tested crosses. FCR values averaged 1.4 among the three crosses and survival averaged 92%. Our results indicated that a) D&B blue crosses may produce a more robust hybrid catfish for intensive production, although these results need additional replication and b) early selection for superior performance in intensive systems during the fry to fingerling stage may help to ensure even, predictable production in later stages of grow-out. .

Although these experiments were run at a research scale, enterprise budgets (both actual and scenarios at production scale) were developed for each of the three hybrid crosses to analyze the economic feasibility of FIPRS production using selected genetic lines. From these budgets it was determined that a majority of the production cost for these systems come from electricity cost and feed. Due to higher electrical costs, producers would need to carefully match up blower usage with biomass needs, avoid overwintering, and maximize stocking density in order to ensure profitable production.

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List of Abbreviations

FIPRS	Floating In-Pond Raceway Systems
IPRS	In-Pond Raceway Systems
SPS	Split-Pond Systems
RAS	Recirculating Aquaculture Systems
PAS	Partitioned Aquaculture Systems
FCR	Feed Conversion Ratio
D.O.	Dissolved Oxygen
GEI	Genotype x Environment Interactions
JSS x D&B	Jubilee Super Select channel catfish x D&B blue catfish
JS x D&B	Jubilee Select channel catfish x D&B blue catfish
KSS x D&B	Kansas Super Select channel catfish x D&B blue catfish

Chapter 1

Introduction/Literature Review

Aquaculture Background

Soaring world populations, coupled with significant declines in wild-capture freshwater and marine fisheries, have in the last decade highlighted the need for a dramatically expanded and reoriented aquaculture industry to serve as a reliable source of high-quality dietary protein. Aquaculture production has seen significant increases, with an average growth rate in production of 3.2%/year outpacing the 1.7%/year increase of the world population (State of World Fisheries and Aquaculture 2012 FAO). By 2010, the world's production of farmed food fish had reached a level of 59.9 million tons. However, US fish producers have seen relatively little benefit from the rapid growth of world aquaculture, with China dominating production and consumption and US consumers increasingly looking offshore for affordable farmed fish.

Still in its infancy compared to other agricultural animal sectors, aquaculture has grown in piecemeal fashion through experimentation and adaptation of techniques proven in a number of key species, among them catfish, tilapias, and carps. These techniques have primarily focused on low-intensity pond-based culture of warm-water finfish. The U.S., while instrumental in the development and spread of these techniques worldwide, is, as noted above, only a small contributor to current world aquaculture production. Globalization of seafood markets, combined with rising feed and energy costs, have exposed the competitive disadvantages of open pond culture methods in countries such as the U.S. with high fixed costs.   At the same time, consumer awareness of the importance of environmental sustainability, security, and safety of food sources has increased demand for affordable, domestically-produced aquaculture products (Larsen and Roney 2013). US aquaculture will have to innovate and adapt and to rely on its ability to produce a clean, sustainable product, in order to emerge as a significant world seafood producer.

Status of US Catfish Aquaculture

The top fish species produced in the United States is catfish (*Ictalurus spp*.). Commercial catfish production in the United States is dominated by the production of channel catfish (Torrans et al 2011), centered in the southern states of Alabama, Mississippi, and Arkansas, where temperature patterns are ideal for catfish spawning and growout (Baumgarner et al 2005). Hybrid catfish, the result of an artificial cross between a blue catfish male and channel catfish female, have been raised in increasing numbers in the last decade, and are now believed to represent 50% of US catfish production (N. Chatakondi, pers. comm). However, catfish producers, and processors, seafood distributors, and US consumers have traditionally made little to no distinction in production and marketing between channel catfish and hybrid catfish, referring to them collectively as US Farm Raised Catfish. Hybrid catfish, as a primary area of focus of this thesis will be discussed in greater depth below.

The US catfish industry, after three decades of rapid and profitable growth, hit stiff headwinds in the last decade in the form of rising input (feed) costs and competition from catfish (*Pangasius spp.*) imports from Vietnam. The result has been significant declines in production which continue today. To illustrate this pattern, one can examine trends over the last several years. In 2008, US catfish producers sold 510 million pounds from 133,600 water acres. Catfish feed prices stood at $388/ton and frozen fillet imports accounted for 49.8% of catfish sales (2008 Catfish Database). By 2013, US catfish production had dropped to 334 million pounds (-35% relative to 2008), on 71,725 water acres (-46% decline). Catfish feed prices stood at $483/ton (+$95/ton) and frozen fillet imports accounted for 75% of catfish sales (+25%) (2013 Catfish Database). Clearly, these dramatic trends, if continued for several more years, would effectively end the US catfish industry.

Catfish/Pond Production

Before examining potential areas for improvement in the catfish industry through better systems and genetics explored in the present thesis project, one must first understand where inefficiencies lie within the US catfish industry. The catfish industry is divided into 3 major components, hatchery/fingerling producers, food fish producers, and processors. These three components are usually not integrated with each other. The hatchery produces fry and fingerlings and sells to the farmers for stocking. The farmers produce food size fish (1.5-1.75 lbs) to sell to the processor. Finally, the processor dresses out and fillets the fish to be sold to market as fresh or frozen fillets.

In part, due to the lack of integration between the hatchery, food fish producer, and processor, the “multiple batch” system has been developed. Multiple-batching refers to continuous production within a pond, with partial harvests of food-size fish accompanied by multiple stockings of batches of fingerlings. In this way, ponds never sit empty waiting for fingerlings (they can be purchased whenever available) and producers are more likely to have harvest-ready fish when the processor calls (USDA Catfish 2010). This method is used more than single batch production in which all fish are stocked in a pond at a single time, usually in the spring, and the pond is not restocked until all fish have been harvested in autumn (USDA Catfish 2010; Li et al 2010). However, the gains made in production stability due to multiple-batching are often offset by losses in certainty regarding inventory, declines in feed conversion ratios due to presence of large uncaptured fish from previous batches, and the inability to accurately compare the performance of different genetics lines or the production of a pond or farm from one year to the next.

Environmental Variability in Pond Production

Beyond the uncertainty introduced by multiple batching, several factors inherent in pond production introduce the potential for tremendous variability in production even among ponds on the same farm. Ponds can often vary by size and depth, both by design and as the result of years of sedimentation. Varying levels of algal blooms, dissolved oxygen levels (D.O.), temperature fluctuations, nitrite levels (TAN), and carbon dioxide levels (CO2) can also send nearby ponds on different trajectories (Cole & Boyd 2011). These problems are seen more in the warmer summer months of production when the feeding rate and feeding activity is high. During the early morning hours, pond D.O. is low while CO2, TAN, and chlorophyll a (algal bloom) concentrations are high (Cole & Boyd 2011). These levels are noticed more frequently in August and September (Cole & Boyd 2011). Ponds with higher feeding rates will have heavier phytoplankton blooms and increase the level of CO2 while decreasing the D.O. even when aeration is provided. NH3-N and NH4-N make up total ammonia nitrogen (TAN). When feeding rates increase, TAN will also increase (Cole & Boyd 2011). TAN is dependent upon pH and temperature. When pH is high during the day and temperatures are warm, TAN can pose a huge problem (Cole & Boyd 2011).

High mortality rates can result from water quality issues (toxic algae blooms, low D.O.) as well as from animal predation and uncontrollable disease outbreaks (USDA Catfish 2010). Bird predation can inflict steady, largely unseen losses over the entirety of a growing season, while disease outbreaks of bacteria such as *Edwardsiella ictaluri*, *Flavobacterium columnare*, and/or *Aeromonas hydrophila* can often deplete greater than 50% of a standing pond crop over several weeks. Often a portion of these mortalities go unaccounted for, as they are carried off by birds or sink to the bottom.

Solutions to these issues of lack of inventory control, sub-optimal water quality, animal predation, and devastating disease outbreaks have been slow in coming to pond aquaculture. The scale of catfish ponds, often greater than 5 acres in size, means that chemicals added for water and disease treatments or nets/fences added for animal predation are often cost prohibitive. As discussed in a subsequent section, new approaches taken from lessons learned from intensive, recirculating aquaculture, may hold the solutions to many of these problems.

Catfish Breeding & Genetics

Channel Catfish Characteristics and Genetics

Channel catfish (*Ictalurus punctatus)* were recognized early on as an excellent candidate for aquaculture, based on temperature and low dissolved oxygen tolerances, high filet yield, and tolerance of high stocking densities (Torrans et al 2012). They grew to food fish size and had higher disease resistance than other catfish species. Beginning in the early 1900s, hatchery and farm stocks were developed. Dunham and Smitherman (1984) catalogued 180 such stocks or strains. However, they noted at that point that 95% of farmed catfish in the US came from stocks originating from the Red River, Denison Dam, Oklahoma in 1949. From that base and smaller contributions from elsewhere, since the 1960s, the catfish industry and supporting companies and universities have been experimenting with strain comparisons and breeding programs to improve catfish production including strain evaluation, intraspecific crossbreeding, interspecific hybridization, and mass selection. These experiments have been used to improve factors such as growth, feed conversion, survival, tolerance to lower dissolved oxygen, seinability, vulnerability to angling, higher carcass yields, disease resistance, and reproductive performance (Smitherman et al 1983).

Four of the main strains of channel catfish, Auburn, Marion, Kansas, and Rio Grande were evaluated by Chappell (1979). He crossed these 4 strains of channels to produce Auburn x Auburn (AUB), Rio Grande x Rio Grande (RG), Auburn x Rio Grande (AxRG), Marion x Marion (MAR), Kansas x Kansas (KAN), and Marion x Kansas (MxK) and showed that crossbreeding can lead to advantages such as overall viability, greater weight gain, higher fecundity, and lower mortality. He showed that Kansas channel catfish were the fastest growing strain of channel catfish. Kansas channel catfish were used in part of the study reported below. Selection efforts in channel catfish have continued since that time. In 1986, the USDA/ARS Genetics Research Unit in Stoneville, Mississippi began genetic selection work on an improved strain USDA-103 (Jackson et al. 2003) which showed improved growth, fillet yield, and seinability relative to other catfish strains.

However, the impact of strain development and genetic selection for channel catfish remains the subject of debate. In 2010 the National Animal Health Monitoring System (NAHMS) published their third examination of production and management for the catfish industry, giving the industry valuable information on production and health management practices. In Catfish 2010, NAHMS found that 81.9% of food fish production operations raised unknown strains of channel catfish on their farms, with 85.5 % of producers not knowing if different strains or species of catfish showed higher disease resistance than others. These results demonstrate the difficulty of making and evaluating genetic progress in pond-culture, particularly under the multi-batch system as described above.

Blue Catfish Characteristics and Strains

Blue catfish (*Ictalurus furcatus)* culture in the US has always been limited, as culturists recognized the fish's relatively poor tolerance of low oxygen, poor disease resistance, and slow sexual maturation (Dunham and Smitherman 1984). However, in the intervening years, blue catfish have been proven to be more disease resistant against certain diseases such as enteric septicemia of catfish (ESC), channel catfish virus (CCV), and proliferative gill disease (PGD) along with other types of diseases (Torrans et al 2012). Additionally, they are more resistant to environmental nitrite problems that cause brown blood disease, have a higher seinability, and are, in general, aggressive, fast-growing fish (Torrans et al 2012). Therefore, from the early days of the catfish industry, hybridization between blue catfish and channel catfish was attempted (Giudice 1966).

Selective breeding, domestication, and strain development of blue catfish has lagged behind that of channel catfish. However, genetic differences among blue catfish strains have been observed and are believed to determine in large part the performance of different hybrid crosses (paternal dominance; Dunham and Smitherman 1984).   Few studies, however, have directly compared among blue strains for a given trait. Xu et al 2012 showed differences among three strains of blue catfish relative to infection levels and mortality rates when exposed to *Ichthyophthirius multifilis*. Rigorous, side-by-side evaluation of blue strains for a suite of important production traits remains to be conducted. The most commonly used strains of blue catfish are D&B, originally from the D & B Fish Farm in Crockett, Texas, Tombigbee blue catfish (T) and the Rio Grande blue catfish (RG) (Torrans et al 2012; Argue et al 2003). However, as blue catfish are sacrificed for hybrid production, strain definition and evaluation of blue catfish has been particularly neglected, with a high percentage of current blue broodstock recently sourced from the wild.

Hybrid Catfish Characteristics

The hybrid catfish resulting from a cross between channel catfish females and blue catfish males has long been an attractive choice for pond production. Several studies have demonstrated significantly faster growth in hybrid catfish than channel catfish (Giudice 1966; Yant et al. 1975; Chappell 1979; Tave et al. 1981). Additionally, hybrid catfish have higher dressing percentage, a higher seinability, and higher resistance to some diseases. As aggressive, competitive feeders, with higher disease resistance, they are ideally suited for use in intensive ponds and systems. However, for several decades, the lack of consistent protocols to produce hybrid catfish prevented their widespread adoption in the industry (Dunham and Smitherman 1984). With development of consistent hormone induction protocols (Masser and Dunham 1998), their use has rapidly multiplied and they now account for approximately 50% of US catfish production. Of note, the gains attributable to hybrid catfish in comparison with channel catfish have been made with minimal attention paid to the strains and performance of the parental channel and blue lines.

Additional gains in performance are likely acheivable by selection of superior channel catfish and blue catfish lines for utilization in hybrid catfish production. In this vein, recently Bosworth and Waldbieser (2014) examined the general and specific combining ability of blue catfish males and channel catfish females, finding that selection for improved carcass yield and growth based on additive genetic merit of blue catfish male and channel catfish female parents should be effective for improving performance of hybrid progeny. One critical need, addressed in part by the study outlined below, is to understand the best combination of channel catfish and blue catfish strains for intensive production. The selected strains could then be the subject of further mass or family-level selection.

Catfish Production Systems

Given the shortcomings of pond culture of catfish addressed above and their impact on making rapid genetic progress, several approaches over the last several decades have attempted to ameliorate these problems through the use of alternative controlled, intensified systems including partitioned aquaculture systems, split-ponds, and in-pond raceways.

Recirculating Aquaculture Systems (RAS)

All three of the systems listed above apply principles from recirculating aquaculture systems to the open-pond environment. While implementation varies, all RAS systems seek to provide a consistent, managed growing environment through stabilizing oxygen levels (pure oxygen, or forced air blowers), handling waste (filters, removal, or diffusion), and maintaining inventory control (reducing/eliminating bird predation, increasing sampling ease, etc.). RAS systems have been used for growing and raising fish for the last 30 years (Masser et al 1992). However, only recently there has been a greater push to raise the production limit on these systems due to the fact that these systems have such great advantages when it comes to production. This includes less land and water requirements and higher environmental control of the system.

The first design for RAS was an indoor system where water is pumped through the system, sent through a biofilter to remove waste, and partially re-used to flow through the system again (Martins et al 2010). However, more recent designs have shifted towards a controlled outdoor system using the same principles where the pond is the biofilter. This has cut down on a majority of the cost on these systems. An example of this system is a simple flow-through recirculating system as illustrated in Figure 1.1. This system utilizes three in-line pumps to deliver 300 GPM to 10, 1000 gallon tanks before allowing it to return to a larger 23 acre pond for waste diffusion and recirculation. While this represents an adequate design for fry rearing, if done at a larger scale for food fish, pumping costs would become prohibitive.

Figure 1.1 Flow through recirculating aquaculture system (RAS) at Auburn University.

Partitioned Aquaculture Systems (PAS)

Partitioned aquaculture systems (PAS) were developed at Clemson University in order to combine the control of recirculating aquaculture with the lower cost of pond production (Figure 1.2). Researchers there found that by managing algal productivity and algal biomass concentrations, higher levels of fish production could be achieved (Drapcho and Brune 2000). The addition of paddlewheel aerators to the pond contributed to a mixing of the water which could increase oxygen, algal photosynthesis, and ammonia removal. PAS also offered the ability to divide the pond into separate partitions that can be controlled and managed for fish production, oxygen production, waste removal and treatment, and algal growth.

The success of the PAS system can be attributed to the energy efficient means of moving large amounts of water slowly throughout the entire pond. Providing the right amount of aeration was achieved by using low rpm paddlewheels (Brune et al 2004). A uniform water velocity field provided mixing of nutrients throughout the pond, turned over and mixed the algae to guarantee good algae production, and removed waste while providing adequate water quality throughout the system (Brune et al 2004).

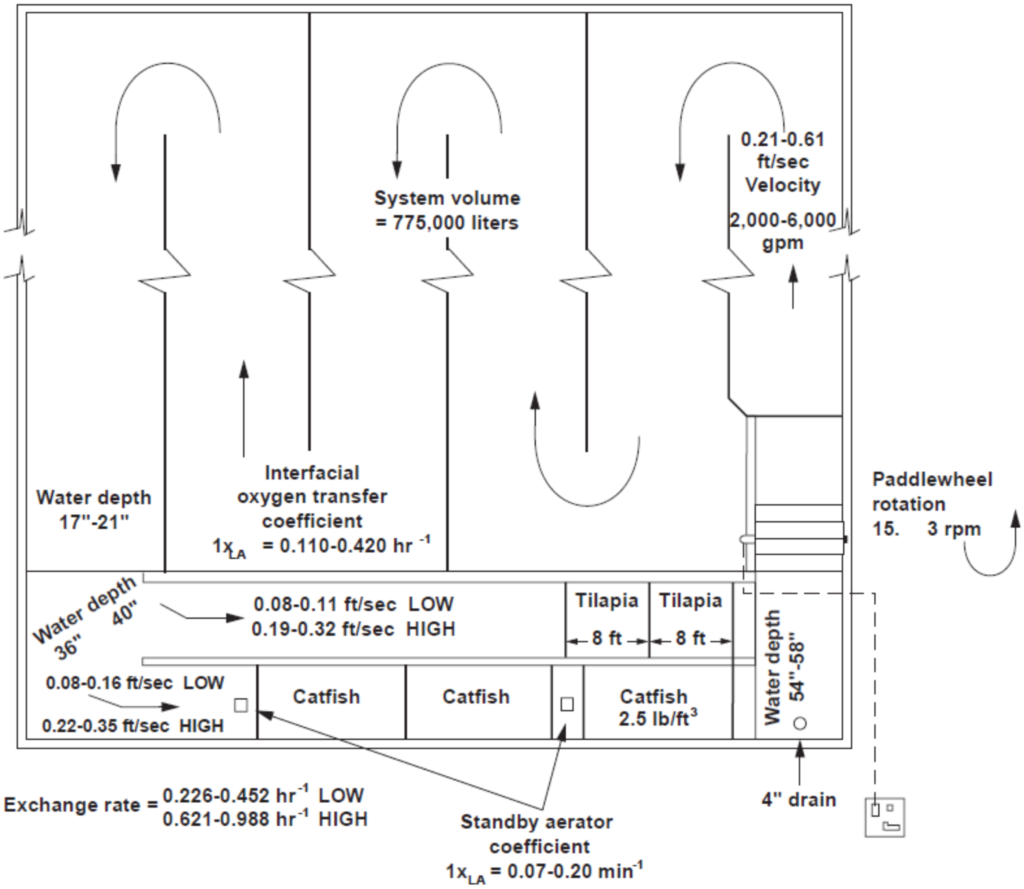


Figure 1.2 1/3 acre PAS unit as operated in 1995 (Brune et al 2004).

Just like in indoor RAS, a higher stocking density can be maintained in PAS raceways. It was shown that 8-10lbs/cubic feet could be raised in the raceways with no adverse effects on growth (Brune et al 2004). PAS allow for co-culture of species so that different species can be raised at the same time but in separate raceways (Brune et al 2004). In spite of these advantages, the primary drawback of PAS has been the cost of construction and implementation, with significant investment costs in concrete and the paddlewheels. Therefore, the principles which were elegantly demonstrated in PAS have been utilized in more affordable systems.

Split Pond Systems

A more recent modification of the PAS, split ponds systems (SPS), takes the advantages and benefits of the PAS to increase production of fish by separating the pond into 2 main areas (Figure 1.3), an algal basin for oxygen production and waste treatment and a fish holding basin leading to a better fish culture environment (Tucker and Kingsbury 2010). An earthen levee with two sluiceways circulates water between the two basins for waste removal and provides aeration to the fish holding basin (Brown and Tucker 2013). SPS can produce two to four times more than a traditional pond on average, producing 17,000-20,000 kg/ha or 15,000-22,000 lbs/acre with typical stocking rates at 25,000 fish/ha (Tucker and Kingsbury 2010; Brown and Tucker 2013).

Figure 1.3 Split-pond system with slow rotating paddle wheel to provide water movement between the fish holding basin and the algal basin (Brown and Tucker 2013).

While split-ponds represent a new, evolving technology, potential drawbacks include costs of paddlewheels/screw pumps to drive water between the fish basin and the waste lagoon, need for generator power backup, and maintenance upkeep of motors, sluice channels, and the waste lagoon. While many of these costs are shared in common with PAS systems and in-pond raceways below, the larger fish holding area of the split pond system reduces benefits such as replication (important for on-farm evaluations), bird and otter predation, and staggered crops inherent in the latter two systems.

In-Pond Raceway Systems

Another modification to the PAS concept, and the one used in the study below, is the in-pond raceway (IPRS). Floating and fixed floor (concrete) models have been examined. Floating versions have the advantage of minimizing costs in concrete and extensive earthwork. Original raceways were enclosed channels or tanks (Figure 1.4) where high volumes of water were constantly being pumped through the system (Masser and Lazur 1997). This lead to an increase of fish production accompanied by the previously mentioned advantages such as higher stocking densities, ease of feeding, easier and more effective disease treatments, ease of harvest, good water quality, and less labor. Previous iterations of raceway technology have found that stocking rates can reach 9-15 fish/cubic foot with ultimate production levels of 15,000- 22,000 lbs/acre (Masser and Lazur 1997; Brown and Tucker 2013; Brown et al 2014).

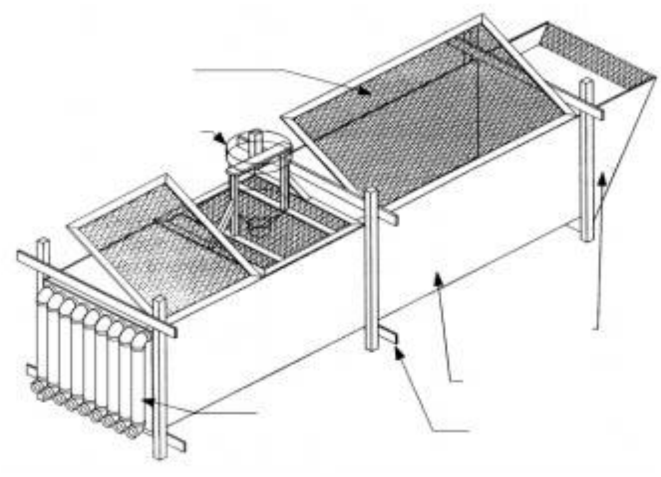


Figure 1.4 Original enclosed raceway schematic (Masser and Lazur 1997).

Fixed Floor In-Pond Raceways

Fixed floor raceways are concrete cells attached together and set on the pond bottom with slow moving paddlewheels at the front to provide water movement throughout the cells (Figures 1.5 & 1.6). The main problem with fixed floor raceways is the high initial construction cost and operational cost. Brown et al 2011 found the total capital, equipment, and machinery cost was $113,279 or $18,880 per water acre to build and operate a fixed floor raceway system (Brown et al 2011; Brown et al 2014). Raceway systems are capable of producing 15,000-22,000 lbs/acre versus traditional pond production numbers of 4,500-9,000 lbs/acre but when more aeration is added traditional ponds have produced10,000-20,000 lbs/acre (Brown et al 2014).

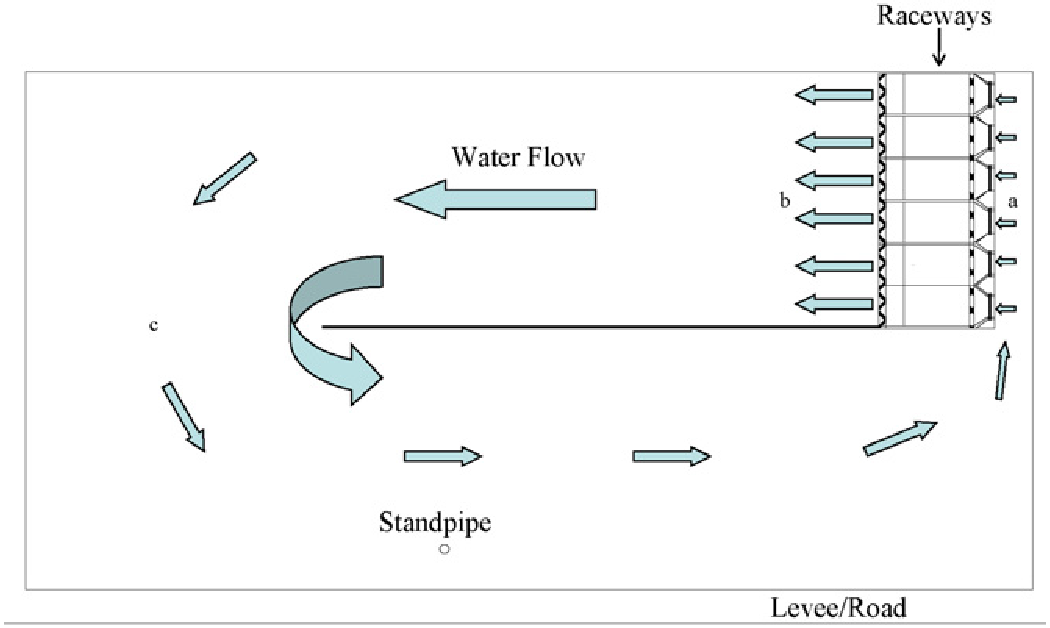


Figure 1.5 Fixed In-Pond Raceway System (Brown et al 2011)

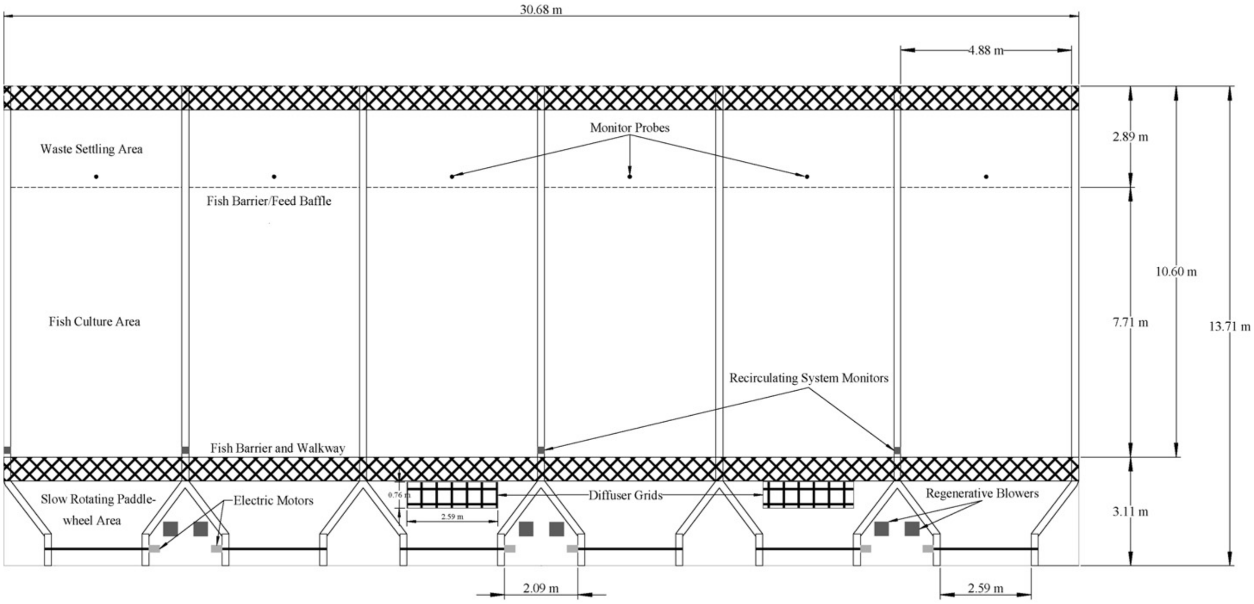


Figure 1.6 A layout of the complete IPRS (Brown et al 2011)

Floating In-Pond Raceway Systems (FIPRS)

The basic floating, in-pond raceway design (as developed at Auburn in 2010) consists of raceways constructed out of a wire mesh and aluminum frame and a HDPE plastic liner (Figure 1.7). Airlift hoods fitted with diffuser racks connected to regenerative air blowers are added to the front to circulate water through the culture unit and to provide even, constant aeration throughout the unit. As in PAS and split-pond approaches, the remainder of the pond not used in intensive culture serves as the biofilter. The main advantage of FIPRS over fixed floor raceways lies in their lower cost and ease of deployment into ponds without costly draining, pond renovation, and concrete work (Fern 2014). However, the use of more affordable materials also means that the life span of FIPRS will necessarily be shorter and that the units require additional annual maintenance over that needed for fixed floor models.

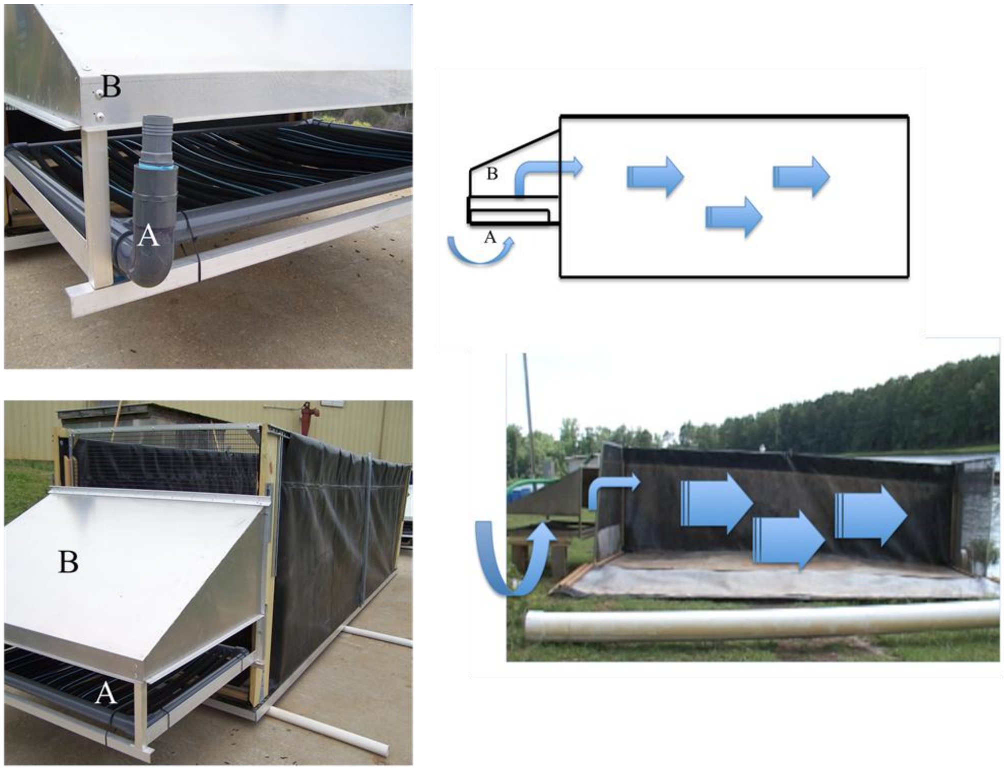


Figure 1.7 The diffuser manifold **(**A) is inserted into the raceway’s hood (B) and connected to a 1.5 hp blower by a rubber hose. The blower forces air down the hose and through the diffuser

manifold which is made up of a number of diffuser tubes. The air leaves the diffuser tubes in the form of tiny bubbles which oxygenate and move water while on their way to the surface. This creates a rich flow of oxygenated water to the fish.

System-Directed Selection

Different systems place different selective pressures on the culture organism. The shift from low density pond culture of catfish to intensive production exerts selective pressures that will favor aggressively-feeding, competitive fish with higher disease resistance. For this reason, farmers using intensive pond production, split-pond, and raceway strategies have all found that hybrid catfish provide superior results. However, different intensive approaches may vary by applying more subtle selective pressure. For example, in-pond raceways can reach higher fish/ft^3 densities, have a greater constant flow of water and more even aeration than split pond systems. Fish, having undergone passive selection (domestication) for performance in static water, with fluctuating oxygen levels, a variety of temperatures throughout the pond, supplemental feed choices (shad), and low fish-to-fish contact may be ill-suited for robust competition in in-pond raceways.

With replicated production systems like in-pond raceways, selection for performance can take place directly in the relevant culture environment rather than in a sterile RAS or aquaria system. This idea of system-directed selection has been successfully applied in the poultry industry, where genetics, diet, and environment have been optimized to work together seamlessly. There, the modern chicken is 6X heavier than the 1957 bird, achieving its harvest weight in 1/3 of the time, with 1/3 of the feed consumed in 1957. Eighty-five percent of this improvement has been found to be attributable to genetics, with the remaining 15% coming from improvements in diet and environment (Welfare of Chickens 2000). With the potential for inventory control, predation control, water quality control, and ease of treatment offered by an intensive, replicated system such as the in-pond raceway, greater attention can now be placed on selection of lines and strains which thrive within that environment.

Conclusion

Sustainable growth of US aquaculture will depend on holistic approaches which simultaneously consider both the genotype (genetics) of the animal, its environments, and their interactions. Current pond production practices in the US catfish industry suffer from widespread environmental variation, lack of inventory control, and lack of operator control. As new, more intensive systems are developed to address these issues, an added emphasis is needed on identifying and conducting selection on the strains and species best suited for growth in these novel environments. Indeed, the replicated nature of some of these systems, makes this selection process a good deal more feasible. The research outlined below is a first step in evaluating the differential performance of hybrid catfish crosses in intensive environments.

In this study, I evaluated 8 different crosses of hybrid catfish from fry in flow-through tanks (unreplicated). The top three performing strains upon reaching ~6 inch fingerling size were transferred to in-pond raceways (four raceways per cross) and more thoroughly evaluated for production parameters until reaching approximate stocker size. Although this was a research-scale trial, I also evaluated basic economic parameters to better understand the costs associated with production of stocker-sized catfish in raceways.

Chapter 2

Materials and Methods

Hybrid Catfish Crosses

Fry were bagged with oxygen at swimup (5 d post hatch) and transported from Jubilee Farms, Inc. located in Indianola, Mississippi to the North Auburn Fisheries station. Eight hybrid crosses were stocked into flow-through tanks on June 21, 2013 at 40,000 fry/tank. The hybrid crosses (channel x blue) were as follows Jubilee Super Select (JSS) x D&B, Jubilee Super Select (JSS) x Tombigbee (TBB), ESS x D&B, Kansas Super Select (KSS) x D&B, Kansas Super Select (KSS) x Tombigbee (TBB), Jubilee Select (JS) x D&B, Jubilee Select (JS) x Tombigbee (TBB), and Kansas Select (KS) x Tombigbee (TBB). Select and Super Select are the nomenclature of Jubilee Farms, indicating different stringency of selection on the channel catfish female strains. No selection has been conducted at Jubilee Farms for the blue catfish strains (D&B and TBB).

Early Rearing—Fry to Fingerling

Early rearing of fry was carried out in a recirculating aquaculture system (RAS) that pumped water from pond S-1 into 10 flow-through tanks (3785L) that were housed under a pole barn enclosed in bird netting and an electric fence to keep out any unwanted predators (Figure 1.1).

Feeding

The fry were fed Aquamax fry starter powder twice a day at 8 am and 3 pm. As the fish grew larger the type of feed was changed to meet their nutritional needs. They were fed Aquamax D01, D02, D03, D04, and a 32% protein floating feed. Feed was scattered throughout the tank so ensure that all the fish were eating.

Dissolved Oxygen and Temperature

Dissolved oxygen was measured with a YSI Pro 20 dissolved oxygen meter. D.O. was checked 4-6 inches below the water surface at the front and backs of the tanks. D.O. levels were checked twice a day once in the morning at 8 am and once in the afternoon at 3 pm. Temperatures were also recorded with the same meter at the same times that the D.O. was checked.

Mortality

Dead fish were removed by using dip nets when the tanks were drained to a half stand pipe to be cleaned. This made it easier to remove the dead fish and get a more accurate count of how many fish were being removed from the system. Mortality counts were recorded every day.

Water Exchange and Cleaning

The tanks were drained down to a half stand pipe and scrubbed and cleaned once a day. This was to remove the bigger particles from the sides of the tanks and give the fish a daily water exchange.

Fingerling to Stocker Evaluations

Floating In-Pond Raceway System (FIPRS)

Raceways were built at Agriculture Land and Resources Management Facility also in Auburn and transported to the site where they were then launched out into the pond. This Floating In-Pond Raceway System (FIPRS) contained 12 individual raceways attached to a floating dock (Figures 2.1, 2.2, & 2.3). Each raceway (6 ft width, 20 ft length, and 5 ft depth) and was attached to an aluminum water-moving unit (6 ft width, 4 ft length, and 3 ft depth) located at the front of the raceway. A PVC frame with 31 diffuser tubes was attached inside the water-moving unit and connected to a 1.5 hp Sweetwater blower with Rollerflex suction hose. Two raceways share one 1.5 horsepower blower that provides aeration and water movement through the raceway. A power generator, 20-kW Eaton Corporation, and a propane tank were installed as a backup power source in case of a power outage (Fig 1.7).

Figure 2.1 A complete view of the Floating In-Pond Raceway System (FIPRS) in pond S1 at the North Auburn Fisheries Unit at Auburn University.

Figure 2.2 A closer look at two FIPRS units in pond S1 at Auburn University.

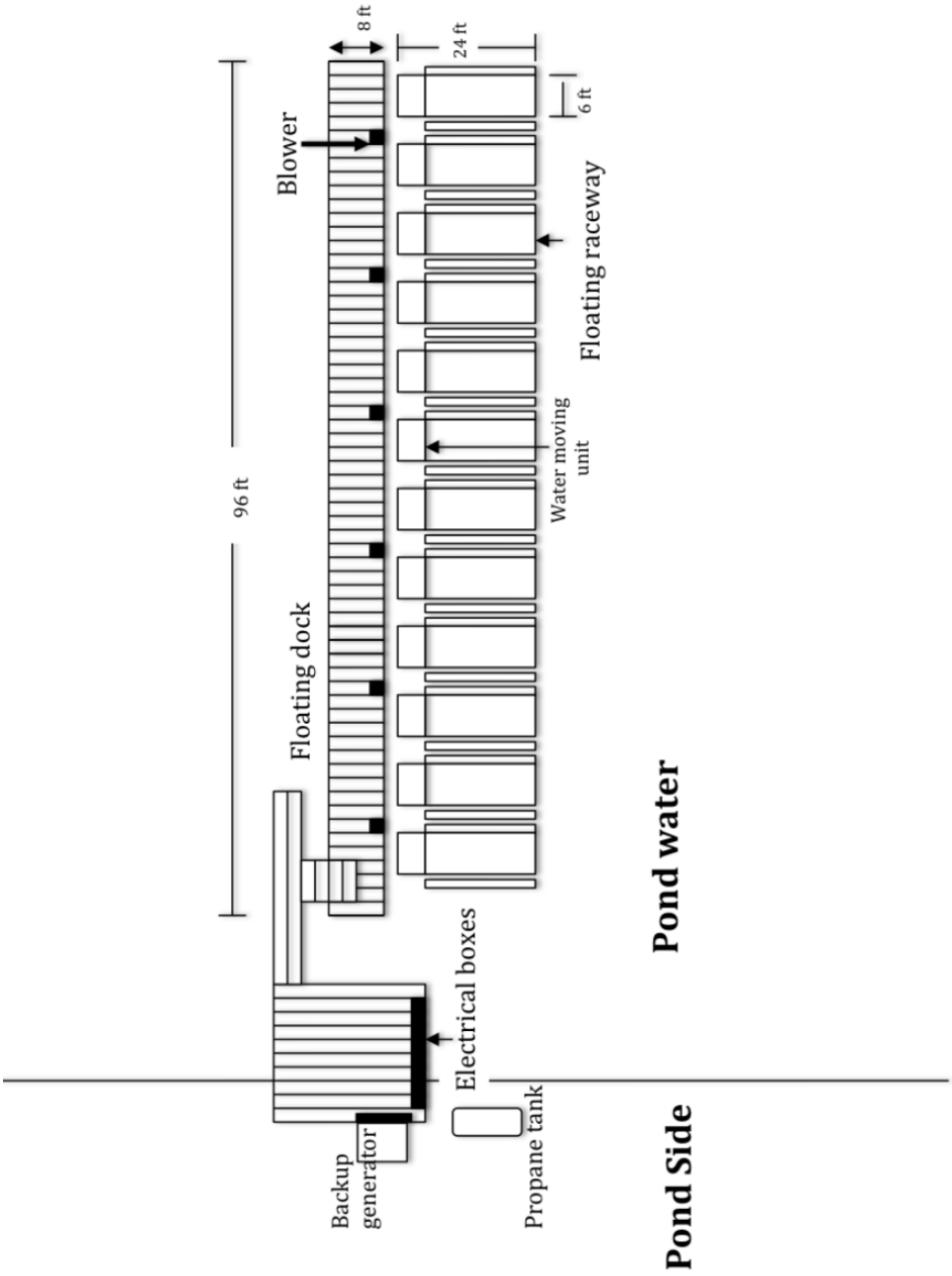

96 ft
8 ft
24 ft
6 ft
Blower
Floating raceway
Water moving unit
Floating dock
Pond water
Electrical boxes
Backup generator
Propane tank
Pond Side

Figure 2.3 A schematic of the floating in-pond raceway system (FIPRS) at Auburn University, Auburn, Alabama. The system is located at S-1, a 23-acre pond (Fern 2014).

Stocking Rates

There were three different treatments which were the three different crosses and each treatment had four replicates. The fish were stocked in at ~2,000 fish/ raceway as 6-7 inch fingerlings. Raceways 1, 4, 5, & 6 were stocked with JSS x D & B crosses at ~2,000 fish/ raceway, raceways 2, 7, 8, & 9 were stocked with JS x D & B at ~2,000 fish/ raceway, and raceways 3, 10, 11, & 12 were stocked with KSS x D & B at ~2,000 fish/ raceway.

Dissolved Oxygen

Dissolved oxygen was measured with a YSI Pro 20 dissolved oxygen meter. D.O. was checked 4-6 inches below the water surface at the front and backs of the raceways. D.O. levels were checked twice a day once in the morning at 8 am and once in the afternoon at 3 pm. Temperatures were also recorded with the same meter at the same times that the D.O. was checked.

Feeding/FCR

Fish were fed a 32% protein floating catfish feed twice a day throughout the study. The amount of feed gradually increased as the fish grew larger and the study continued. Fish were fed to satiation in the mornings and afternoons after the D.O. and temperature had been recorded. Feed was dispensed behind the front screen of each cell, due to the aggressive feeding of the catfish all feed was eaten before it made it to the back of the cell so a feed barrier in the middle of the cell wasn’t necessary.

Sampling

Once a month, 3-4 raceways were sampled for fish growth. The catfish were seined within the raceway and sample counts of 20-25 catfish were obtained by using a dip net. The samples were counted and placed in a bucket of water to be weighed and then placed back into the cell. The average fish weight was determined by dividing the weight measured by the number of fish in the sample. This was replicated three or four times per raceway and the average weights for each raceway were obtained.

Mortality

Minimal mortalities were recorded during this study. Daily mortality numbers were recorded. Dead fish were removed from the raceways with a net and buried in a compost pile.

Chemical Treatments

Salt and formalin treatments were administered twice a week as a precautionary measure against diseases during May and June when water temperatures were fluctuating. Formalin treatments were administered twice a week at a treatment rate of 100 ppm, 1.3 liters of formalin, for a raceway cell of 13,250 liters. Salt treatments were given every other day at 50 lbs of salt/ cell. Each cell received treatments 4 days a week and had 3 days of no treatment. To treat the raceways, the blowers were shut off and the back screens were covered to make a treatment bath within the raceway. Raceways were static for 20-30 minutes while D.O. was steadily monitored. After the treatment, the screens were uncovered and blowers turned back on.

Cleaning

The front and back screens were scrubbed 3-4 times a week to remove debris and algae buildup to allow for an improved water flow. The blowers and blower hoods were also cleaned 3-4 times a week to remove any dirt or algae buildup.

Electricity Usage

Electricity usage (kWh) was also recorded once in the morning and once in the afternoon so that power usage could be evaluated on the system.

Statistical Analysis

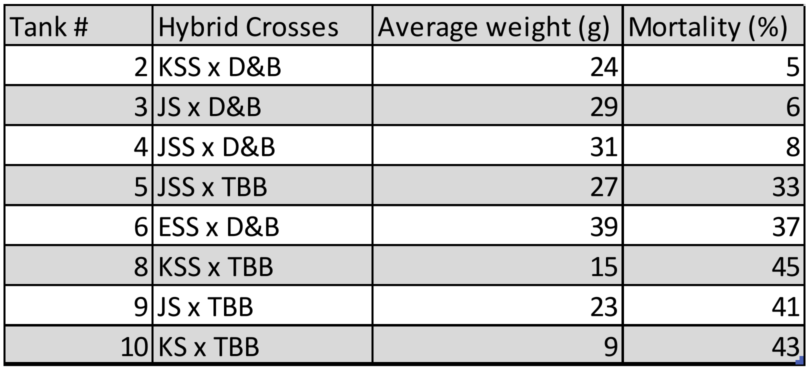
Statistical tests for this project accomplished using the statistics programs R and Rstudio. Growth rates were determined by using the sample weight data in Microsoft Excel and then Rstudio was used to check distributions and perform ANOVAs on the growth data. ANOVA tests, with an alpha=0.05, were performed on growth, harvest size, harvest weight, survival, and FCRs to calculate p values to determine significant differences in this factors between the three crosses. A strain distribution boxplot was generated in Rstudio to show growth rates among the three different strains. Length weight regressions and R^2-values were calculated for all 3 crosses using R Studio to show correlations. All other tables created and used in this paper were generated in Microsoft Excel.

Chapter 3

Results and Discussion

Fry to Fingerling Evaluation

Given system constraints for fry-to-fingerling rearing, swimup fry of eight hybrid crosses were stocked in June 2013 in un-replicated flow-through tanks for rearing to fingerling size. The original study design called for evaluating them in three replicated raceways per cross beginning at 5-6 inch fingerlings (24 raceways). However, mortality from *F. columnare* and/or inadequate growth in the tank environment made it necessary to carry only the three best performing hybrid crosses forward for raceway evaluations. Table 3.1 lists the evaluated crosses in the fry-to-fingerling phase along with sample weights and mortality prior to raceway stocking.



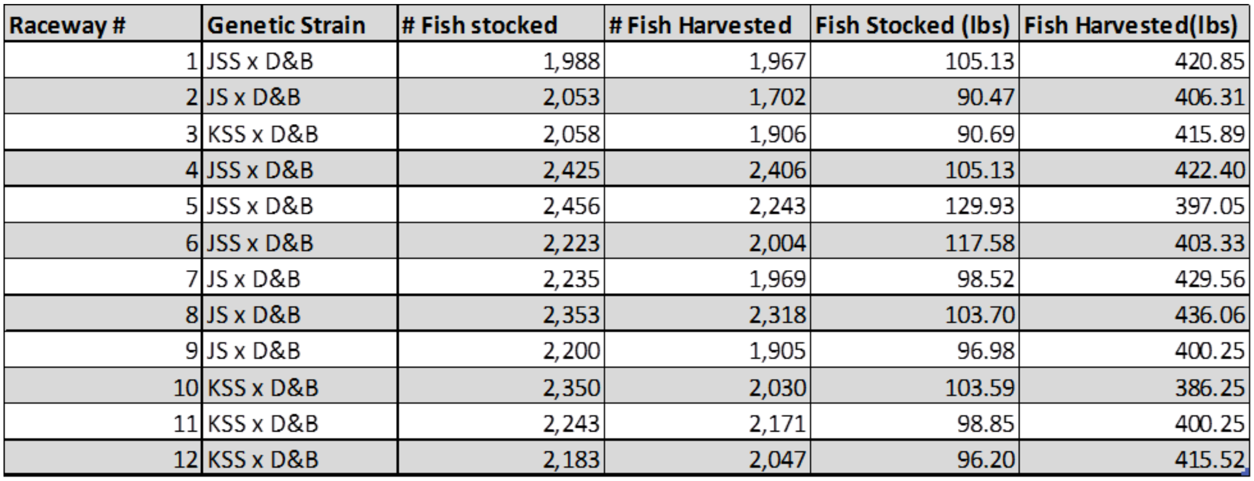
Tank #	Hybrid Crosses	Average weight (g)	Mortality (%)
2	KSS x D&B	24	5
3	JS x D&B	29	6
4	JSS x D&B	31	8
5	JSS x TBB	27	33
6	ESS x D&B	39	37
8	KSS x TBB	15	45
9	JS x TBB	23	41
10	KS x TBB	9	43

Table 3.1 Fry to fingerling weights and mortalities by crosses in RAS tanks

Although un-replicated, higher growth and survival in crosses with the D&B blue catfish strain relative to the TBB strain were notable. Despite high mortality reducing tank biomass, TBB crosses remained smaller than D&B crosses with the exception of JSS x TBB. Failure to grow was particularly notable in Kansas x TBB crosses, likely indicating strong genetic-environmental interactions. TBB blues come from the Tombigbee River and likely have a shorter domestication history and smaller founder population than do D&B blue catfish. D&B blue catfish are believed to be the most widely cultured blue catfish broodstock line (Li et al. 2014). ESS x D&B crosses also stood out from the other D&B crosses for their high mortality rate, potentially accounting for the ultimately higher average weight. KSS x D&B, JS x D&B, and JSS x D&B all showed low mortality rates and good growth and were carried forward for raceway evaluation. In the future, it would be valuable to evaluate all eight crosses again in a replicated manner to confirm our results.

Fingerling to Stocker Evaluation

KSS x D&B, JS x D&B, and JSS x D&B fingerlings were stocked in the fall of 2013 into 12 floating in-pond raceways (4 replicate raceways per cross) which had been constructed in late summer of that year. Table 3.2 lists the number of fingerlings stocked per raceway.



Raceway #	Genetic Strain	# Fish stocked	# Fish Harvested	Fish Stocked (lbs)	Fish Harvested(lbs)
1	JSS x D&B	1,988	1,967	105.13	420.85
2	JS x D&B	2,053	1,702	90.47	406.31
3	KSS x D&B	2,058	1,906	90.69	415.89
4	JSS x D&B	2,425	2,406	105.13	422.40
5	JSS x D&B	2,456	2,243	129.93	397.05
6	JSS x D&B	2,223	2,004	117.58	403.33
7	JS x D&B	2,235	1,969	98.52	429.56
8	JS x D&B	2,353	2,318	103.70	436.06
9	JS x D&B	2,200	1,905	96.98	400.25
10	KSS x D&B	2,350	2,030	103.59	386.25
11	KSS x D&B	2,243	2,171	98.85	400.25
12	KSS x D&B	2,183	2,047	96.20	415.52

Table 3.2 Raceway stocking numbers and stocking weights to harvest numbers and harvest weights for the FIPRS.

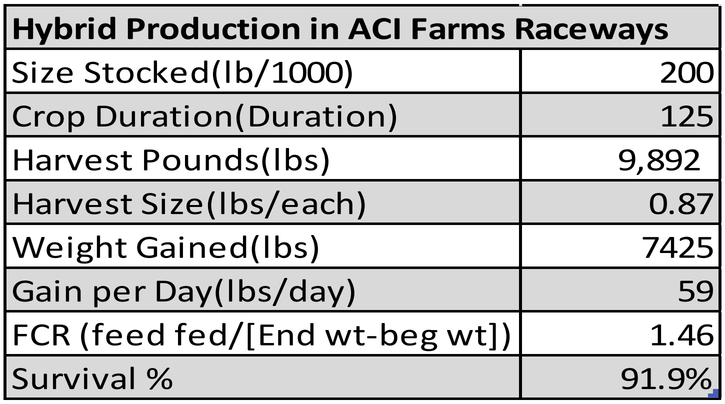
Due to record cold temperatures in late fall/winter of 2013/2014, stocked fingerlings did not resume active feeding until mid-March 2014. All crosses and raceways displayed active, vigorous feeding and minimal disease-related mortality from that point until termination of the study in early July 2014. At that point, the raceways were clean harvested and fish transported to ACI Farm (Harvest Select Catfish, Inc., Marion Junction, AL) for continuing raceway demonstrations. The following sections provide results of production parameters and enterprise budgets based on fingerling-to-stocker production in a spring to early summer time frame.

Production Parameters

Table 3.3 provides production parameters for fingerlings averaged across four replicate raceways per cross. As shown, there were no significant differences in growth, FCR, or survival among the three hybrid crosses (based on ANOVA analysis with significance set at $p<0.05$). All crosses reached a size of approximately 90 grams (8-9 inch) by the harvest date (Figure 3.1). A larger final size of 97 grams was observed in the JS x D&B cross. However, this difference was not found to be significant. Perhaps relatedly, survival was lowest in the JS x D&B (89%), in comparison with JSS x D&B (95%) and KSS x D&B (92%). While the lower survival in JS x D&B could be speculated to allow for faster growth among the surviving fingerlings, these differences were not statistically significant.

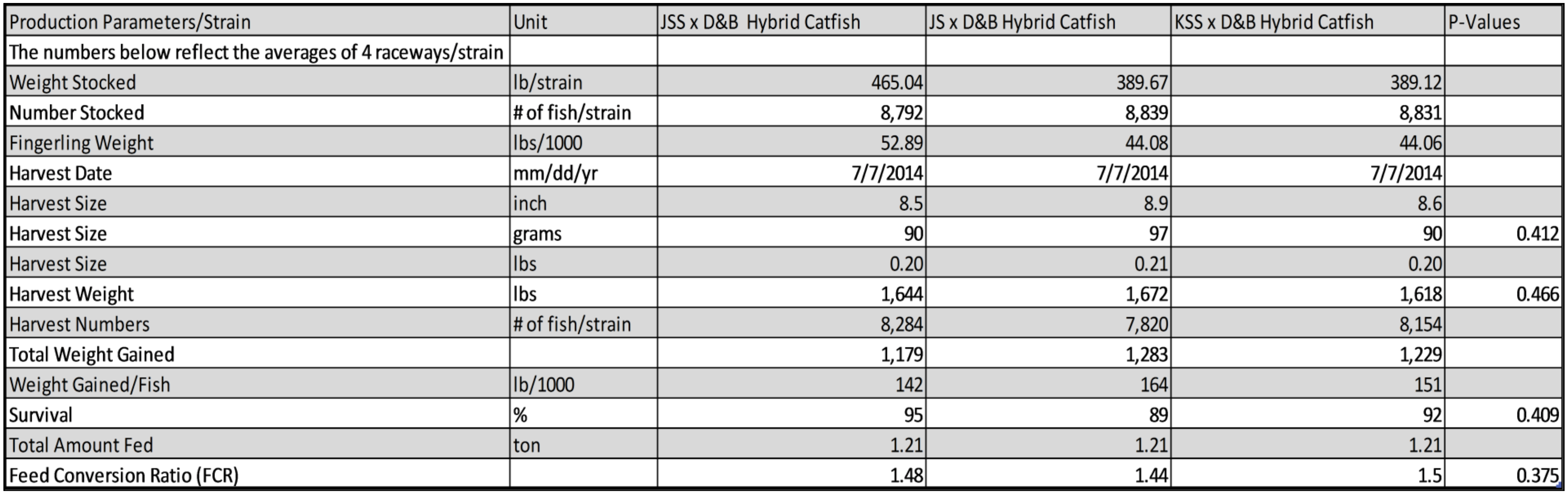
Similarly, FCRs showed only small, non-significant levels of variation among the three crosses with JS x D&B having the lowest FCR at 1.44:1, KSS x D&B with the highest FCR at 1.5:1, and JSS x D&B with an FCR of 1.48:1. There was no evidence of genetic strain or small differences in stocking numbers impacting final biomass on a per raceway basis (Table 3.2), indicating that all three strains were well adapted for growth in the in-pond raceways and not constrained by biomass within each cell. Lack of statistical differences between crosses was likely due in part to the early selective pressures imposed by fry-to-fingerling rearing in the flow-through tank system. It will be important in future studies to conduct side-by-side comparisons of growth of fingerlings whose early rearing was carried out in the tank system versus fingerlings reared from fry in traditional fingerling ponds.

As mentioned earlier the fish were harvested and transported to ACI Farms/Harvest Select in Marion Junction, Alabama where the fish were stocked and used in another raceway study/demonstration in 10'x 40'x4' raceway cells were stocked with the hybrids and compared to channel catfish grown in neighboring raceway cells. In order to get the necessary stocking numbers, the hybrid crosses used in this study were mixed together and stocked into 2 raceway cells. Production parameters were taken at the end of the study and averaged across the hybrid raceways cells. Table 3.2 shows their feed conversion ratio (FCR) was 1.46, percent survival was 91.9%, and a final harvest size of 0.87 lbs (Wilson Holland, personal communication).



Hybrid Production in ACI Farms Raceways	
Size Stocked(lb/1000)	200
Crop Duration(Duration)	125
Harvest Pounds(lbs)	9,892
Harvest Size(lbs/each)	0.87
Weight Gained(lbs)	7425
Gain per Day(lbs/day)	59
FCR (feed fed/[End wt-beg wt])	1.46
Survival %	91.9%

Table 3.3 Hybrid Catfish Production in Floating In-Pond Raceways at ACI Farms/ Harvest Select in Marion Junction, AL.



Production Parameters/Strain	Unit	JSS x D&B Hybrid Catfish	JS x D&B Hybrid Catfish	KSS x D&B Hybrid Catfish	P-Values
The numbers below reflect the averages of 4 raceways/strain					
Weight Stocked	lb/strain	465.04	389.67	389.12	
Number Stocked	# of fish/strain	8,792	8,839	8,831	
Fingerling Weight	lbs/1000	52.89	44.08	44.06	
Harvest Date	mm/dd/yr	7/7/2014	7/7/2014	7/7/2014	
Harvest Size	inch	8.5	8.9	8.6	
Harvest Size	grams	90	97	90	0.412
Harvest Size	lbs	0.20	0.21	0.20	
Harvest Weight	lbs	1,644	1,672	1,618	0.466
Harvest Numbers	# of fish/strain	8,284	7,820	8,154	
Total Weight Gained		1,179	1,283	1,229	
Weight Gained/Fish	lb/1000	142	164	151	
Survival	%	95	89	92	0.409
Total Amount Fed	ton	1.21	1.21	1.21	
Feed Conversion Ratio (FCR)		1.48	1.44	1.5	0.375

Table 3.4 Production Parameters for JSS x D&B, JS x D&B, and KSS x D&B hybrid stockers produced in FIPRS.

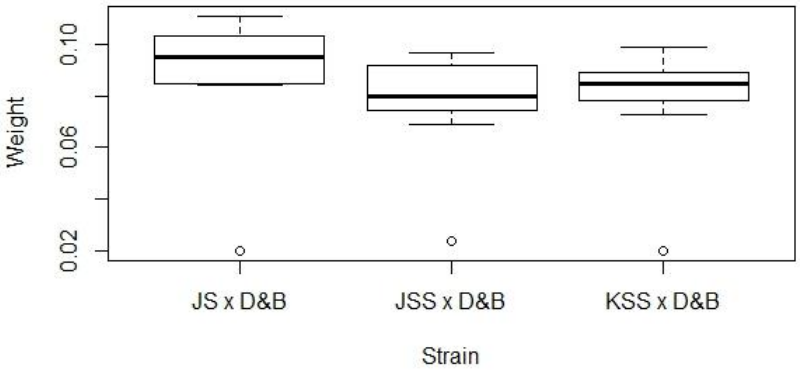


Figure 3.1 Distribution boxplot of growth for the 3 hybrid catfish crosses.

Individual Fish Length Weight Regression

During final harvest, 3-4 sample counts of 50 fish each were taken from each cross to determine growth. From these sample counts, the fish were individually weighed and measured for length weight data analysis. Length weight regressions were made for all three crosses to show their growth and size distributions. While JS x D&B and KSS x D&B (Figures 3.3 & 3.4) showed strong correlations between length and weight (r^2 -value of 0.7637 and 0.6547, respectively), JSS x D&B had an r^2 –value of .0004 (Figure 3.2). The lack of correlation between length and weight in this cross was surprising. Several explanations are possible from data collection error to raceway effects to a genetic basis. Batches of fry have on occasion high numbers of "stump-body" fish, fish which may gain weight normally but do not show expected length growth (Dunham 1991; Bosworth and Waldbieser 2014). These fish alongside phenotypically normal fish can wreak havoc on length/weight correlations. We did observe a number of stump-body phenotype fish among all hybrid crosses and these fish may have been in a larger proportion in the JSS x D&B cross. Additionally, as strong selective pressure has been applied on these fish, the result may be a subset of fish eating voraciously and reaching high weights without commensurate gains in length. Future studies should examine growth of these hybrid crosses with varying feed regimens and varying flow regimes to examine the impact of these factors on producing a more uniform stocker size distribution. Additionally, future studies should examine these distributions in hybrid crosses carried to food-fish size.

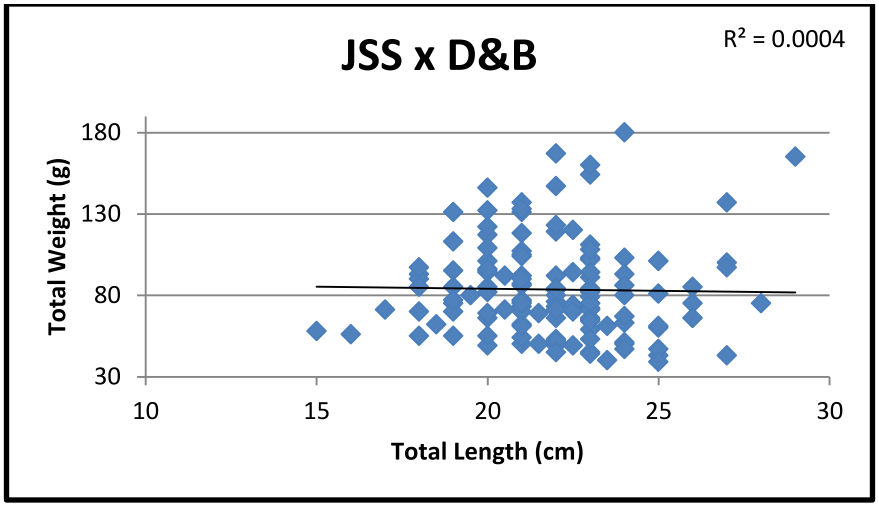


Figure 3.2 Length weight regression with a trendline and r-value for JSS x D&B.

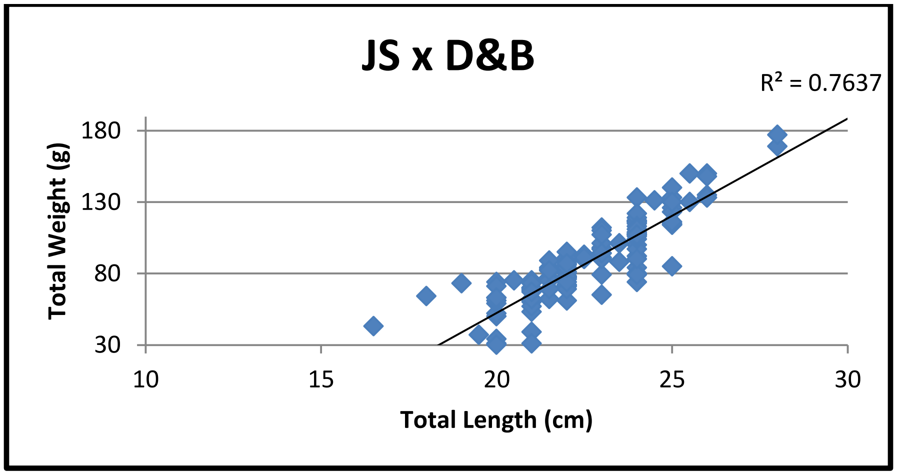


Figure 3.3 Length weight regression with a trendline and r-value for JS x D&B.

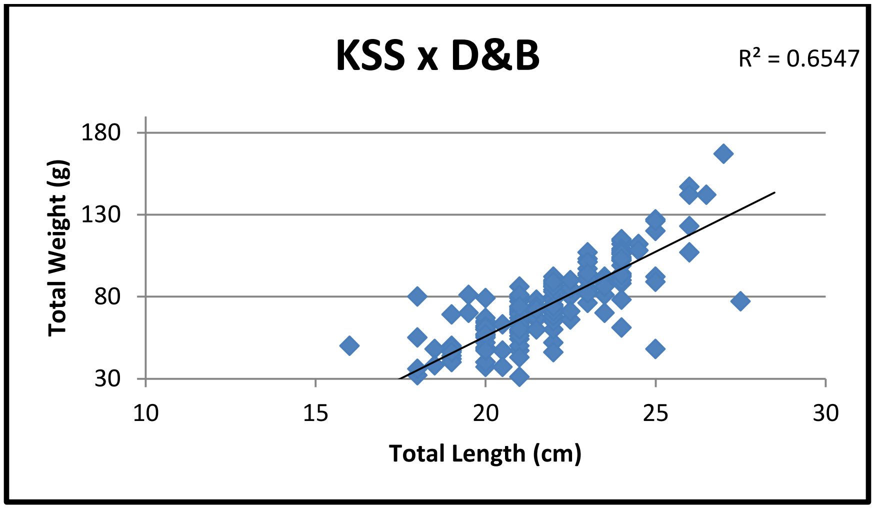


Figure 3.4 Length weight regression with a trendline and r-value for KSS x D&B.

Environmental Parameters

Dissolved Oxygen

A low level of dissolved oxygen is the most common water quality problem in fish production. Catfish fingerling growth can be dramatically impacted if D.O. levels drop and remain below 3 parts per million (ppm) for long periods of time (Andrews et al 1973). Although death may not be a result of low D.O., the amount of stress induced usually leads to a higher chance of disease outbreak in the system (Andrews et al 1973).

While pond producers are used to diurnal swings in oxygen, raceway production can largely eliminate these detrimental fluxes in oxygen levels. Indeed, dissolved oxygen levels remained constant throughout the study and never dropped to a critical level (Figure 3.5). The D.O. data from both morning and afternoon checks were averaged together by month so that the month trend could be seen. Lower D.O. levels were recorded in the mornings and during the warmer months. D.O. levels varied from 4.5 ppm at its lowest point in October to its highest point at 11.5 ppm in January.

The daily temperature data from morning and afternoon checks were averaged together by month so that monthly temperature data could be presented. Temperatures were measured at the same time that D.O. readings were measured. Temperatures were recorded from October 20, 2013 until the end of the study on July 6, 2014. The temperatures varied from the lowest temperature recorded in January at 5°C to the highest temperature recorded in July at 31°C.

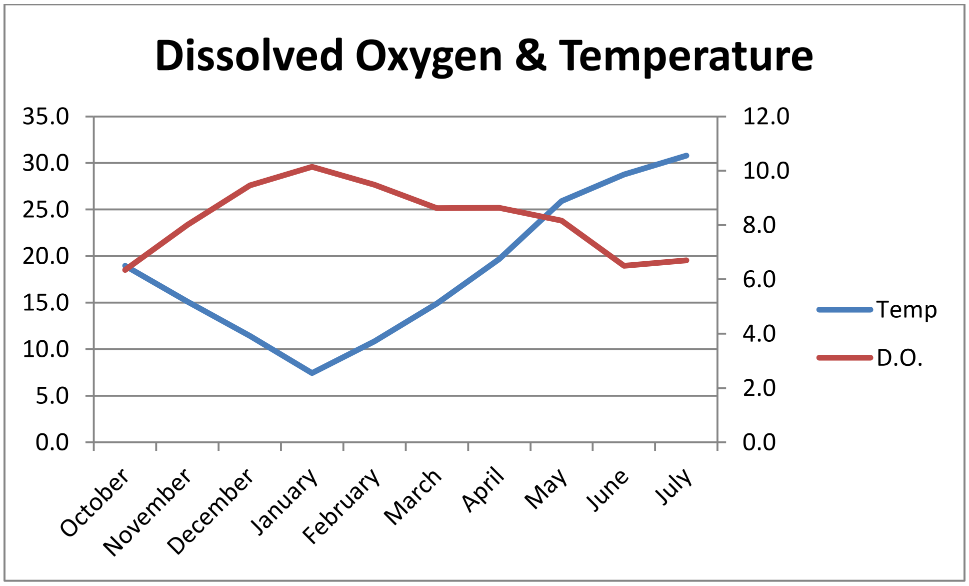


Figure 3.5 Dissolved oxygen and temperature chart for the FIPRS during the time of the study.

System Economics

Initial Investment Cost for FIPRS

It should be noted that this FIPRS were designed and built for research purposes and not for production purposes so bigger cells holding more volume would be necessary for a commercial farm. The cost to construct one floating in-pond raceway cell, which includes the cell itself, air hood, and part of the floating dock was $ 2,917 and the associated equipment and gear, including the blower, back-up generator, electrical system, and propane tank installation was $2,431, for a total cost of $5,348 (Fern 2014). The construction cost for a 12-cell FIPRS unit was $34,998 with machinery and equipment cost of $29,176 for a total system cost of $64,174.

Electricity Usage

The advantage of stable dissolved oxygen and waste-diffusing flow comes at the cost of additional electrical power usage relative to a traditional pond. Power usage was recorded in Kw-H. Daily power usage was 205 Kw-H/day to power 12 cells on the FIPRS. The price per Kw-H was $0.11 accounting for $22.55 in cost per day. In order to better understand costs likely encountered by a producer using a FIPR system for stocker production, subsequent economic analyses were run during the feeding period of 93 days, simulating a scenario of stocking fingerlings into the system in late winter/early spring. Total electricity usage for the system over this period was 19,065 Kw-H which is 6,355 Kw-H/ hybrid cross with a total electricity cost of $699/hybrid cross or a total system cost of $2,097. Future studies should examine ways to reduce these costs particularly while biomass in each raceway is low. In this regard, at the conclusion of this study, we have re-engineered the blowers to allow the 12 raceways to run on shared air from as few as one blower. Production runs in the future will attempt to better match power usage with biomass at a given time point.

Enterprise Budgets

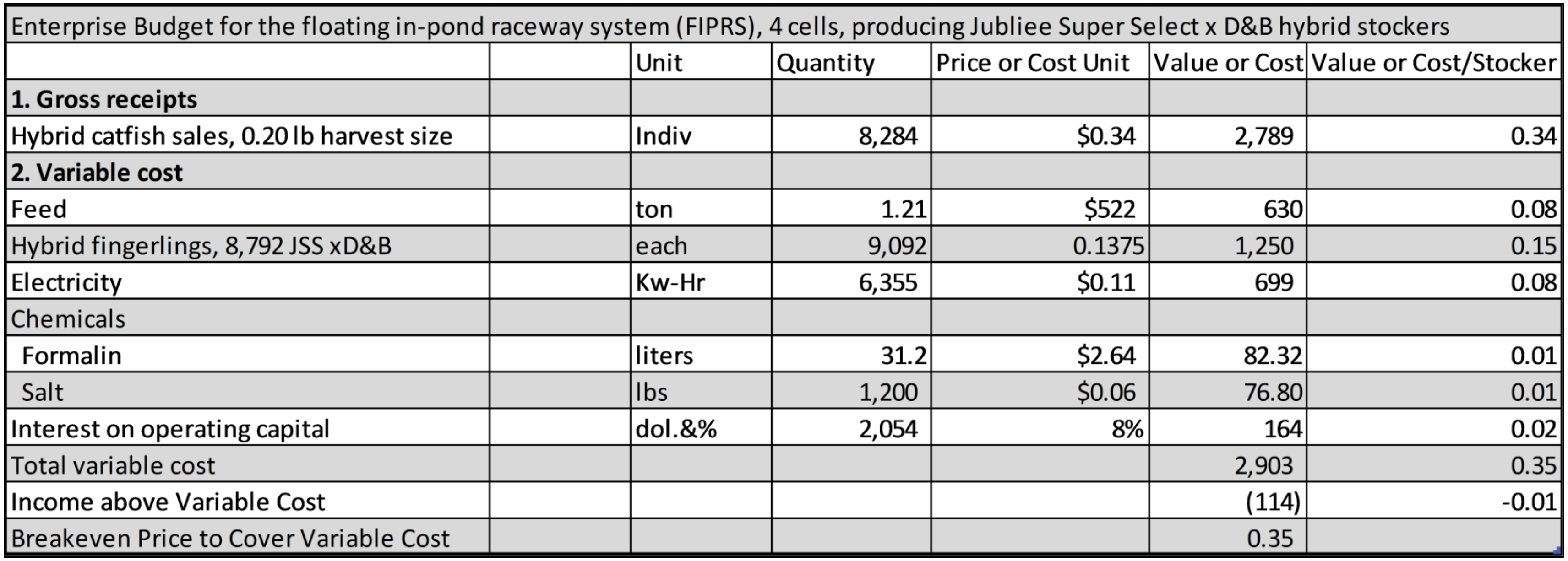
Enterprise budgets were constructed for each of the 3 catfish crosses used in this study. The 4 replicates raceways for each cross were averaged together to form one table per hybrid catfish cross. Enterprise budgets reflect variable costs including costs of purchasing fingerlings. Producers raising their own fingerlings (as done in this study) may have lower variable cost in this category. Additionally, as these studies were for research rather than aimed at profitable production, numbers of fingerlings stocked per raceway were not optimized. We estimate that for stocker generation, producers could go as high as 10-15 thousand fingerlings stocked without adverse consequences on growth, dramatically changing the profitability of this approach from that shown below. Future production studies should determine the number of stockers and associated biomass which can be achieved without undue risk or slowed growth.

Fingerling cost, electricity, and feed composed the three highest variable costs, respectively. Electricity costs, as discussed above, reflect stocking a smaller number of fish in the system than would be advisable in a commercial setting. In order to produce a .20 lbs Jubilee Super Select x D&B hybrid stocker it cost $0.35 per individual fish. The stockers were sold for $0.34/ fish resulting in a total of $2,789 in sales for all the JSS x D&B stockers and variable costs of $2,903 leaving a negative value of $114 (Table 3.5).

In order to produce a .21 lbs Jubilee Select x D&B hybrid stocker it cost $0.37 per individual fish. The stockers were sold for $0.34/ fish resulting in a total of $2,633 in sales for all the JS x D&B stockers. Variable costs reached $2,866 leaving a negative value of $233 (Table 3.6).

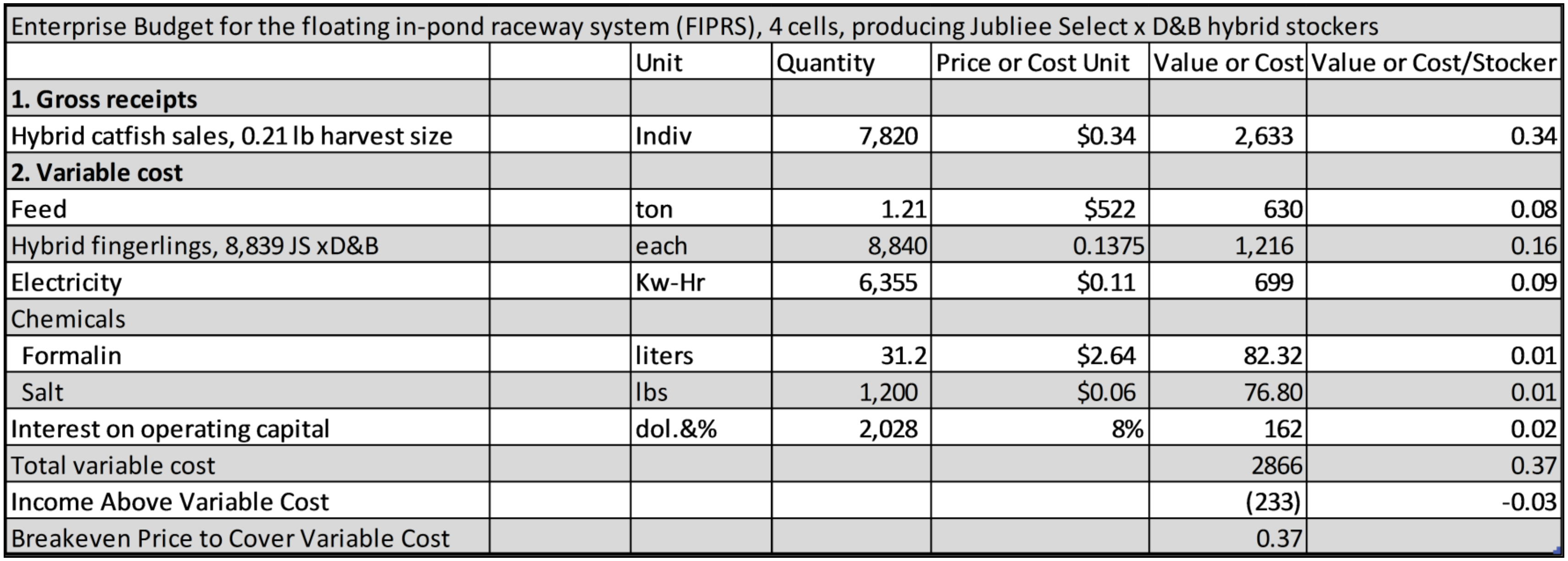
In order to produce a .20 lbs Kansas Super Select x D&B hybrid stocker it cost $0.35 per individual fish. The stockers were sold for $0.34/ fish resulting in a total of $2,746 in sales. Costs reached $2,865 leaving a negative value of $119 (Table 3.7).

In this study, raceway cells were not stocked to full capacity since the goal was genetic comparison rather than full production. However, to allow for high electricity costs, production-level scenarios where stocking numbers were increased from 2,000 fingerlings/cell to 10,000 fingerlings/cell were run for JSS x D&B, JS x D&B, and KSS x D&B (Tables 3.8- 3.10). Assuming that feed amounts, growth, and survival would stay the same for higher stocking numbers all the variable costs could be determined. Stocker price also remained the same at $0.34/ catfish stocker. Four raceway cells would produce about 40,000 stockers so one FIPRS with 12 cells could produce about 120,000 hybrid catfish stockers and show profits of $4,011 for JSS x D&B, $3,413 for JS x D&B, and $3,982 for KSS x D&B.



Enterprise Budget for the floating in-pond raceway system (FIPRS), 4 cells, producing Jubliee Super Select x D&B hybrid stockers						
		Unit	Quantity	Price or Cost Unit	Value or Cost	Value or Cost/Stocker
1. Gross receipts						
Hybrid catfish sales, 0.20 lb harvest size		Indiv	8,284	$0.34	2,789	0.34
2. Variable cost						
Feed		ton	1.21	$522	630	0.08
Hybrid fingerlings, 8,792 JSS xD&B		each	9,092	0.1375	1,250	0.15
Electricity		Kw-Hr	6,355	$0.11	699	0.08
Chemicals						
Formalin		liters	31.2	$2.64	82.32	0.01
Salt		lbs	1,200	$0.06	76.80	0.01
Interest on operating capital		dol.&%	2,054	8%	164	0.02
Total variable cost					2,903	0.35
Income above Variable Cost					(114)	-0.01
Breakeven Price to Cover Variable Cost					0.35	

Table 3.5 Partial Enterprise Budget for the FIPRS, 4 cells, producing JSS x D&B hybrid stockers.



Enterprise Budget for the floating in-pond raceway system (FIPRS), 4 cells, producing Jubliee Select x D&B hybrid stockers

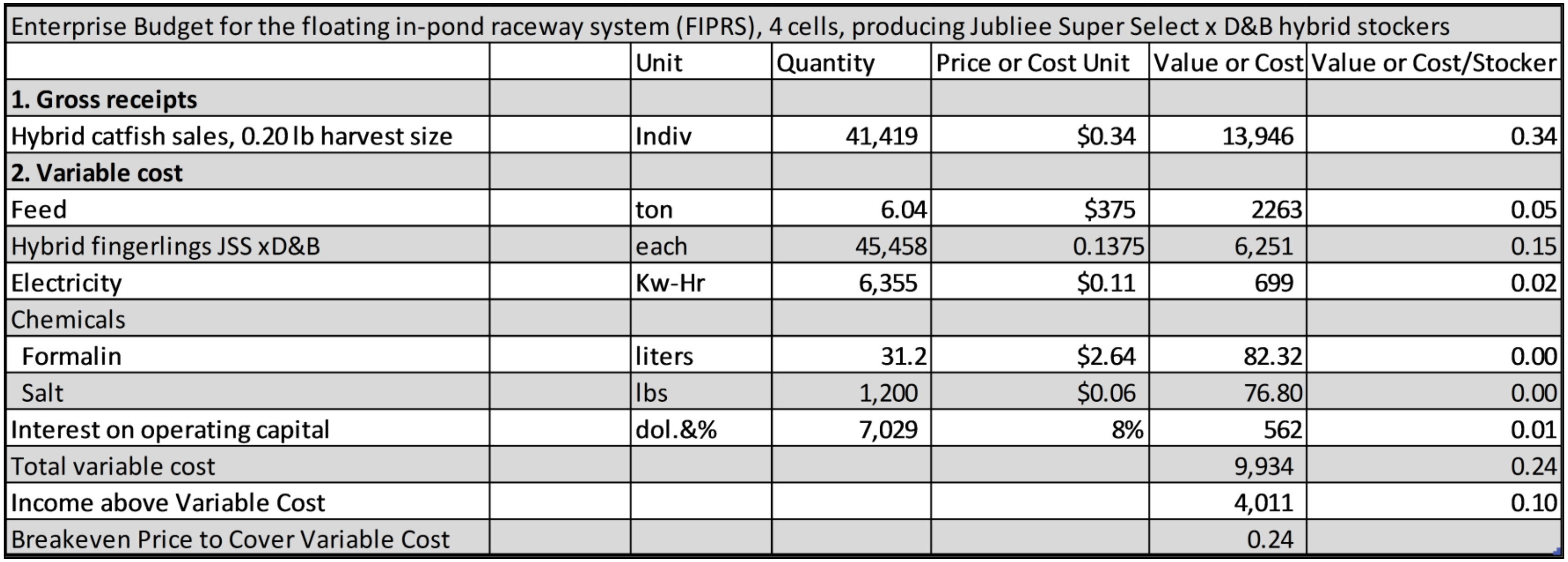
		Unit	Quantity	Price or Cost Unit	Value or Cost	Value or Cost/Stocker
1. Gross receipts						
Hybrid catfish sales, 0.21 lb harvest size		Indiv	7,820	$0.34	2,633	0.34
2. Variable cost						
Feed		ton	1.21	$522	630	0.08
Hybrid fingerlings, 8,839 JS xD&B		each	8,840	0.1375	1,216	0.16
Electricity		Kw-Hr	6,355	$0.11	699	0.09
Chemicals						
Formalin		liters	31.2	$2.64	82.32	0.01
Salt		lbs	1,200	$0.06	76.80	0.01
Interest on operating capital		dol.&%	2,028	8%	162	0.02
Total variable cost					2866	0.37
Income Above Variable Cost					(233)	-0.03
Breakeven Price to Cover Variable Cost					0.37	

Table 3.6 Partial Enterprise Budget for the FIPRS, 4 cells, producing JS x D&B hybrid stockers

Enterprise Budget for the floating in-pond raceway system (FIPRS), 4 cells, producing Kansas Super Select x D&B hybrid stockers

		Unit	Quantity	Price or Cost Unit	Value or Cost	Value or Cost/Stocker
1. Gross receipts						
Hybrid catfish sales, 0.21 lb harvest size		Indiv	8,154	$0.34	2,746	0.34
2. Variable cost						
Feed		ton	1.21	$522	630	0.08
Hybrid fingerlings, 8,839 JS xD&B		each	8,833	0.1375	1,214	0.15
Electricity		Kw-Hr	6,355	$0.11	699	0.09
Chemicals						
Formalin		liters	31.2	$2.64	82.32	0.01
Salt		lbs	1,200	$0.06	76.80	0.01
Interest on operating capital		dol.&%	2,027	8%	162	0.02
Total variable cost					2865	0.35
Income Above Variable Cost					(119)	-0.01
Breakeven Price to Cover Variable Cost					0.35	

Table 3.7 Partial Enterprise Budget for the FIPRS, 4 cells, producing KSS x D&B hybrid stockers.



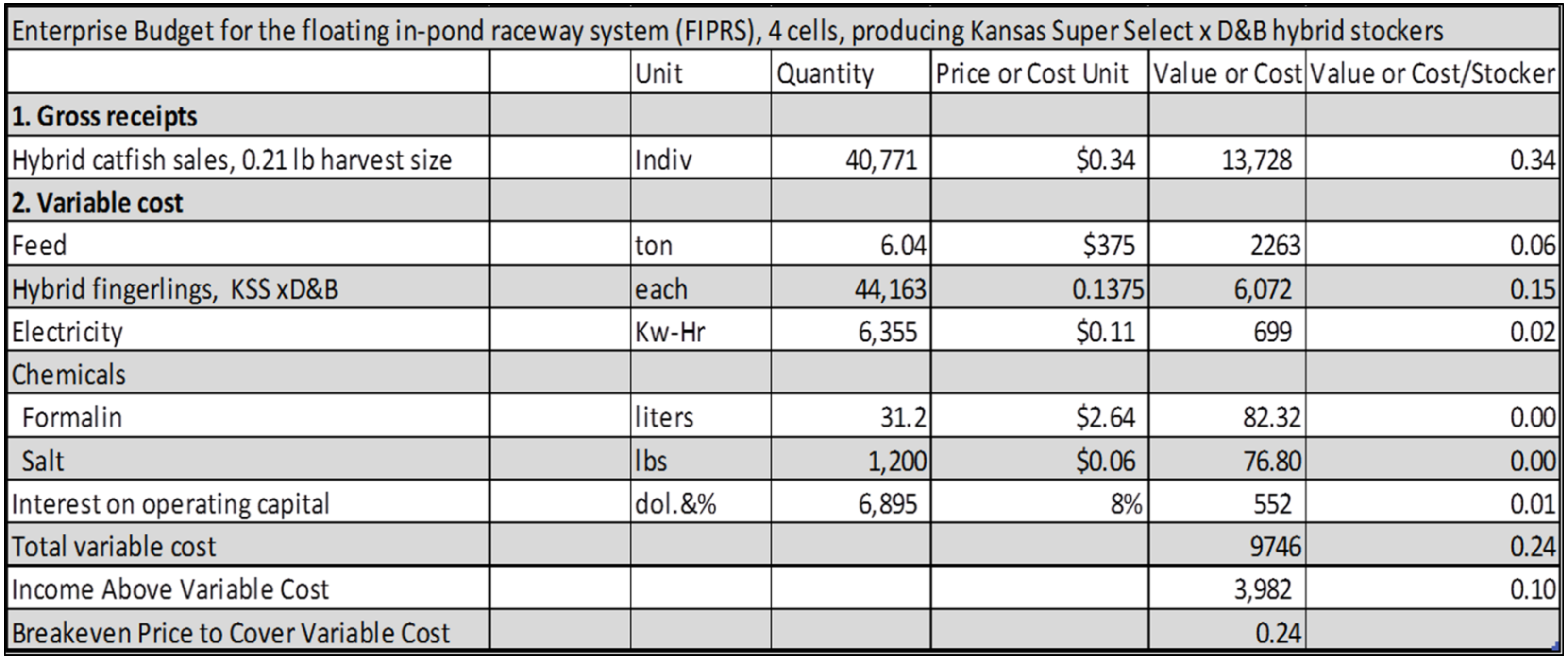
Enterprise Budget for the floating in-pond raceway system (FIPRS), 4 cells, producing Jubliee Super Select x D&B hybrid stockers						
		Unit	Quantity	Price or Cost Unit	Value or Cost	Value or Cost/Stocker
1. Gross receipts						
Hybrid catfish sales, 0.20 lb harvest size		Indiv	41,419	$0.34	13,946	0.34
2. Variable cost						
Feed		ton	6.04	$375	2263	0.05
Hybrid fingerlings JSS xD&B		each	45,458	0.1375	6,251	0.15
Electricity		Kw-Hr	6,355	$0.11	699	0.02
Chemicals						
Formalin		liters	31.2	$2.64	82.32	0.00
Salt		lbs	1,200	$0.06	76.80	0.00
Interest on operating capital		dol.&%	7,029	8%	562	0.01
Total variable cost					9,934	0.24
Income above Variable Cost					4,011	0.10
Breakeven Price to Cover Variable Cost					0.24	

Table 3.8 Partial Enterprise Budget Scenario for the FIPRS, 4 cells, producing JSS x D&B hybrid stockers.

Enterprise Budget for the floating in-pond raceway system (FIPRS), 4 cells, producing Jubliee Select x D&B hybrid stockers

		Unit	Quantity	Price or Cost Unit	Value or Cost	Value or Cost/Stocker
1. Gross receipts						
Hybrid catfish sales, 0.21 lb harvest size		Indiv	39,098	$0.34	13,164	0.34
2. Variable cost						
Feed		ton	6.04	$375	2263	0.06
Hybrid fingerlings JS xD&B		each	44,200	0.1375	6,078	0.16
Electricity		Kw-Hr	6,355	$0.11	699	0.02
Chemicals						
Formalin		liters	31.2	$2.64	82.32	0.00
Salt		lbs	1,200	$0.06	76.80	0.00
Interest on operating capital		dol.&%	6,899	8%	552	0.01
Total variable cost					9751	0.25
Income Above Variable Cost					3,413	0.09
Breakeven Price to Cover Variable Cost					0.25	

Table 3.9 Partial Enterprise Budget Scenario for the FIPRS, 4 cells, producing JS x D&B hybrid stockers.



Enterprise Budget for the floating in-pond raceway system (FIPRS), 4 cells, producing Kansas Super Select x D&B hybrid stockers

		Unit	Quantity	Price or Cost Unit	Value or Cost	Value or Cost/Stocker
1. Gross receipts						
Hybrid catfish sales, 0.21 lb harvest size		Indiv	40,771	$0.34	13,728	0.34
2. Variable cost						
Feed		ton	6.04	$375	2263	0.06
Hybrid fingerlings, KSS xD&B		each	44,163	0.1375	6,072	0.15
Electricity		Kw-Hr	6,355	$0.11	699	0.02
Chemicals						
Formalin		liters	31.2	$2.64	82.32	0.00
Salt		lbs	1,200	$0.06	76.80	0.00
Interest on operating capital		dol.&%	6,895	8%	552	0.01
Total variable cost					9746	0.24
Income Above Variable Cost					3,982	0.10
Breakeven Price to Cover Variable Cost					0.24	

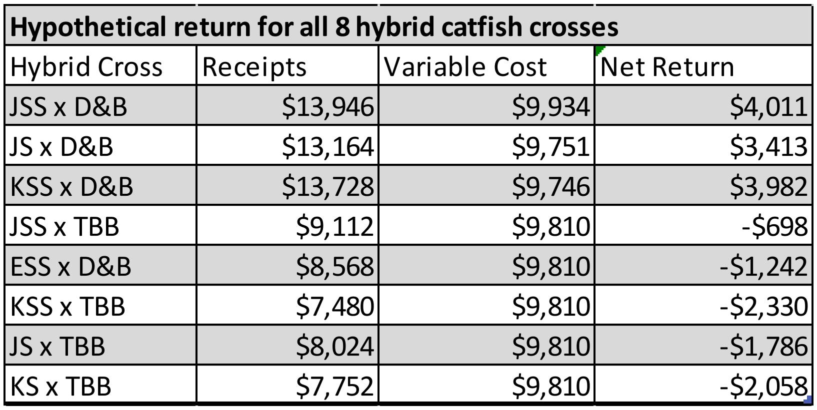
Table 3.10 Partial Enterprise Budget Scenario for the FIPRS, 4 cells, producing KSS x D&B hybrid stockers.

Net Return Scenarios for all Hybrid Catfish Crosses

As previously shown if the stocking numbers of fingerlings were increased from 2,000 to 10,000 fingerlings per cell then the FIPRS could operate at a profit (variable costs only) producing stocker catfish. The first part of the study showed the eight hybrid catfish crosses that were grown from fry to fingerlings and from those results only three crosses were used based on growth and survival. However, we are also interested in scenarios where unselected fingerlings from other hybrid crosses were stocked as fingerlings in the raceway. Table 3.11 shows the prospective results if all eight hybrid catfish crosses were grown from fingerlings to stockers in the FIPRS.

Similar growth and survival was noted in fry to fingerling grow-out as in fingerling to stocker grow-out for the three hybrid crosses used, JSS x D&B, JS x D&B, KSS x D&B. Assuming that the same parallel would be seen in the other five hybrid crosses, JSS x TBB, ESS x D&B, KSS x TBB, JS x TBB, and KS x TBB, a hypothetical situation in which these 5 crosses were grown from fingerling to stocker catfish in FIPRS was developed.

The receipts value is determined by using the stocking number of 40,000 fingerlings and multiplying it by survival rate to determine the harvest quantity. Once harvest quantity has been determined it is multiplied by price of stockers, which was $0.34/stocker, to determine the total receipt cost for each cross (ex. 40,000*survival rate*0.34/stocker). Variable cost (Table 3.8-3.10) includes feed cost, fingerling cost, electricity cost, and chemical costs. Net return value is determined by subtracting variable cost from receipts. Receipts and variable cost were determined for JSS x D&B, JS x D&B, KSS x D&B previously in tables 3.8, 3.9, and 3.10. In order to determine receipts for the other five hybrid crosses, survival during the fry to fingerling stage were used (Table 3.1). The variable cost for these 5 crosses came from averaging variable cost from JSS x D&B, JS x D&B, and KSS x D&B.



Hypothetical return for all 8 hybrid catfish crosses

Hybrid Cross	Receipts	Variable Cost	Net Return
JSS x D&B	$13,946	$9,934	$4,011
JS x D&B	$13,164	$9,751	$3,413
KSS x D&B	$13,728	$9,746	$3,982
JSS x TBB	$9,112	$9,810	-$698
ESS x D&B	$8,568	$9,810	-$1,242
KSS x TBB	$7,480	$9,810	-$2,330
JS x TBB	$8,024	$9,810	-$1,786
KS x TBB	$7,752	$9,810	-$2,058

/1. Stocker selling price is $0.34/ stocker.

/2. The variable cost for JSS x TBB-KS x TBB is the average variable cost for JSS x D&B-KSS x D&B.

Table 3.11 Hypothetical net return for all 8 hybrid catfish crosses if grown from fingerling to stockers in FIPRS.

The result of this analysis, while based on projected data, again indicate the value of selection of hybrid crosses suited for intensive environments rather than treating hybrid catfish as a single genotype with uniform growth and disease resistance characteristics.

Chapter 4

Summary and Conclusion

In recent years, the US catfish industry has made positive advances in intensifying fish production techniques with systems such as recirculating aquaculture systems, intensive aeration approaches, partitioned aquaculture systems, in-pond raceways, and split-ponds. Production volumes now commonly reach greater than 12,000 lbs/acre. The hybrid catfish has been integral to these intensified approaches, demonstrating the importance of optimizing genetics for a given production strategy. Floating in-pond raceways offer a flexible, lower cost approach to intensive production. Unlike other approaches, it also offers the potential for real-time evaluation of genetic potential through the use of replicated unit sharing a common water source. In this study, therefore, we utilized research-scale in-pond raceways for evaluation of the growth of three hybrid crosses from fingerling to stocker. Several findings from this study may be useful in application to commercial-level trials and/or in setting the direction of future research.

1) Early rearing of fry in intensive systems such as recirculating aquaculture tanks or modified raceways may help select for superior performance and disease resistance in later fish growth in intensive systems. Currently, fingerlings used in evaluation of raceway and split-pond approaches are, in the vast majority of cases, reared in traditional fingerling ponds. Upon stocking in the intensive system, unselected fingerlings have, in certain cases, shown high disease related mortality levels. While these issues can be ameliorated in part by a careful regimen of prophylactic chemical treatments, a better

2) solution is the identification and selection of robust genetic stocks during fry-to-fingerling rearing. The three best performing hybrid crosses in early rearing continue to excel when transferred to the in-pond raceways. Further study is needed to observe whether these crosses would show significant performance differences if carried to food-fish size in the same units.

3) A significant learning curve is associated with development of new best management practices for raceway rearing of catfish. While not necessarily reflected in the objectives of this study, operating these new systems allowed day-by-day observance of the costs and benefits of this approach. Dissolved oxygen levels were remarkably stable, providing peace of mind during summer months not enjoyed by farmers in traditional pond production. However, high dissolved oxygen levels came at a significant economic cost in terms of higher electrical costs. These costs can be overcome at higher production levels, but producers need to carefully match up blower usage with biomass needs, to avoid mounting power costs on fish during maintenance feeding/over-wintering periods. Daily maintenance tasks can also require additional labor. Raceway screens and hoods need scrubbing on a daily basis, systems needs to be closely monitored for fish mortalities, chemical treatments are conducted weekly, generators need weekly checks, and floats, screens, and shade cloths require repairs. Additionally, harvest of the floating in-pond raceways is still being optimized, with current strategies under study including fish pumps and a live car raceway attachment.

4) In-pond raceways provide an excellent research platform for conducting studies of genetics, therapeutants, or diets. We achieved remarkably consistent production results across all twelve raceways, indicating the importance of conducting replicated studies in a shared environment rather than replicated ponds which vary in water chemistry and algal population dynamics. Future studies on selected hybrid crosses could further optimize production protocols through examination of performance of improved diets, following the poultry model of wedding genetics, nutrition, and environment for maximal production.

5) Among the 3 evaluated hybrid crosses, JSS x D&B, JS x D&B, and KSS x D&B, significant differences were not observed, with all three crosses demonstrating excellent growth, survivability, and FCRs to stocker size. In future studies, one or more of these crosses should be further evaluated at a) higher stocking densities, b) in a full production cycle, and c) in comparison to unselected hybrid catfish and channel catfish lines to determine improvement over currently used genetic lines.

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