Factors Affecting the Frequency of Oversized and Undersized Channel Catfish, *Ictalurus punctatus*, ♀ X Blue Catfish, *I. furcatus*, ♂ Hybrid Catfish at Food Fish Harvest and their Economic Impact

by

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Abstract

Hybrid catfish (channel catfish, *Ictalurus punctatus,* ♀ x blue catfish, *I. furcatus,* ♂) farming is a prime example of yield intensification but has witnessed growth variability problem. Investigating the causative factors of such problem and the economic impact analysis are critical to understand fish producer's profitability related to the fish processor's demand for specifically sized categories of fish (undersized, premium, and oversized). A comprehensive industry-wide fish sampling and survey were conducted in Mississippi, Arkansas, and Alabama from 2015 to 2017. In total, 164 culture units were sampled, which included single batch (N=25), multiple batch (N=16), split pond (N= 98) and in-pond raceway system (IPRS, N=25) of which, 4 raceways were from research settings and 21 from commercial settings.

The causative factors of the undersized and oversized hybrid catfish were related to feeding and stocking management. Most of the variables under the feeding, and stocking management and few other operational variables significantly influenced the growth variability of hybrid catfish production. These included feed usage, feed conversion ratio (FCR), stocking density, individual weight of fingerling, number of fish harvest, graded fingerling, pond area, depth, aeration, and fingerling sources.

The best management practices may vary from one production system to another, and the results for the IPRS were the most unique compared to the pond systems. For example, deep ponds reduced oversized fish percentage, but deep raceways increased the oversized fish frequency.

Although, the factors affecting size distribution were not always exactly the same or of the same magnitude among the different production systems, some generalizations can be made regarding which variables such as high stocking rates, stocking of large fingerlings, everyday feeding, relatively high feeding rates, adequate length of culture, use of small ponds, utilization of more than 4 hp/ha (aeration rate) and harvest of large numbers of fish (presumed efficient harvest and grading), had the most impact.

Comparative economic analyses were developed by using standard enterprise budgeting, partial budgeting and sensitivity analysis. Split pond systems were the most profitable enterprise compared to traditional systems (single and multiple batch) and IPRS (research). Split ponds had higher net returns ($8,578/ha), resulting from the highest availability of premium size fish (0.45-1.81 kg in weight and sales price = $2.46/kg). Current analyses also showed that variations in dockage rates for the price of undersized (sales price = $2.34/kg) and oversized fish (sales price = $2.08/kg), had a significant economic impact on net returns that resulted in revenue loss. This loss, in total, was $1,712/ha for undersized and oversized fish, regardless of the production system. Partial budget analyses showed that using 20 cm fingerlings was economically feasible, but it resulted in lesser net returns to operator's labor, and management compared to medium size fingerlings (18 cm). Sensitivity analyses also showed that split pond systems would give greater net returns compared to other production systems for all potential scenarios of decreasing dockage prices for undersized and oversized fish at the 25%, 50%, and 75% reductions to the base sales price.

Dedication

To my beloved mom, Mrs. Kalpana Rani Ghosh, without her continuous inspiration and support, this long journey of my life, especially adhering to education would not be possible

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List of Abbreviations

IPRS	In-pond raceway system
FCR	Feed conversion ratio
CV	Coefficient of variation
TVC	Total variable cost
TC	Total cost
TFC	Total fixed cost
BEY	Breakeven yield
BEP	Breakeven price
ANOVA	Analysis of variance
FAO	Food and Agriculture Organization
Avg.	Average
SD	Standard deviation
Poly	Polynomial
U.S	United States of America
USDA	United States Department of Agriculture

CHAPTER ONE
GENERAL INTRODUCTION

Introduction

World Aquaculture

The growth of global fish supply used for human consumption has been increasing at an impressive rate, which has already been outpaced the population growth (FAO 2016). Global per capita fish consumption has recently increased to 20 kg per year for the first time in its history (FAO 2016). The aquaculture sector is the main contributor in this progression paradigm, which contributes approximately 44% to the human consumption in 2014 in relative to 7% in 1974 (FAO 2016). However, the contribution from the global capture fisheries sector had remained static since 1980 (FAO 2016). Countries from Asia, America (includes North America, Latin America and the Caribbean only), Africa, Europe, and to some lesser extent, Oceania are playing the major role (FAO 2016). The U.S. aquaculture sector has been continuously growing (Fig. 1.1) as this sector has proven to be a profitable and feasible enterprise (Engle, 2004)

U.S. Aquaculture

The U.S. aquaculture sector is comprised of food fish, ornamental fish, baitfish, mollusks, crustaceans, and other fish production (NASS 2014). These species grow in a wide range of climates. Among these species, catfish is the most prominent and commonly cultured species in the U.S. (NASS 2014; Engle 2004).

U.S. aquaculture had contributed approximately 276 million kilograms of freshwater and marine water species, valued at approximately $1.33 billion in 2014 (NMFS 2016). This output, however, slightly declined by 8.30 million kilograms in volume and $4 million in value from the previous year (2013) (NMFS 2016). In general, this aquaculture sector had contributed nearly $1.4 billion to the U.S economy (2013), where Southern states alone (Alabama, Arkansas, Mississippi and Texas) contributed 32% in 2013 (NASS 2014). The per capita fish consumption in the U.S also increased from 6.62 kg (2014) to 7.03 kg (2015) (NMFS 2016). U.S farm raised catfish remained in eighth position (2013), a slight decline from the sixth position (2006), as catfish was consumed at a constant rate of 0.56 pound/head/year (Hanson and Sites 2015). This was a slight rise from the ninth position in 2012 (Hanson and Sites 2015). Consumption rate of *Pangasius bocourti* and *Pangasius hypophthalmus* (or Vietnamese basa and tra) had surpassed U.S farm raised catfish since 2010 and rose to sixth place in 2012 and stayed there in 2013 (Hanson and Sites 2015). Similarly, tilapia also surpassed the U.S farm raised catfish in 2003 and remained at number four since 2013 (Hanson and Sites 2015).

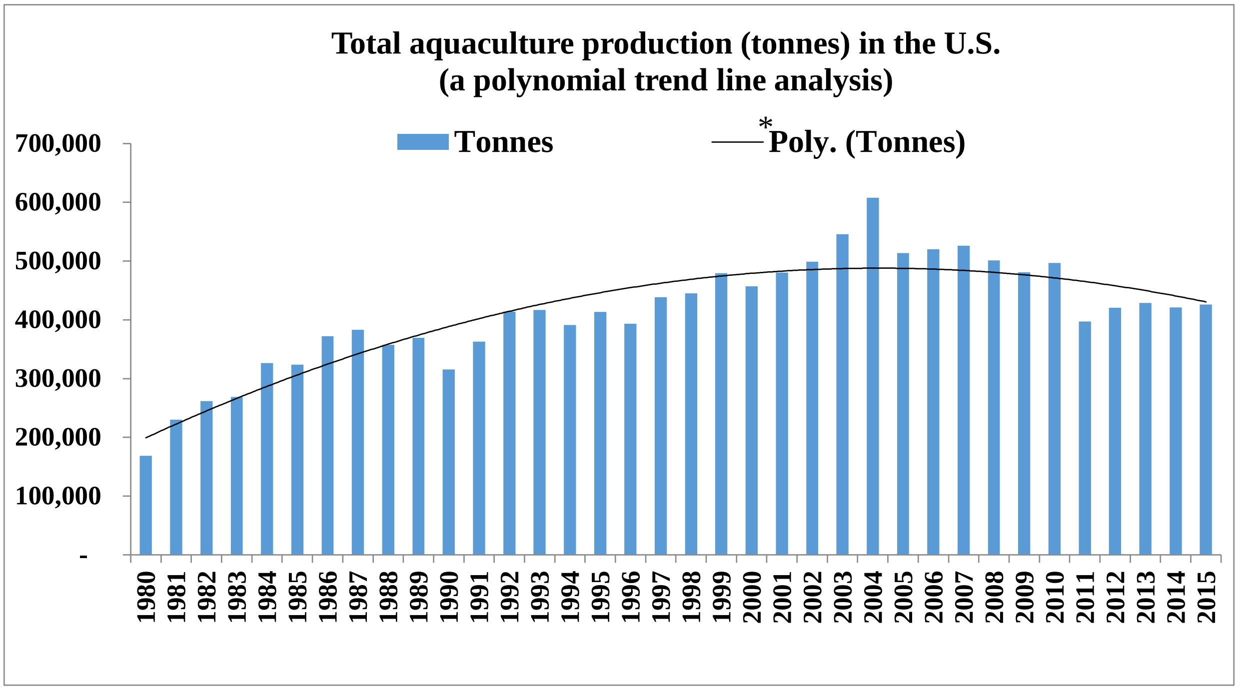

Figure 1.1. Total aquaculture production (tonnes) in the U.S. (a polynomial trend line analysis) (FAO Fishstat Plus 2016) (*Poly.=polynomial trend line, which is an expression consisting of variables and coefficients, that involves only the operations of addition, subtraction, multiplication, and non-negative integer exponents of variables)

U.S catfish industry and rationale

The catfish industry is one of the largest sectors of U.S. aquaculture (Engle 2003), which contributed approximately $386 million to the U.S. economy in 2016 (USDA 2017). Catfish production mostly occurs in the Mississippi, Alabama, Arkansas and Texas, which in combination accounts for 96% of the total sales in the U.S (2016) (USDA 2017). The catfish fry and fingerling sector contributed approximately $11 million to the U.S economy in 2013 (NASS 2014). In general, the overall impact of this industry is substantially greater as it is characterized by higher levels of economic development (Engle 2003). In Mississippi alone, the economic impact of the catfish industry was approximately $816 million, resulting from employment generation, value addition, farm gate sales and processor sales (Avery et al. 2013). Numerous counties have also improved their economic condition from catfish production. A prime example of such improvement is Chicot county, Arkansas, where the catfish industry had generated significant economic growth through total output/production, value addition, employment generation, and thus, increased tax/revenue for the government (Kaliba and Engle 2004).

Channel catfish, *Ictalurus punctatus*, was originally the most cultured species in the U.S (Engle 2003). This species grew and reached marketable size faster than other members of catfish family (Dunham et al. 1993) such as, bullhead catfish (genus *Ameiurus*), flathead catfish (*Pylodictis olivaris*), white catfish (*Ameiurus catus*), and blue catfish (*I. furcatus*). Beginning in the late 1990s, the hybrid between channel catfish females and blue catfish males started to be adopted in the catfish industry (Rex Dunham, personal communication). In 2005, this adoption rate began to rapidly increase and has impressively continued (Li et al. 2014; Nagaraj Chatakondi, personal communication), resulting in the production of 250 million fry in 2017 as this hybrid has proven profitable in commercial settings (Dunham and Masser 2012). At present, this hybrid contributes more than 70% of U.S farm raised catfish production (food fish) in the U.S (Brian Bosworth, and Nagaraj Chatakondi, personal communication). These superior traits of the hybrid catfish include faster growth rate, efficient feed conversion ratio (FCR) (Smitherman et al. 1996; Li et al. 2004), higher survival rate (Dunham et al. 1987), high disease resistance (Wolters et al. 1996; Wolters and Johnson 1995), and tolerance of low dissolved oxygen (Dunham et al.1983).

The hybrid catfish industry has a major problem with oversized food fish, which needs to be addressed as the fish processor demands certain premium-sized fish (0.45 to 1.81 kg or 1 to 4 lb.) based on their dockage rate and policy (Wiese et al. 2006). Out of this size range i.e., undersized (<0.45 kg or 1 lb.) and oversized fish (>1.81 kg or 4 lb.), fish producers are penalized monetarily by the fish processor when the tolerance limit is exceeded by 5-10% (Wiese et al. 2006). This tolerance limit varies across processing plants. Finding the potential factors causing growth variability problems are critical as the fish producers face financial burden due to the increased input costs. The farmer has no financial option to combat the docking rate due to the lack of market power and control in catfish supply chain (Neira 2007). Additionally, the availability of cheap basa and tra catfish in the U.S market imported from Vietnam and/or other Asian countries aggravates these marketing problems. The U.S. imports 80% of its catfish and catfish-like fillet products from Asian countries (Hanson and Sites 2015). Moreover, the governments of the importing countries provide a huge subsidy to their catfish industry, which assist in exporting the catfish to U.S at a cheaper price ((ITA 2012). Hence, catfish producers can face a negative net return created by high fish inventories, low price/export and excessive imports.

Variables related to feeding management, grading, partial harvesting, genetics, strains, and to some extent, stocking density are likely to affect the catfish growth variation (Brooks et al. 1982; Budhabhatti and Maughan 1993; Jiang et al. 2008; Dunham et al. 2014a; Zhang et al. 2016; Mischke et al. 2017) in single batch and multiple batch, split pond and in-pond raceway systems (IPRS). Very little information exists with regards to the effect of these potential factors on the growth variability and economic impact on hybrid catfish production.

The objectives of the current study were 1) to evaluate the potential management techniques that reduce the growth variability problem in hybrid catfish production (food fish) and 2) to analyze the economic impact resulting from the growth variation found in hybrid catfish production (food fish). The overall goal is to develop best management techniques for the hybrid catfish producer that will reduce the growth variability ensuring both short- and long-term economic profitability.

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CHAPTER 2

FACTORS AFFECTING THE FREQUENCY OF OVERSIZED AND UNDERSIZED HYBRID CATFISH (CHANNEL CATFISH, *ICTALURUS PUNCTATUS*, ♀ X BLUE CATFISH, *I. FURCATUS*, ♂) AT FOOD FISH HARVEST IN EXTENSIVE AND INTENSIVE PRODUCTION SYSTEMS

Abstract

Hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) are prone to growth variability under certain environmental conditions, resulting in undersized, but more commonly oversized fish at food fish harvest. The current study indicated that the causative factors were related to feeding and stocking management. Among the variables under feeding management, feed conversion efficiency (FCR), feeding cap and maximum feeding rate were influential factors in producing oversized catfish. Among the variables under stocking management, stocking density, weight of fingerlings, and graded fingerling were the most dominant factors causing growth variability. In multiple batch system, weight of fingerlings, and graded fingerling could, in combination, significantly influence the coefficient of variation.

The current study identified key factors to be included for best management practices. However, further study is needed to find the ideal values for these variables to best accomplish the goal of eliminating oversized and undersized hybrid catfish. The best management practices may vary from one production system to another, and the results for the IPRS were the most unique compared to the pond systems. For example, deep ponds reduced oversized fish percentage, but deep raceways increased the oversized fish frequency. Although, the factors affecting size distribution were not always exactly the same or of the same magnitude among the different production systems, some generalizations can be made regarding which variables cause variability such as high stocking rates, stocking of large fingerlings, everyday feeding, relatively high feeding

rates, adequate length of culture, use of small ponds, utilization of more than 4 hp/ha (aeration rate) and harvest of large numbers of fish (presumed efficient harvest and grading).

Literature Review

Growth variation in food fish production

Fish growth variation usually varies from species to species in food fish production. Feeding frequency and feed intake are likely to be the main factors behind fish growth variability, although it is not clear, which of these two variables or their combination has the greatest impact. Hatlen et al. (2006) noticed that growth variability increased in Atlantic cod production, *Gadus morhua* (L), if the fish were fed in restricted condition. Moreover, food competition also causes growth variation in those fish populations (Hatlen et al. 2006). Zakęś et al. (2006), however, found minor growth variation in pikeperch, *Sander lucioperca* (L.) if the fish were fed either excessive or restricted feedings.

Stocking density had a significant impact on growth variation, which was observed for channel catfish production (food fish), *Ictalurus punctatus* (Budhabhatti and Maughan 1993). Opposite results were observed in other studies as growth variation increased with increasing the stocking density in hybrid yellow catfish production, *Pelteobagrus fulvidraco* (♀) *x P. vachelli* (♂) (Zhang et al. 2016). The coefficient of variation (CV) was 15-30%, when these fish were cultured in aquaria (Zhang et al. 2016).

Genetic and phenotypic variation both impact on growth variation of rainbow trout, *Oncorhynchus mykiss* (Linder et al. 1983). The CV for body weight varied, 16-33%, among strains.

Growth variability among various species of fish is impacted by feeding, stocking density, partial harvesting and genetics (Table 2.1 and, Fig 2.1).

Growth variation in hybrid catfish

Hybrid catfish (channel catfish ♀ x blue catfish ♂) was the best aquaculture candidate among 28 interspecific Ictalurid hybrids (Dunham et al. 2000). These hybrids were generated from channel catfish, blue catfish, black bullhead (*Ameiurus melas*), yellow bullhead (*A. natalis*), brown bullhead (*A. nebulosus*), flathead catfish (*Pylodictis olivaris*), and white catfish (*I. catus*) (Goudie et al. 1993). Channel catfish, ♀ X blue catfish, ♂ has shown faster growth rate (Dunham et al. 1990; Dunham and Brummett, 1999), higher tolerance to low dissolved oxygen concentrations, greater resistance to major bacterial disease such as, enteric septicemia of catfish (ESC, causative agent: *Edwardsiella ictaluri*) (Wolters et al. 1996), higher dress-out percentage (Smitherman et al. 1983; Argue et al. 2003), higher seinability (Dunham et al.1986), better feed conversion efficiency (Li et al. 2004), and lower mortality rates (Dunham et al. 1987). Overall, channel-blue hybrid catfish is likely to have an increased production of 18-100% compared to channel catfish (Dunham et al. 1990; Dunham and Brummett, 1999). Hence, the adoption rate of hybrid catfish farming has been increasing at an impressive rate of 0.5% in 2002 to 70% in 2017 (USDA–APHIS, 2003; Li et al. 2014, Nagaraj Chatakondi, personal communcaiton). Along with these advantages, hybrid catfish farmers have experienced certain impediments such as growth variability (Brooks et al. 1982; Mischke et al. 2017). Two-year old hybrid catfish have been observed to a range from 0.23 kg to 2.26 kg (Wiese et al. 2006). Since the fish processor demands certain premium size fish (0.45 kg to 1.81 kg) as part of their dockage policy, potential management techniques must be developed to address this variability problem. This will ensure not only better processing, but also increased the profitability to the business.

Table 2.1: Potential explanatory variables causing growth variation in food fish production (unit: coefficient of variation, CV, %)

Species	Scientific name	Growth Expression	Explanatory Variables (Xi)	Results (/Relationship)	CV (%) (Y)	References
Hybrid catfish	*Ictalurus punctatus,* ♀ *x I. furcatus,* ♂	Body weight (g)	Strain effect	Proportional[a]	52.10-69.90	Dunham et al. (2014)
			Strain effect	Proportional	50.10-65.00	Dunham et al. (2014)
			Strain effect	Significant[b]	41.80 ± 1.70	Jiang et al. (2008)
			Strain effect	Significant	30.30 ± 2.00	Jiang et al. (2008)
			Partial harvest	Reciprocal[c]	Not studied	Mischke et al. (2017)
Channel catfish	*Ictalurus punctatus*	Body weight (g)	Stocking density	Insignificant[d]	Not studied	Budhabhatti and Maughan (1993)
			Strain effect	Significant	38.60 ± 2.60	Jiang et al. (2008)
			Strain effect	Significant	35.40 ± 2.70	Jiang et al. (2008)
Blue catfish	*Ictalurus furcatus*	Body weight (g)	Strain effect	Significant	29.90 ± 3.90	Jiang et al. (2008)
Hybrid yellow catfish	*Pelteobagrus fulvidraco (♀) X P. vachelli (♂)*	Specific growth rate ($\%d^{-1}$)	Stocking density	Proportional	26.40± 1.27	Zhang et al. (2016)
Brown trout	*Salmo trutta*	Length-at-age	Age	Significant	63.00	Carlson et al. (2016)
Pikeperch	*Sander lucioperca (L.)*	Body weight (g)	Feeding (restricted)	Proportional	1.12 ± 0.05	Zakęś et al. (2006)
			Feeding (excessive)	Proportional	1.17 ± 0.05	Zakęś et al. (2006)
Rainbow trout	*Oncorhynchus mykiss*	Body weight (g)	Genetics	Significant	16.00-33.00	Linder et al. (1983)
			Stress response	Reciprocal	Not studied	Fevolden et al. (2002)

[a] Proportional relationship means the rate of dependent variable (Y) changes equally, when the rate of explanatory variable (Xi) changes; [c] Reciprocal relationship means the rate of dependent variable (Y) changes inversely, when the rate of independent variable (Xi) changes; [b] Significant relationship means p value of the analyzed regression analysis is <0.1; [d] Insignificant relationship means p value of the analyzed regression analysis is >0.01

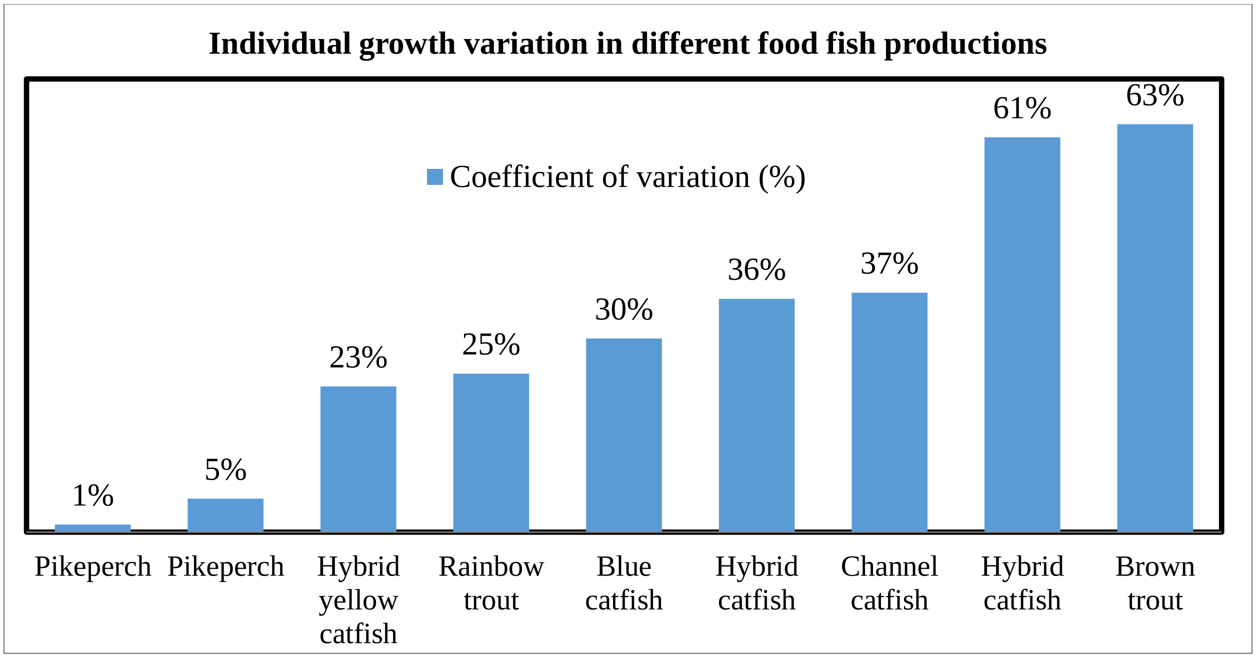

Figure 2.1. Individual growth variation in food fish production (Y= average of coefficient of variation, %) (Linder et al. 1983; Zakęś et al. 2006; Jiang et al. 2008; Dunham et al. 2014; Zhang et al. 2016; Carlson et al. 2016)

Existing hybrid catfish production systems in U.S.

Usually, the production system of hybrid catfish follows similar culture techniques that are used for channel catfish production (Dunham and Masser, 2012). In the U.S., single-batch and multiple-batch systems are the two most commonly practiced systems for channel catfish production (Tucker et al. 1993; Tucker and Robinson 2013); although the basic production system used on most of the commercial farms is a continuous, multiple-batch production system (Engle and Valderrama, 2001; Engle, 2003). However, newer production system include a three-stage production system (Pomerleau and Engle, 2003), in pond raceways (Davis et al. 2017), split-pond systems (Kumar et al. 2016) and intensively aerated pond (Kumar and Engle 2017) as strategies to improve farm productivity and profitability in last decade.

The single- and multiple-batch production systems basically differ in the number of cohorts of fish present in the pond at a given point in time. The single-batch production system is characterized by stocking fingerlings, growing them to the desired size range and completely harvesting them when they reach to 0.4 -0.8 kg/fish (Tucker et al. 1993; Tucker and Robinson 2013) before stocking a new year-class of fingerlings. Since single cohorts of fish are maintained in the pond at one time, this system is beneficial for reducing size variability at harvest, competition and the feed conversion ratio (Schwedler et al. 1989; Schwedler et al. 1990). The single batch production system is more profitable than multiple-batch systems in situations where off-flavor of catfish did not exist (Engle and Pounds 1993). However, the problem of year-round availability and the need to design production systems to allow complete harvest are major limitations to single-batch culture (Terhune et al. 1997).

In multiple-batch cropping systems, commercial catfish farmers stock 10-15 cm (4-6 in) fingerlings each spring at densities varying from 12,000 – 25,000 fingerlings per ha (Engle, 2003), into ponds that have sub-harvestable fish of the previous year. Hence, this system of raising catfish has multiple size cohorts of fish within the same pond, which allows farmers to distribute harvest dates throughout the year (Terhune et al. 1997). The major drawback to this culture system lies in the food competition that exists in between larger and smaller sizes of fish (Collier and Schwedler 1990), which eventually increases the feed conversion ratio (Busch 1985) and to some extent, growth variability. Multiple-batch systems may slow the growth of carry-over fish that are already present in the pond (Engle and Valderrama 2001).

A three-phase system of catfish production was developed to improve production efficiency and increase productivity. This technology may address the need for producing larger fish, which is no longer relevant with the oversized fish problem, required by processors and may also improve inventory control. In this system, stocker catfish between 15 and 33 cm (Pomerleau and Engle 2005) are produced from fingerlings in one growing season and are transferred to grow-out ponds for food fish production. These large-sized fish that are under-stocked might compete for feed more aggressively than fingerlings in multiple-batch ponds and therefore, grow faster. Producing stockers in separate ponds may improve efficiency of use of rearing pond space and result in an increase in overall productivity of the pond (Pomerleau and Engle 2005). The addition of an extra stage may increase net daily gain on the farm, but may also increase the length of the production cycle (Engle, 2003) and consequently the yield and price risk. Hence, the economic feasibility of the three-stage production system over a broad range of economic conditions is doubtful (Pomerleau and Engle 2003). However, Hanson and Steeby (2003) demonstrated higher net returns from a three-phase (modular) system compared to the multiple-batch system.

The split-pond system is a new aquaculture system that is an extension of the partitioned aquaculture system (PAS) (Brown and Tucker 2013). There are approximately 526 ha of split ponds in Mississippi, Arkansas, and Alabama (Brown and Tucker 2013). In this system, the pond is usually split into two unequal basins. The smaller basin usually occupies 15-20% of the total pond area and holds the fish for feeding, aeration and harvesting. The other basin treats the fish waste and produces oxygen through photosynthesis. A barrier is used between these two basins to prevent fish escapement. Water circulates between the two basins during the day, but it is closed at night (Tucker and Kingsbury 2010; Brune et al. 2012). Net annual production on pilot and commercial scale split-pond systems ranges from 16,812 to more than 24,659 kg/ha (Brown and Tucker 2013).

Similarly, in-pond raceway system (IPRS) is an intensive aquaculture system where fish are grown throughout the production cycle either in fixed or floating enclosures within the pond settings (Courtwright 2013). Polyculture can easily be performed in IPRS by growing catfish in one cell and culturing tilapia and paddlefish in the pond (Brown et al. 2010). This can help to control the plankton population while earning extra money from the production system (Brown et al. 2010). Growth uniformity can also be enhanced by reducing the feed competition among different year-classes of fish (Courtwright 2013). Treatment cost can also be minimized by treating the diseased fish only in the targeted IPRS rather treating the whole pond (Courtwright 2013). Seining cost can also be minimized by harvesting the desired year-class from a raceway. A recent production trial showed that hybrid catfish (food fish) can be produced at the rate of 14,978 kg/ha in the raceway compared to conventional ponds (7,800 kg/ha) in Alabama (Davis et al. 2017).

Intensively aerated pond is another production-intensifying practice, where additional electric aerators are installed to increase the productivity. Catfish producers increased aeration rates over time, and some of them, in total 475 ha operation, were using above 12.50 hp/ha (2013) (Kumar and Engle 2015), an increased from 6.25 hp/ha (2010) (USDA–APHIS, 2010). A recent commercial level study has showed that intensively aerated hybrid catfish ponds are an economically feasible enterprise, which could provide an yield of 13,083 ± 2,935 (minimum) to 17,560 ± 2,549 (maximum) (Kumar and Engle 2017).

Aeration is a key part in catfish production that supports increased catfish yield (Torrans 2005). Aeration rates, mostly by using electric paddle wheel aerators, have been increasing from 2.50 hp/ha in 1982 to 6.25 hp/ha in 2010 (Boyd 1998; USDA–APHIS 2010) A recent study showed that the body weight of hybrid catfish increased (an average weight gained by 44%), if dissolved oxygen concentration was maintained at the rate of 3.8 mg/L (total aeration rate maintained was 1.50 hp) when compared to 1.4 mg/L (Torrans et al. 2015) .

Stocking density had a significant effect on the net production of hybrid catfish (Bosworth et al. 2015). Net production was rising with increasing density from 7,425 to 22,275 fish/ha, but was unchanged between 22,275 and 27,225 fish/ha. Percentage of sub-marketable fish (<0.45 kg) was not affected if the stocking density was kept from 7,425 to 22,275 fish/ha (average, 2.3%); but was higher at the rate of 27,225 fish/ha (8.8%). Harvest weight was unchanged between 7,425 to 22,275 fish/ha (average size 0.85kg), but the average fish size was slightly reduced (average, 0.72 kg) at 27,225 fish/ha. Probable explanations for this outcome were overcrowding, lack of equal access to feed, and water quality degradation (Bosworth et al. 2015). The selection of appropriate stocking density depends, in general, on the cropping systems employed (Bosworth et al. 2015), carrying capacity and the input capacity that a farmer could afford based on feed input, aeration and water exchange (USDA–APHIS 2010; Courtwright 2013).

Feed was the single most important variable in estimating the production cost and growth determination in hybrid catfish production (Courtwright 2013). Similar to other fishes, hybrid catfish requires a certain protein percentage, 28%, 32% or 36%, in their diet for optimum growth (Li and Robinson 2012). Changing the protein percentage in the diet (28%, 32% or 36%) did not have a significant impact on the total feed fed, net yield, weight gain, feed conversion ratio (FCR), or survival rate of hybrid catfish (Li and Robinson 2012). However, fish fed with a 36%-protein diet had a higher fillet yield and lower fillet fat compared to the fish fed with a 28%-protein in the diet (Li and Robinson 2012). Besides these, other factors of feed management need to be studied, including feeding until satiation, feeding cap, maximum feeding rate, feeding days and winter feeding. Catfish can grow efficiently if the fish are fed after 90% of satiation (what they can consume in 5-10 minutes of the feeding) (Masser et al. 1997). Feeding more can generate excessive feed wastes that deteriorate the water quality and increase the production cost (Li and Robinson 2012). Even though it was difficult to measure the satiation point during the feeding, Li and Robinson (2012) suggested to feed the catfish at a minimum rate of 112 to 135 kg/ha/day to overcome that problem. The maximum feeding rate should be 168 kg/ha/day (150 lb./ac/day), assuming that the aeration rate is sufficient. Feeding the fish once a day was optimum for production as two times feeding did not affect the net yield and net weight gain in hybrid catfish production. Feeding twice would increase the overfeeding rate (Li and Robinson 2012) and thereby, increase the production cost. Hybrid catfish convert the feed efficiently, particulary with restiricted rations as compared to satiation feeding (Green and Rawles 2010; Li and Robinson 2012).

Wellborn (1986), found that feeding 7 days (/whole week) reduced the production period in channel catfish by four weeks compared to feeding 6 days per week. However, Wu et al. (2004) did not find any difference in weight gain if channel catfish were fed either 6 or 7 days in week. For winter feeding, daily feeding and feeding the fish based on tempearture were suggested for hybrid catfish production as these two feeding options had a significant impact on increasing mean weight, gross yield, and growth rates compared to not feeding the fish during winter, which was considered to be 113 days (Kumar and Engle 2013). Moreover, Bosworth (2012) suggested that hybrid catfish should be fed 2% of their body weight twice per week during winter as this could improve the growth and fillet yield in compared to unfed fish in a 98 day winter.

Graded partial harvesting reduced the percentage of oversized fish (>1.81kg) in hybrid catfish production, (*Ictalurus punctatus,* ♀ *X I. furcatus,* ♂), if the grading was performed before the main harvesting period (Mischke et al. 2017). However, this reduced overall production by 16% and thus, net revenue compared to control ponds (Mischke et al. 2017). Increasing the harvesting frequency from 2 to 4 times per year reduced the oversized fish in channel catfish production (Engle et al. 2011). Moreover, the University of Arkansas at Pine Bluff (UAPB) grader significantly decreased the percentage of undersized fish from the total biomass by 14% as compared to the traditional live car (Engle et al. 2011).

Adoption of different types of strains in the production system could also have an impact on the growth variation and body weight gain in channel catfish, blue catfish and hybrid catfish production (Dunham et al. 2014b). The coefficient of variation for body weight ranged from 52.1 to 69.9% and 50.1 to 65.0% for four different genetic types of hybrid catfish fingerlings stocked at 19,770 fish/ha and 14,250/ha, respectively (Dunham et al. 2014b). However, the number of culture days did have an effect on growth variation. Jiang et al. (2008) reported that blue catfish strains had higher growth uniformity than channel catfish and hybrid catfish cultured in earthen ponds for 277 days at 12,500 fish/ha. However, Kumar and Engle (2010) did not find any significant difference between hybrid (Channel catfish, ♀ x blue catfish, ♂) and channel catfish strain (NWAC-103) in terms of growth, yield, survival, dress-out yield, and mean daily feed fed. Though the hybrid catfish strain had attained a better FCR than that of NWAC-103 but this channel catfish strain showed more size uniformity in compare to hybrid catfish strain (Kumar and Engle 2010).

Introduction

Growth and variation

Growth refers to the actual increase in size and/or weight of an individual or a population over time under known or specific conditions (Froese and Pauly 2017). This usually varies within species, strains or population or between the individuals within the same population. Fish show the largest amount of growth variation among farmed animals, as the coefficient of variation (CV), which is usually 7-10% for farmed animals, is 20-35% for fish species (Gjedrem 1997). In general, this is an important aspect of the aquaculture industry (Brooks et al. 1982) as it is prevalent in most fish populations reared in aquaculture settings (Martins 2005). In natural setting individual variation in growth may affect survival (Vilizzi and Walker 1999), and reproductive success rate (Deangelis et al. 1980). Similarly, fish from aquaculture settings may also exhibit certain aggression, stress (Gregory and Wood 1998), cannibalism (Baras et al. 2000), and to some extent, adverse effects from water quality deterioration resulting from the increased feed wastage (McDonald et al. 1996). On the other hand, this growth variation is necessary if selective breeding programs are to be successful for aquaculture species. Response to selection may increase the growth rate by 10-15% per generation, leading to increased production output (Gjedrem 2000). Analysis of the individual growth variation is advantageous as it allows the discovery of the potential causative factors of variation from the production system. Learning such causative factors is important as it can improve not only the production output (Martins 2005), but also increase the profitability of the business.

The objective of the current study was to evaluate variables that could potentially lead to oversized and undersized hybrid catfish, and to determine management of these factors that could potentially reduce the growth variability problem in hybrid catfish production (food fish).

Methods

Data collection

As part of the data collection, a comprehensive industry wide hybrid catfish sampling and survey was conducted from 2015 and 2017, on commercial farms from Mississippi, Arkansas and Alabama. In total, 164 ponds and raceways were sampled, which included single batch (N=25), multiple batch (N=16) and split pond (N= 98) ponds and in-pond raceway systems (IPRS) (N=25). Primary data were collected from 44 ponds/culture units, while the rest of the data were collected from secondary sources.

Ponds were harvested when there were at least 15,000-20,000 kg of on-flavor market-sized fish (> 0.45 kg; >1 lb). The harvested fish were typically held overnight in a "sock" (a type of net pen used to hold fish) to allow sub-marketable-sized fish (100-300 gm in weight/head) to grade out of the sock back into the pond. Fish were then loaded onto hauling trucks early next morning for delivery to the processing plant. Prior to loading, fish sampling was conducted by transferring approximately 300 (minimum) to 500 (maximum) live hybrid catfish from the sock to a portable plastic container (placing it on the pond bank). Before transferring the fish, the plastic container was filled with approximately 250 to 300 gallons of water from the sampling pond. Dissolve oxygen was provided through a portable aerator by connecting it with a portable generator (model # Honda EU2200i 2200W). Dissolved oxygen was maintained at the rate of >5 ppm during the whole sampling period to ensure fish welfare. Individual fish were weighed on a digital weight scale and returned to the loading truck or pond after finishing the sampling (Appendices 3.8-3.9).

A face to face interview was conducted with the pond owner/farm manager to obtain the details of the production systems. This survey questionnaire included 44 questions (Appendix 2.1). Fish processors were also contacted by phone and email to collect growth variation data, dockage price ($/kg) and loadings of premium size (0.45 -1.81 kg or 1 to 4 lb.), undersized (<0.45kg or 1 lb) and oversized (>1.81 kg or 4 lb) fish. This procedure helped to crosscheck the percentage of undersized and oversized fish that were obtained from the fish sampling survey. For culture unit size, ha or kg/ha were used for traditional (single/multiple batch) and split pond systems, while the cubic meter (m^3) was used for IPRS system. In total, 5 million fish were weighed.

Data analysis

Mean, standard deviation and coefficient of variation (CV) for body weight were calculated. CV for body weight, also known as relative standard deviation (RSD), is a standardized measure of dispersion of a probability distribution or frequency distribution. It is often expressed as a percentage, and is defined as the ratio of the standard deviation to the mean. Analysis of variance (ANOVA) was conducted to determine any differences among the mean, standard deviation and CV of the production systems at $P< 0.1$.

Four statistical procedures were then applied, which included variance inflation factor (VIF), principal component analysis (PCA), linear regression, and model diagnostic test (Appendix 2.2). These tests were performed for four dependent variables (Yi) that included coefficient of variation (CV) for body weight; undersized, oversized and premium sized fish (%). Production variables were considered as the independent variables (X_i) in all the above analyses (Table 2.2). The independent variables are listed and defined in Table 2.2-2.3. These analyses were performed with ‘R’ software (version: Ri386 3.3.1).

Variance inflation factor (VIF) was conducted for the variables (Table 2.2) to quantify the severity of the multicollinearity that was present in regression analysis. This analysis gave an index (acceptable range: 1-10) by measuring the variance of an estimated regression coefficient that could increase due to the collinearity problem.

The second step in the analysis was to perform a principal component analysis (PCA) to determine which linear combinations of the significant variables ($P< 0.01$) explained the most variation in the dataset. Variables evaluated included the area, aeration, depth. stocking density, weight/fingerling, feeding period, feed used, FCR, number of fish harvest, culture period, sock size, survival rate, fingerling sources, graded/ungraded fingerling, feeding cap (Y/N), feeding during winter (Y/N) and frequency of feeding days/week (winter season). These variables were selected as their VIF value was found < 10 in current analysis for all systems combined or within systems. Bi-plots were also developed to determine the scores of observations and the vectors that represented the coefficients of the variables on PCA components (Appendix 2.3).

Linear regression was performed afterwards to determine the potential variables (Table 2.4) that best fit to the regression model. This regression equation was expressed as follows:

$$Y = \alpha + \beta i X i$$

Where: Xi= explanatory variables, Y= dependent variables, β = slope of the line and α = intercept (the value of y, when $x = 0$).

Once the model was selected, then the model was confirmed by using the following diagnostics tests to ensure that the quantitative results obtained from the hypothesized relationships between variables were correct and acceptable. The validation tools utilized were adjusted R^2:

coefficient of determination; residual vs fitted analysis (graphical analysis): used to test the assumption of linearity and homoscedasticity; normality test (QQ plot): used to test the normality assumption by comparing the residuals with the ideal normal observations; scale location/spread-location plot: used to check the assumption of equal variance (homoscedasticity); and residuals vs leverage/ Cook's distance: used to find out the influential cases (i.e., subjects or outliers) (Appendix 2.4).

Table 2.2: Variables selected for variance inflation factor (VIF) and principal component analysis (PCA) for studying the growth variability of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in traditional and intensive systems

Continuous variables (Xi)	*Categorical variables (Xi)*
1. Area (ha) (or m^3)	1. Fingerling source (own or others)
2. Depth (m)	2. Feeding cap (yes/no)
3. Aeration (hp/ha; /m^3)	3. Stocked fingerling (graded/ungraded)
4. Stocking density (#/ha;/m^3)	4. Sock used (Y/N)
5. Weight per fingerling (kg)	5. Harvesting method (partial/complete)
6. Feeding period (days)	6. Heikes bar grader (Y/N)
7. Feeding/week: growing (days)	7. Feeding until satiation (Y/N)
8. Feeding/week: winter (days)	
9. Total feed used (kg/ha;/ m^3)	*Dependent variables (Yi)*
10. Maximum feeding rate (kg/ha)	1. Coefficient of variation (%)
11. Feed protein (%)	2. Undersized fish (%)
12. FCR (feed conversion ratio)	3. Oversized fish (%)
13. Culture period (days)	4. Premium size fish (%)
14. Sock size (cm)	
15. Survival rate (%)	
16. Production (kg/ha;/m^3)	
17. Harvesting head (#/ha;/m^3)	

Table 2.3 Definition of explanatory variables used in survey questionnaire and analyses in growth variability study of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in traditional and intensive systems

Explanatory variables	Notes
• Feeding/week: growing season (days)	Used production practice if the operations fed foodsize fish during the growing season
• Feeding/week: winter (days)	Used production practice if the operations fed foodsize fish during the winter season (usually December through February)
• FCR (feed conversion ratio)	Calculated from the total feed fed (kg) divided by net weight gain (total harvesting weight-total stocking weight)
• Culture period (days)	Used days that was needed to grow the foodsize fish from the fingerling stage
• Feeding period (days)	Used feeding days that was applied to grow the foodsize fish. This data was calculated based on the following four questions; ✓ What month did you begin feeding daily? ✓ What month did you stop feeding daily? ✓ During main growing season how many days feeding/ week? ✓ Did you feed during winter and how often?
• Feeding cap (yes/no)	Used production practices if the operation applied any feeding cap during growing the foodsize fish
• Feeding until satiation (yes/no)	Used production practices if the operation fed the fish until satiation level or not
• Stocked fingerling (graded/ungraded)	Used production practices if the operation stocked the fingerling in graded or ungraded manner
• % of parent strains used in fry production	Used production practices if the operation had known the percent of parent strains of channel and blue to make hybrid fry
• Fingerling source (own or others)	Used production practices if the operation had known the sources of stocked fingerlings to produce foodsize fish

Table 2.4: Explanatory variables (X_i) selected for regression analysis in studying the growth variability of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) of traditional and intensive systems after VIF and PCA analyses

Quantitative variables (X_i)	
Continuous variables	*Categorical variables*
Area (ha) (or m^3)	Fingerling sources (own or others)
Aeration (hp/ha; /m^3)	Stocked fingerling (graded/ungraded)
Stocking density (#/ha;/m^3)	Feeding cap (Y/N)
Weight/ fingerling (kg)	Feeding during winter (Y/N)
FCR (feed conversion ratio)	
Feed usage (kg/ha;/m^3)	
Culture period (days)	
Feeding in winter (days)	

Assumptions for the IPRS data (commercial)

Most of the production data of 15 raceways (commercial) were missing, hence the imputed data were used taken from the other raceways (n=10). These missing variables were, area, depth, and aeration, stocking density, variables under feeding management, and number of harvesting head.

Limitations and potential remedy

Sample size should be increased to more accurately determine the potential causative factors for growth variability in hybrid catfish production. Moreover, missing and incomplete data could be gathered to strengthen the data analysis. Survey instruments could also have included the questions for economics, especially for the operating and fixed variables, as it could generate a current price/cost data rather than using the secondary data for the economic analysis.

Validity and reliability of this survey instrument/questionnaire was not estimated due to the time limitation. This could be an important part of the survey that could ensure the authentic data collection from the field.

Results

Population distribution

Comparative analysis of population distribution data showed that the skewness value for hybrid catfish was <1 for multiple batch and intensive systems, but >1 for single batch system (Fig. 2.2). The lowest and highest value for skewness were found for multiple batch (0.59) and single batch system (1.40), respectively (Fig. 2.2). Population distributions of individual populations, taken from four different environments, are illustrated in Figs. 2.3- 2.6.

Production

Split pond and IPRS (research + commercial) systems were stocked with hybrid catfish fingerlings of 32,432 ± 7,901 and 15,569 ± 7,431/ha (= 158 ± 72 head/m^3), respectively, while the single batch and multiple batch were stocked with hybrid catfish fingerlings of 24,433 ± 12,441 and 24,301 ± 11,949/ha, respectively (Table 2.5). Both these traditional and intensively managed systems were stocked with small to larger sized fingerlings (average size 18 to 20 cm) (single batch, 50 ± 20g; multiple batch, 40± 20g, split pond, 60 ± 20 g; and IPRS, 40± 10 g) (Table 2.5). The protein percentage in feed also varied among these production systems. Traditional and split pond systems often used 28% protein in feed, while the IPRS used 32% protein in feed as part of the feeding management strategy (Table 2.5). FCR was the lowest in IPRS and this might be related to higher percentage of protein use for this system. FCR of the single and multiple batch, split pond and IPRS systems were different, 2.47 ± 0.50, 2.75 ± 0.66, 2.48 ± 0.55, and 1.63 ± 0.12, respectively ($P < 0.05$). Survival rate (%) was also slightly differed among the production systems ($P < 0.05$). The survival rate (%) of hybrid catfish in single batch, multiple batch, split pond and IPRS systems was 84 ± 15, 87 ± 10, 80 ± 11, and 77 ± 10, respectively (Table 2.5). The culture periods of single batch, multiple batch, split pond and IPRS (research + commercial) systems were 372 ± 90, 383 ± 86, 221 ± 47, and 250 ± 43 days, respectively (Table 2.5). Gross yields for hybrid foodsize fish production (kg/ha) were higher for split pond system (19,122 ± 5,237), ($P < 0.05$) followed by multiple batch (15,766 ± 5,025), single batch (13,821 ± 4,149) and IPRS (research + commercial) (8,530 ± 5,582 kg/ha or 77 ± 35 kg/m^3) systems (Table 2.5).

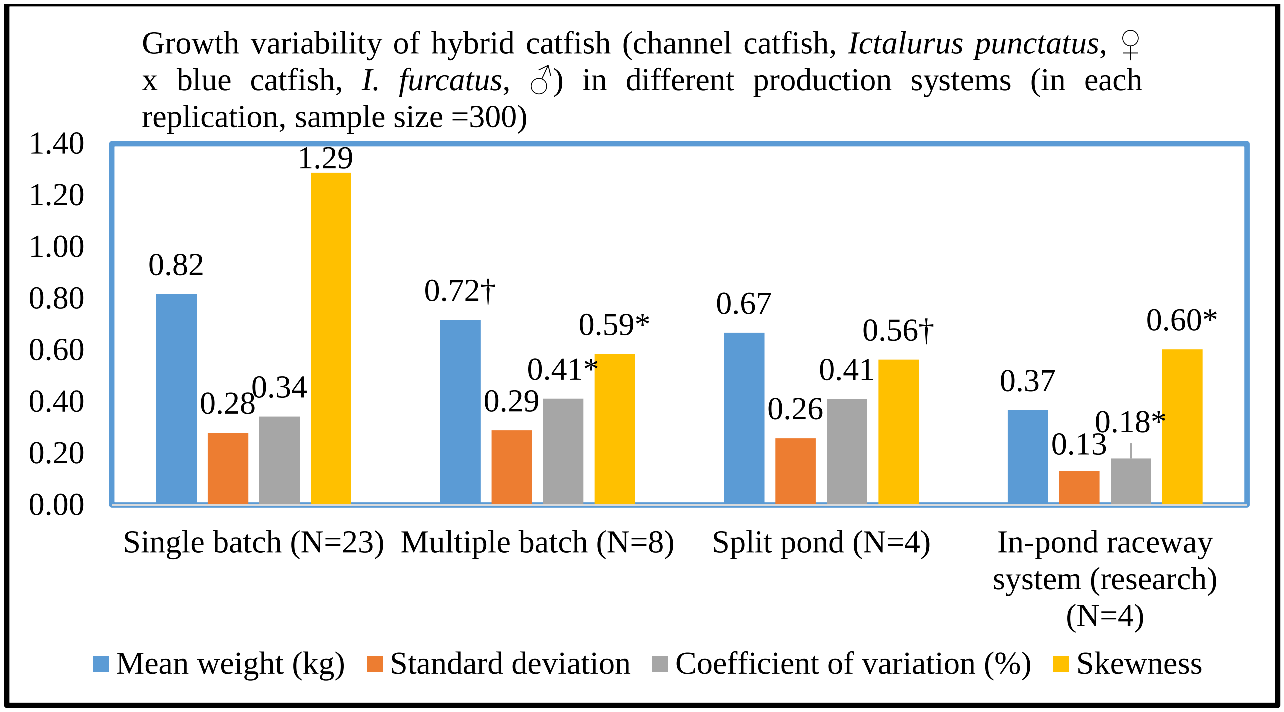

Figure 2.2. t-test (unpaired, two tailed) for mean body weight (kg), standard deviation, coefficient of variation for body weight (%) and skewness of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in different production systems (sample size =300). Means were compared pair wise to the single batch system as standard treatment

Significant differences at P< '***' 0.001 '**' 0.01 '*' 0.05 '†' 0.1, t-test.

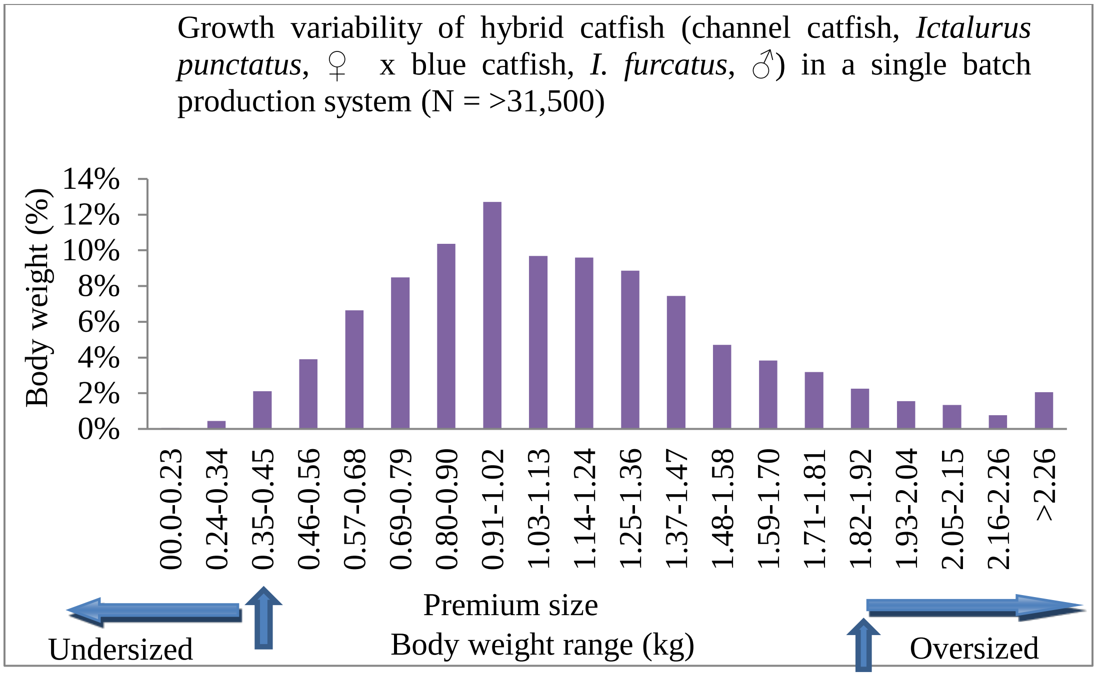

Figure 2.3. A typical example of growth variability of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in a single batch system (N=>31,500) (pond size 4.98 ha, stocking density 17,558/ha, skewness=0.85)

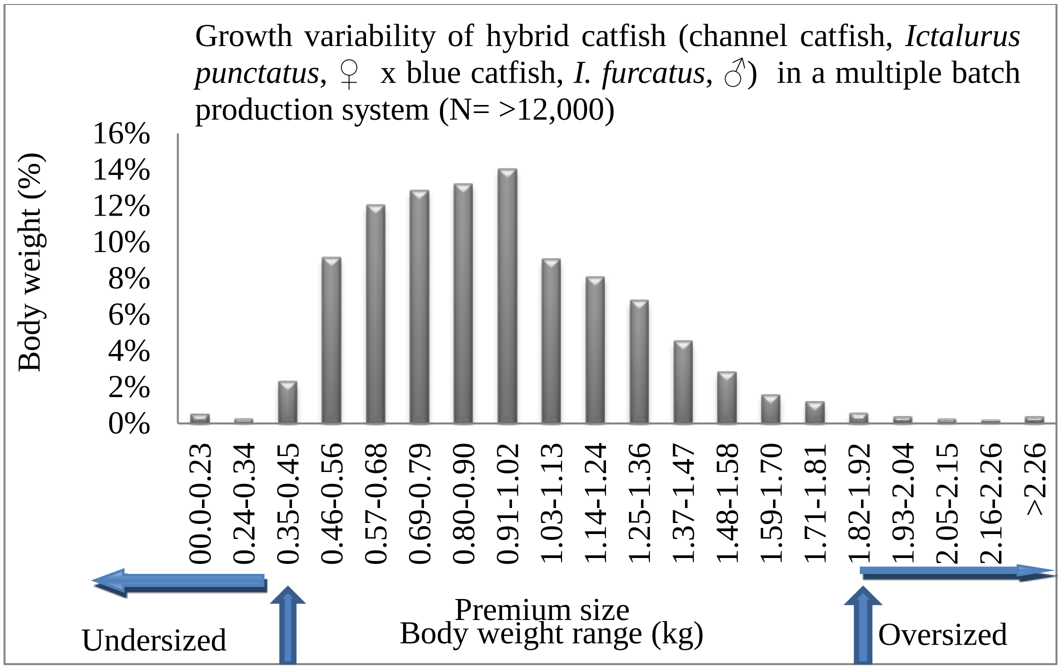

Figure 2.4. A typical example of growth variability of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in multiple batch system (N= >12,000) (pond size 2.00 ha, stocking density 36,300 /ha, skewness=0.65)

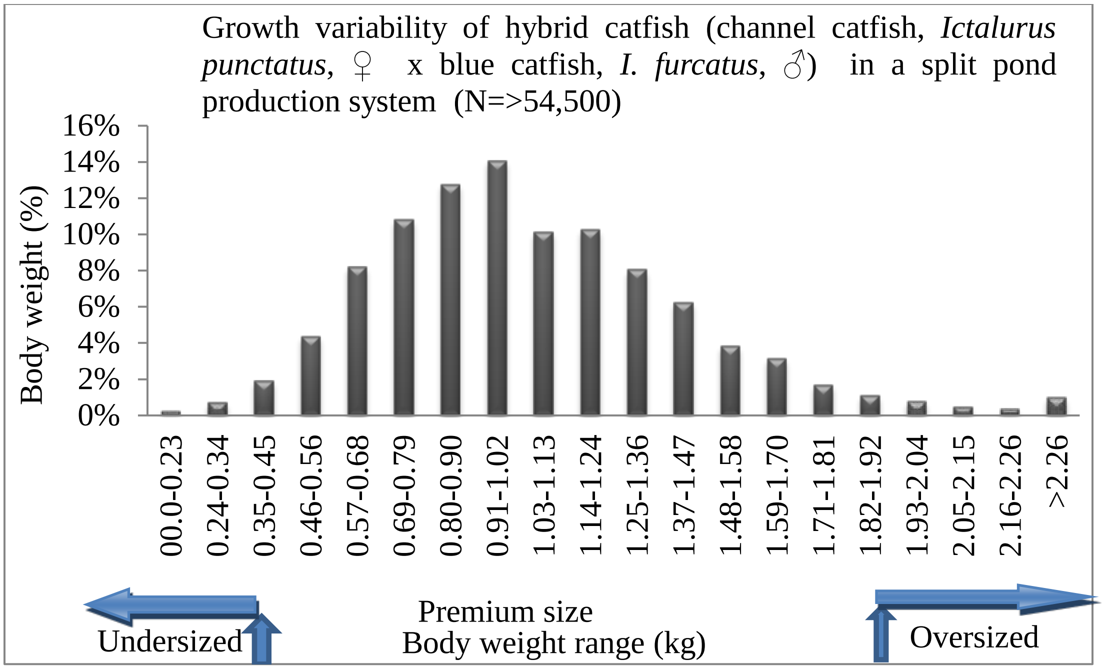

Figure 2.5. A typical example of growth variability of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in split pond system (N=>54,500) (pond size 5.90 ha, stocking density 21,573 /ha, skewness=0.73)

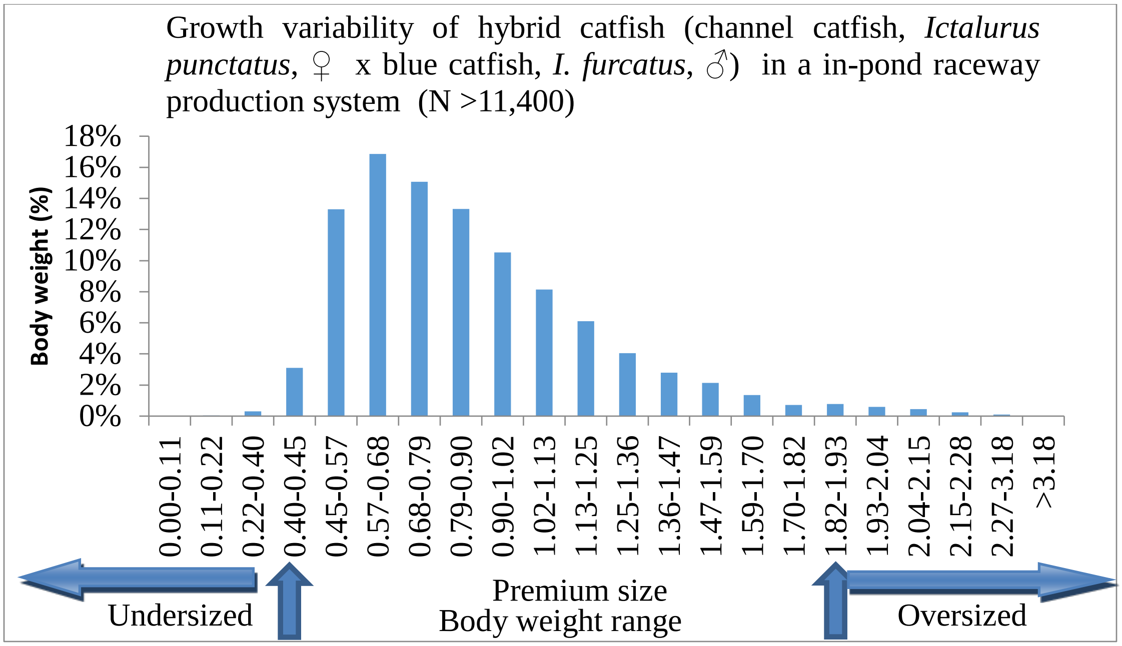

Figure 2.6. A typical example of growth variability of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in in-pond raceway production system (N >11,400) (raceway size 55 m^3, stocking density 269 /m^3, skewness=1.25)

Table 2.5. Mean ($\bar{X}$) and standard deviation (SD) of production variables that were used in hybrid catfish of (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) of single batch (N=25), multiple batch (N=16), split pond (N=98) and in-pond raceway production systems (N=25).

Variables	Unit	Single batch		Multiple batch		Split pond		IPRS (research)		IPRS (commercial)		IPRS (res.+comm.)	
		$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Area	^{a}ha or ^{b}m^{3}	3.47	1.53	3.42	1.18	3.60	1.58	55	9.07	55	0.26	55	3.66
Depth	m	1.91	0.30	1.95	0.15	1.86	0.12	1.22	0.00	1.42	0.05	1.39	0.09
Aeration	hp/ha; m^{3}	9	9.00	8	3.47	10	2.98	0.04	0.008	0.045	0.00	0.05	0.00
Stocking density	hp/ha; / m^{3}	24,433	12,441	24,302	1,1949	32,433	7,901	158	2	155	78	158	72
Weight/ fingerling	kg	0.04	0.01	0.04	0.01	0.06	0.04	0.05	0.00	0.05	0.01	0.05	0.01
Feeding period	days	267	100	328	66	217	41	246	0	242	51	246	48
Feeding/week: winter	days	2	1	3	0	3	0	2	0	2	0	2	0
Total feed used	kg/ha;/ m^{3}	31,573	11,419	39,324	18,486	42,298	13,766	108	11	97	57	108	58
FCR	ratio	2.47	1	2.75	1	2.48	1	1.63	0.05	2	0.13	2	0
Protein used in feed	%	28	0	28	0	28	0	32	0	32	0	32	0
Culture period	days	372	90	383	86	221	47	246	0	246	43	250	40
Harvesting head	#/ha;/ m^{3}	17,377	5,892	13,236	9,430	28,689	3,1031	121	14	115	56	121	53
Production	kg/ha;/ m^{3}	13,821	4,149	15,766	5,025	19,122	5,237	77	9	70	35	77	35
Survival rate	%	84	15	87	10	80	11	86	7	75	9	77	10
Average weight	kg	0.85	0.2	0.90	0	0.74	0	0.73	0.06	0.65	0.19	1	0
Undersized fish	%	5	6	4	4	13	5	10	5	21	20	19	19
Oversized fish	%	4	5	12	8	4	2	1	2	4	7	3	6
Premium size fish	%	91	8	84	8	82	4	90	5	75	19	77	18
Coefficient of variation	%	37	9	50	12	45	7	37	3	44	10	43	10

^{a}ha= unit used for traditional and split pond systems; ^{b}m^{3} =unit used for IPRS (research), IPRS (commercial) and IPRS (research + commercial); res. =research; comm. =commercial

Growth variability

Differences were present among the fish categories (under/premium/oversized fish) of the production systems when they were compared to a standard control, the single batch system (t-test, α=0.05) (Table 2.6). IPRS (research+ commercial) had the highest amount of undersized fish (< 0.45 kg) followed by split pond, single and multiple match system (Fig. 2.7). The multiple batch production system had the highest amount of oversized fish (> 1.81 kg), which was most likely due to the repeated stocking and harvesting procedures engaged in this system (Fig. 2.7).

Results from the current analysis (ANOVA) also showed that differences existed for the coefficient of variation (CV) (%) in these production systems ($P < 0.05$) (Table 2.7). The highest and lowest CV were found for multiple batch (49.5 ± 11.6) and single batch systems (36.5 ± 8.9) ($P < 0.05$), respectively (Table 2.7). In general, the average CV (%), regardless of the production system, was 43.31 ± 9.33 in hybrid catfish farming in the current study (Table 2.7).

Table 2.6. T-test (unpaired, two tailed) for coefficient of variation (CV) for body weight, undersized, oversized and premium sized of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) (%). Pair wise comparisons were made by considering the single batch system as the standard control treatment (N >5,000,000)

Treatment	CV (%)	Undersized fish (%)	Oversized fish (%)	Premium sized fish (%)
Single vs multiple	0.00*	0.88	0.00*	0.01*
single vs split	0.00*	0.00*	0.87	0.00*
single vs IPRS (research)	1.00	0.17	0.05*	0.58
single vs IPRS (commercial)	0.01*	0.00*	0.99	0.00*
single vs IPRS (research+ commercial)	0.03*	0.01*	0.70	0.00*

‘*’ Significantly different, P < 0.05, t-test.

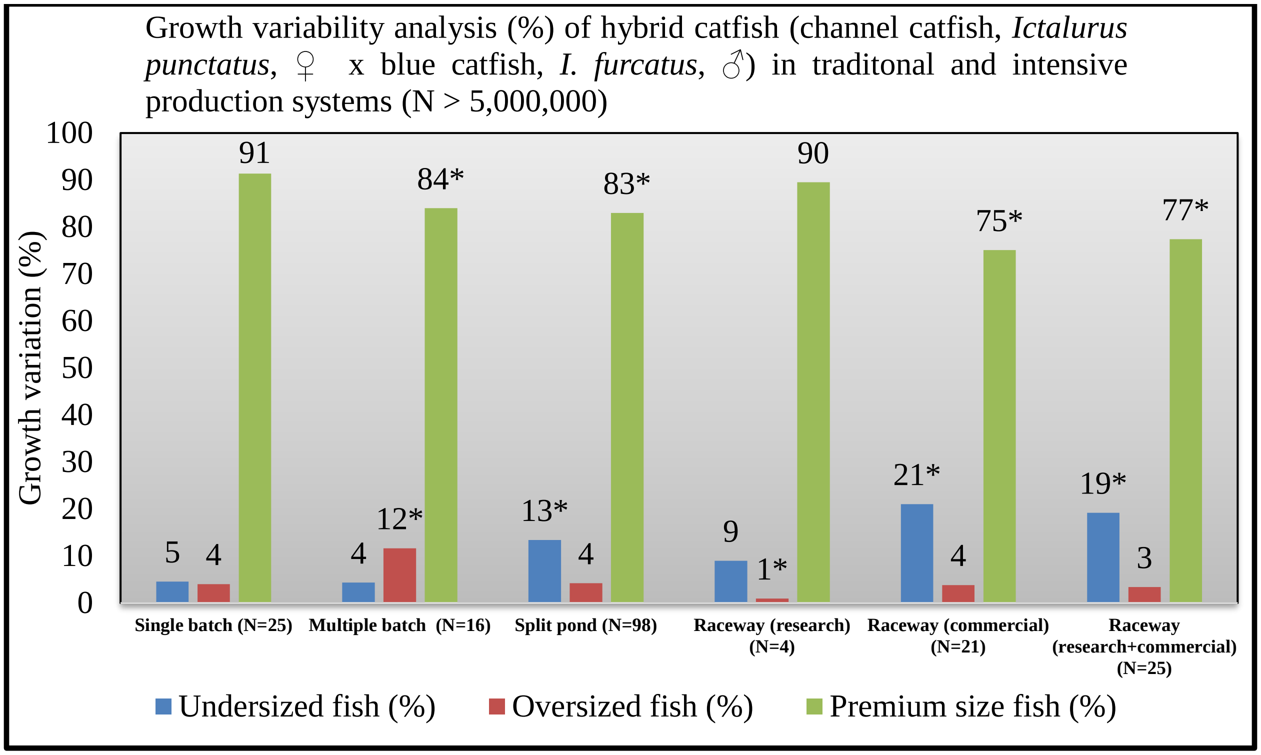

Figure 2.7. T-test (unpaired, two tailed) for undersized, oversized and premium sized (%) of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂). Means for each system were compared to the single batch system as standard control treatment (N >5,000,000) Significance codes: ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05, ‘†’ 0.1

Table 2.7. ANOVA for average weight (kg) and coefficient of variation (CV) (%) for body weight in hybrid catfish farming (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂).

Treatments	N	Average weight ± SE (kg)	CV ± SE (%)
Single batch	25	0.85 ± 0.31*	36.5 ± 8.9*
Multiple batch	16	0.90 ± 0.45*	49.5 ± 11.6*
Split pond	98	0.74 ± 0.32*	44.5 ± 7.2*
Raceway (research + commercial)	25	0.66 ± 0.28*	42.6 ± 9.6*
Raceway (research)	4	0.73 ± 0.27*	36.5 ±2.8*
Raceway (commercial)	21	0.65 ± 0.28*	43.8 ±9.9*
Average		0.79 ± 0.34	43.3 ±9.3

'*' Significantly different, $P < 0.05$, ANOVA test

Factors affecting growth variability

Single batch production system

Growth variation of hybrid catfish in the single batch production system was mostly influenced by the variables under the stocking and feeding managements (Table 2.8). Fingerling weight of 0.04 kg/head could increase the growth variability resulting in a higher CV and oversized fish (%) (Figs. 2.8-2.9). There was a trend of decreased oversized fish with increased length of higher FCR trended toward producing a higher percentage of oversized and undersized fish as well as increasing the CV for body weight (Fig. 2.10). A longer feeding period could reduce the percent of oversized fish (Fig. 2.11). An extended culture period, however, was correlated with reducing the percentage of undersized fish and increased the percent of oversized fish (Fig. 2.12, Table 2.8). The effect of pond size was non-linear as very small ponds had a low percentage of wrong size fish (Fig. 2.13). The percentages of wrong sized fish increased with increasing the pond size, and then trended downward (Fig. 2.14). Aeration was also non-linear as increasing aeration could decrease wrong sized fish (Fig. 2.15). Initially, increasing the aeration rate could increase the wrong size fish which reached to a plateau and then further aeration reversed the trend (Fig.2.16). Although not significant and with low replication, the highest maximum feeding rate of greater than 200 kg/ha reduced the proportion undersized and oversized fish (Fig. 2.17). CV (%) had a proportional relationship with FCR (Fig. 2.10), while it had a reciprocal relationship with weight per fingerling and maximum feeding rate (Table 2.8; Fig. 2.17). These variables could potentially affect the hybrid catfish production in regards to producing undersized and oversized fish (%) as well (Table 2.8). CV (%) had a proportional relationship with FCR (Fig. 2.10), while it had a reciprocal relationship with weight per fingerling and maximum feeding rate (Table 2.8; Figs. 2.8-2.9, and 2.17). These two variables, weight per fingerling and maximum feeding rate, could potentially affect the hybrid catfish production in regards to producing undersized and oversized fish (%) as well (Table 2.8, Figs. 2.8-10 and 2.17).

Source of hybrid fingerlings was correlated with the percentage of undersized food fish. Surprisingly, grading increased the percentage of oversized fish (Fig. 2.18, Table 8). A feeding cap of a maximum of 200 kg/ha reduced the percentage of oversized fish (Fig. 19, Table 8). As stocking density increased, the percentage of undersized fish increased while that for oversized fish decreased (Table 8).

In terms of premium size fish production (%), weight of individual fingerling was the most influential parameter in the single batch system. The dependent variable, premium size fish, was proportionally related to this explanatory variable (Table 2.8)

Table 2.8: Potential causative factors for growth variation in hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) farming in single batch system

System	Y[a]	Causative factors	Unit	Coefficients[b]	Std. error[c]	t value	Pr (>t)[d]	M. R^{2}[f]	Adj. R^{2}[g]	P[h]
Single Batch	CV	Weight/ fingerling	kg	-1.167e+00	4.818e-01	-2.422	0.0296	0.4847	0.1166	0.3099
	Undersized Fish	Culture period	days	-2.499e-02	1.315e-02	-1.900	0.0781	0.7075	0.4986	0.0187
		Fingerling sources	own/other	8.362e+00	3.284e+00	2.546	0.0232			
		Fingerling graded	Y/N	1.712e+01	4.428e+00	3.867	0.0017			
		Stocking density	#/ha	5.134e-04	1.228e-04	4.181	0.0009			
	Oversized Fish	Weight/ fingerling	kg	-5.646e+01	2.941e+01	-1.920	0.0755	0.5381	0.2082	0.1954
		Feeding cap	Y/N	-6.376e+00	3.518e+00	-1.813	0.0914			
		Stocking density	#/ha	-3.054e-04	1.327e-04	-2.301	0.0373			
	Premium size	Weight/ fingerling	kg	9.441e+01	4.408e+01	2.142	0.0503	0.4606	0.07538	0.3696

Y[a]= dependent variable; Coefficients[b]= regression coefficients; Std. error[c]= standard error; Pr (>t)[d]= probability value> t value; M. R^{2}[g]= multiple r square; Adj. R^{2}[h]= adjusted r square; P[i]=probability value

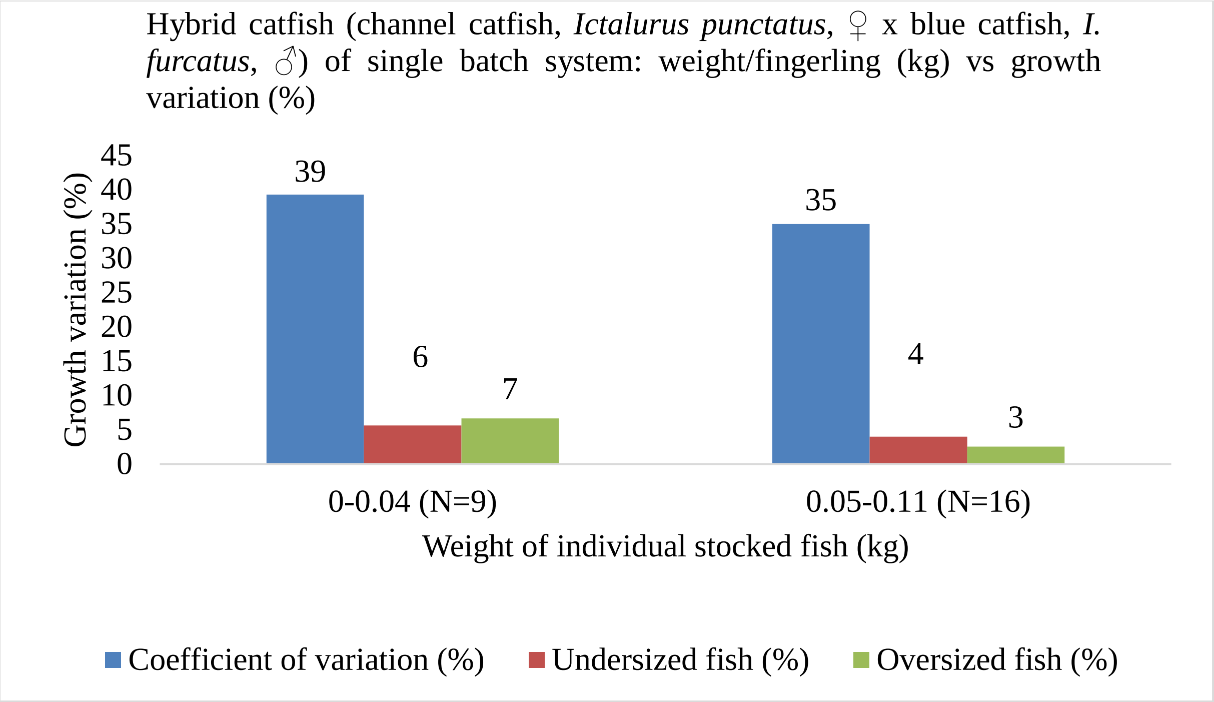

Figure 2.8. Effect of weight per fingerling on the growth variation of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in single batch system

Significant differences at P< ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘†’ 0.1, t-test.

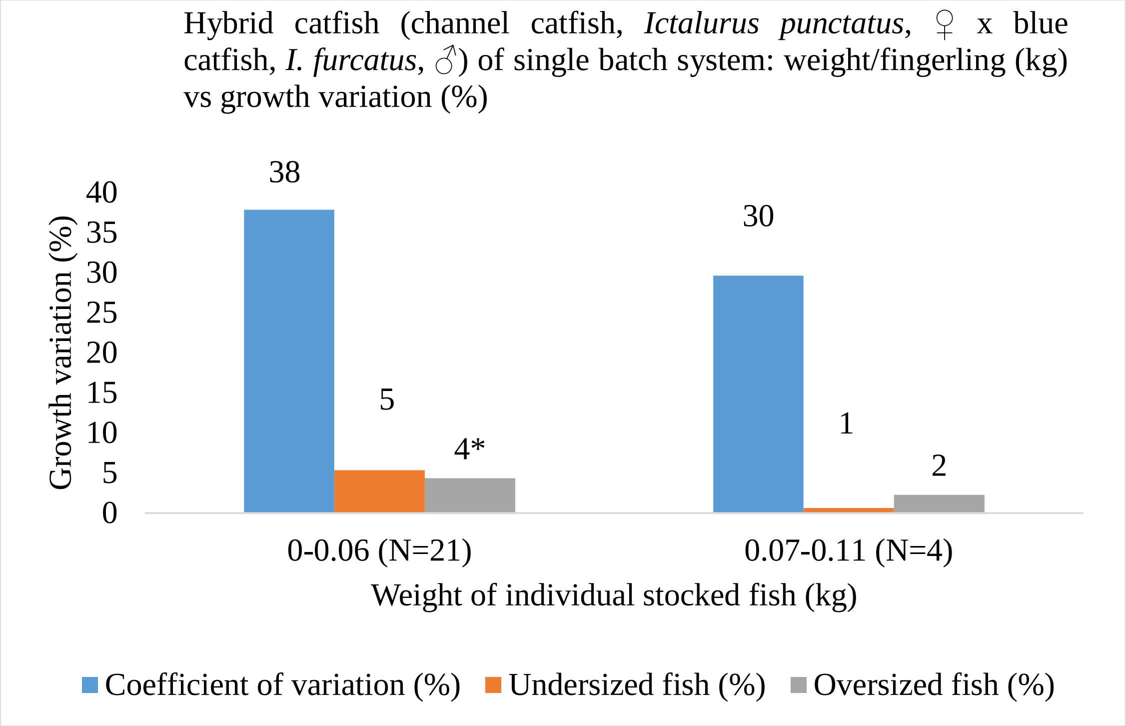

Figure 2.9. Effect of weight per fingerling on the growth variation of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in single batch system Significant differences at P< ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘†’ 0.1, t-test.

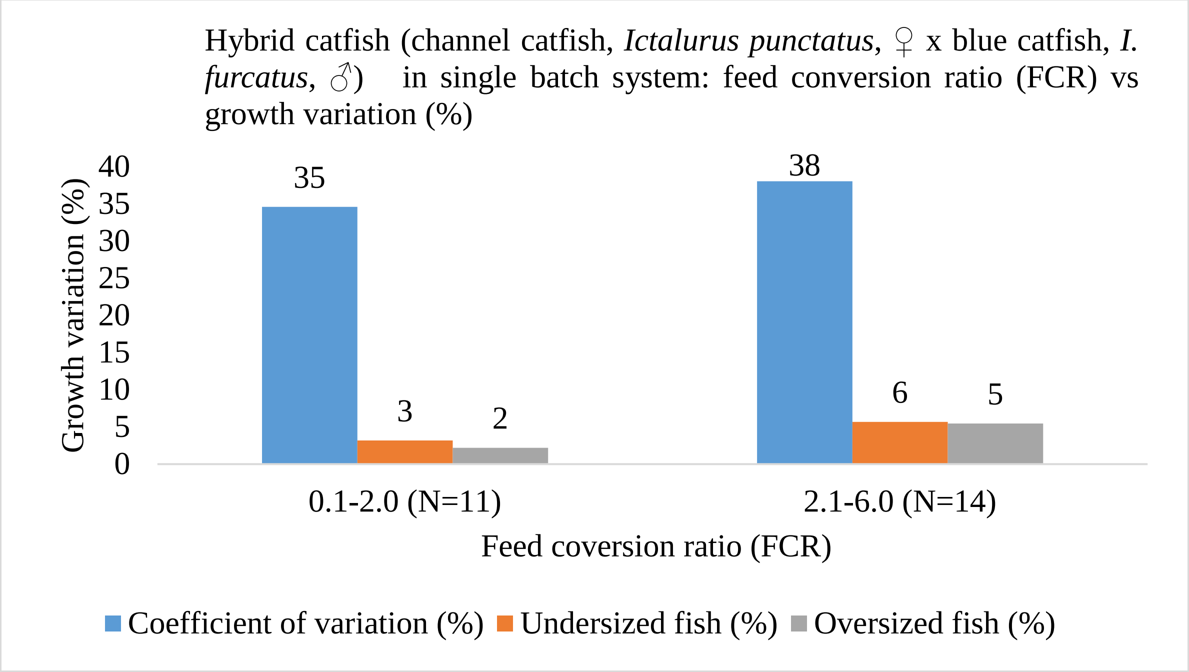

Figure 2.10. Effect of feed conversion ratio (FCR) on the growth variation of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in single batch system Significant differences at P< '***' 0.001 '**' 0.01 '*' 0.05 '†' 0.1, t-test.

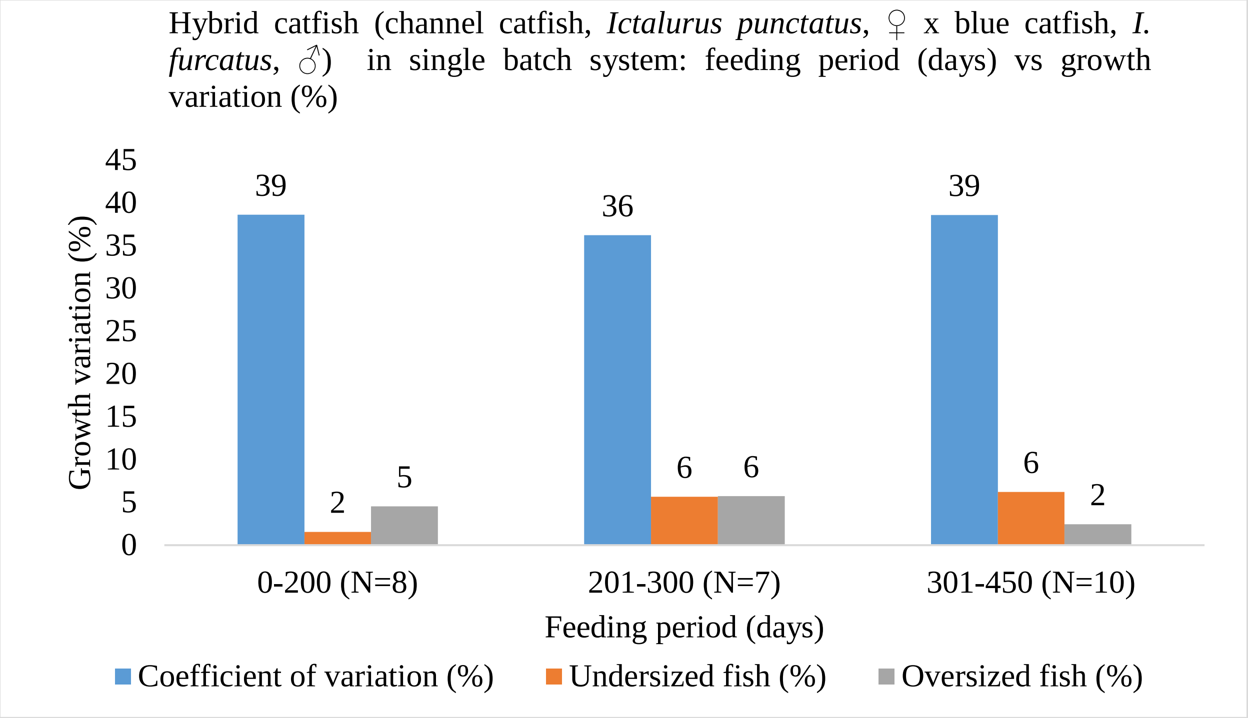

Figure 2.11. Effect of feeding period on the growth variation of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in single batch system

Significant differences at P< '***' 0.001 '**' 0.01 '*' 0.05 '†' 0.1, t-test.

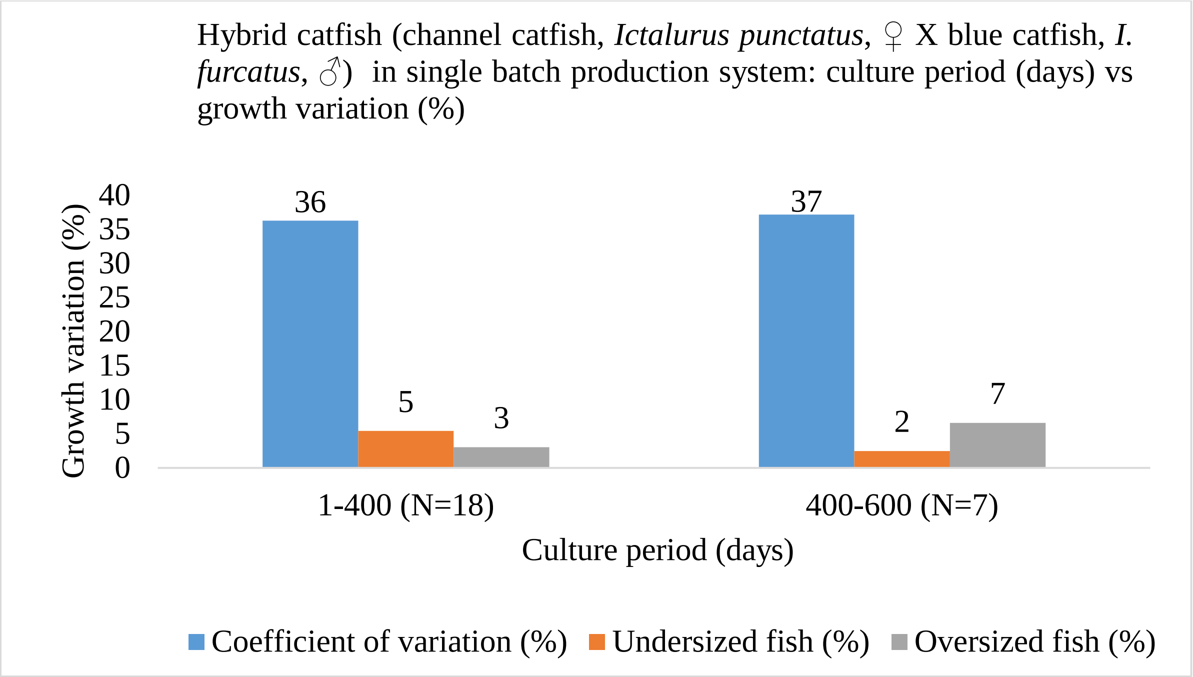

Figure 2.12. Effect of culture period on the growth variation of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in single batch system

Significant differences at P< ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘†’ 0.1, t-test.

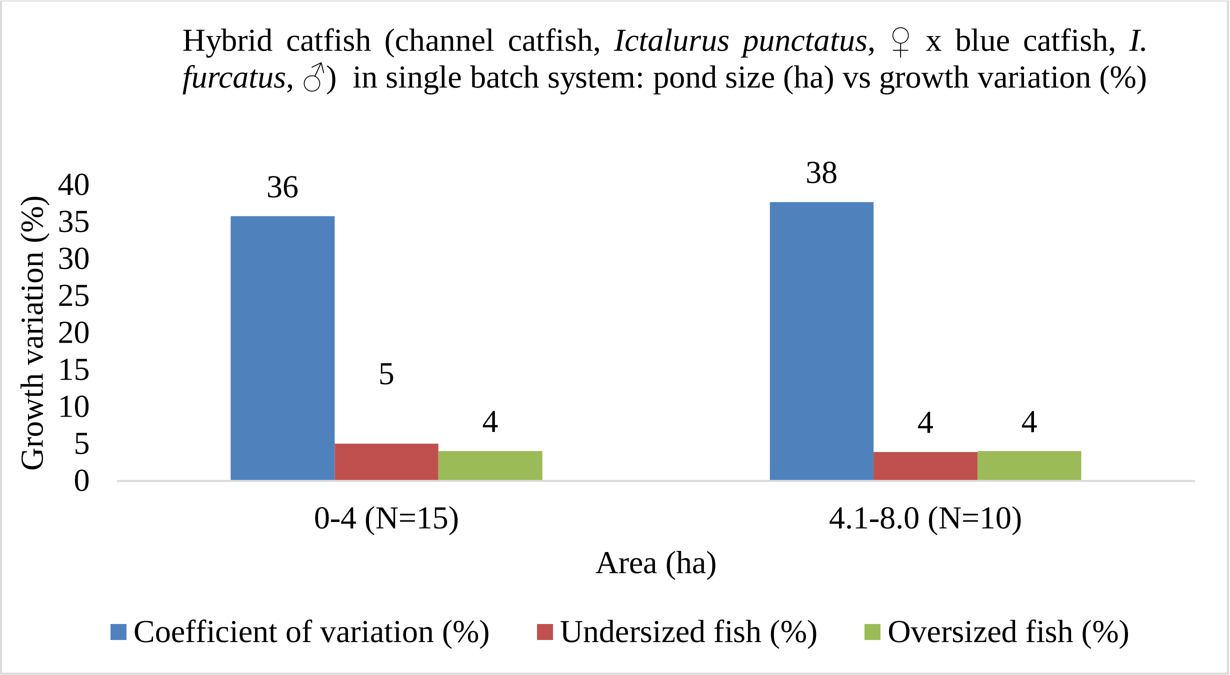

Figure 2.13. Effect of pond size on the growth variation of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in single batch system

Significant differences at P< '***' 0.001 '**' 0.01 '*' 0.05 '†' 0.1, t-test.

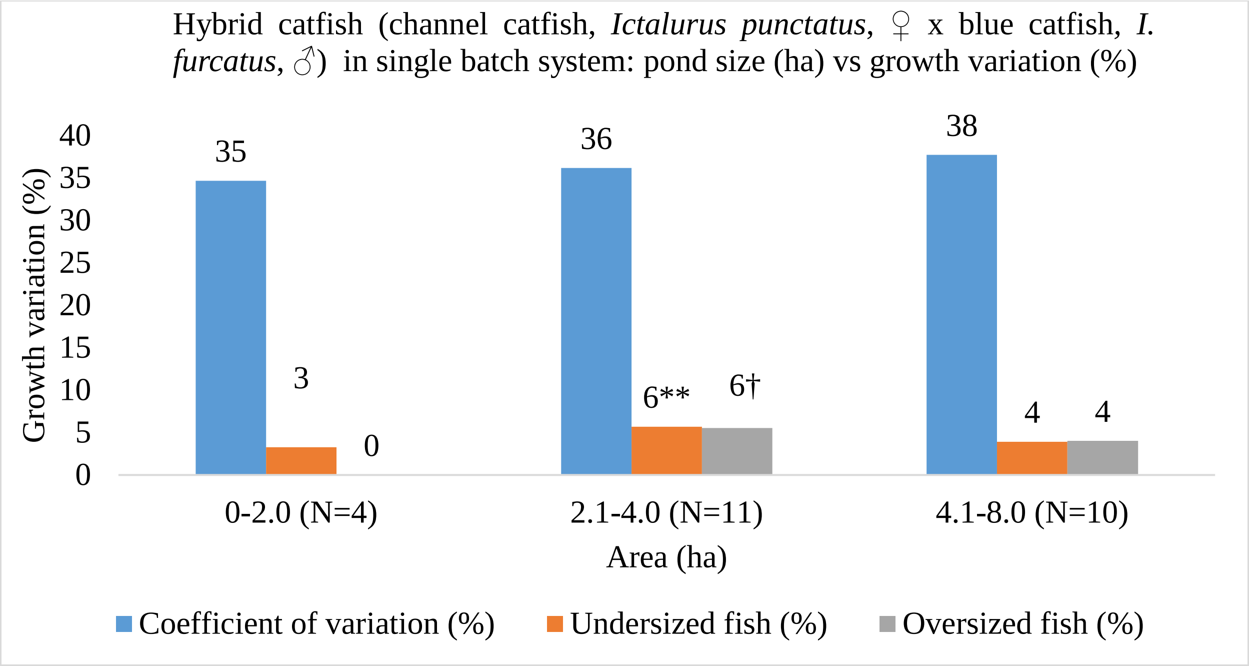

Figure 2.14. Effect of pond size on the growth variation of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in single batch system

Significant differences at P< '***' 0.001 '**' 0.01 '*' 0.05 '†' 0.1, t-test.

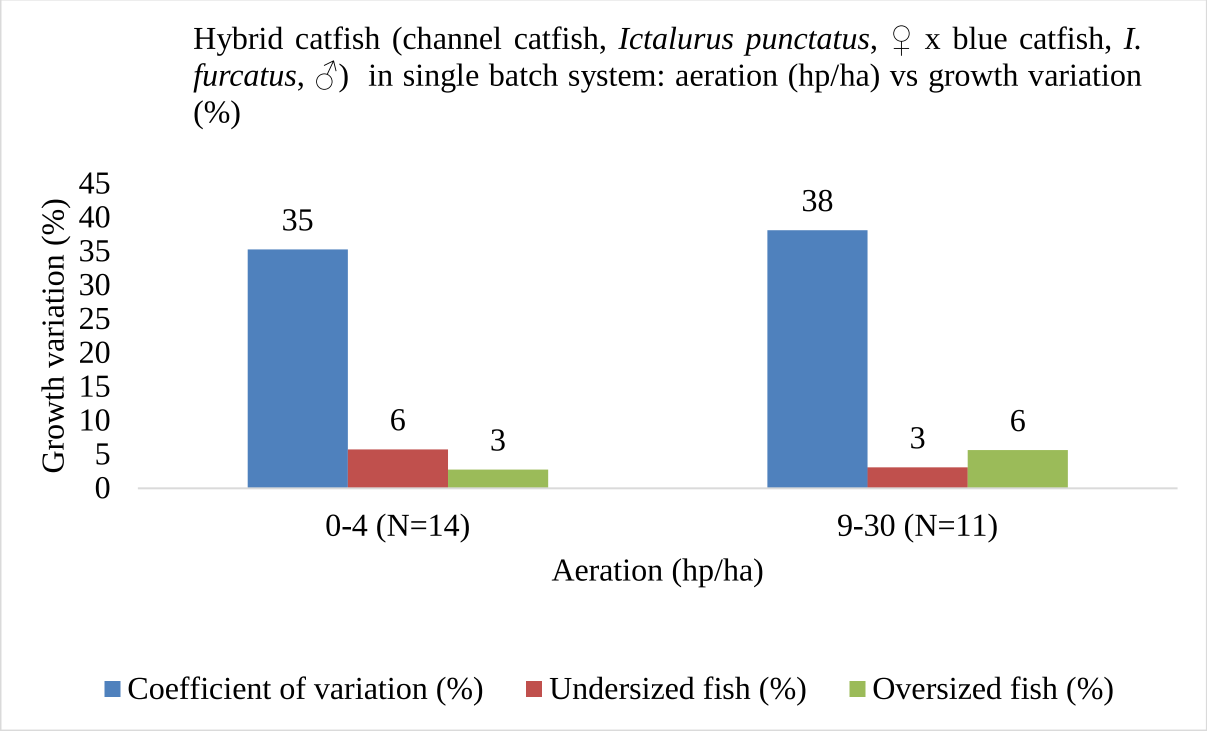

Figure 2.15. Effect of aeration on the growth variation of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in single batch system

Significant differences at P< ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘†’ 0.1, t-test.

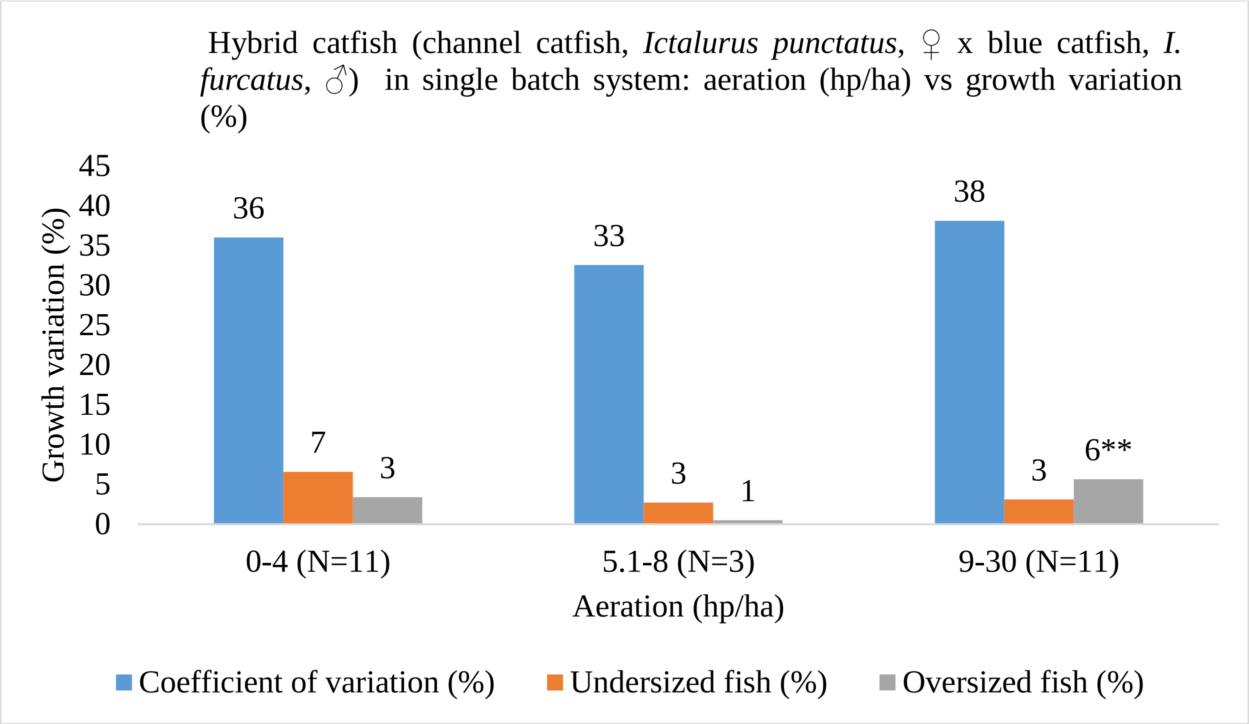

Figure 2.16. Effect of aeration on the growth variation of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in single batch system

Significant differences at P< ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘†’ 0.1, t-test.

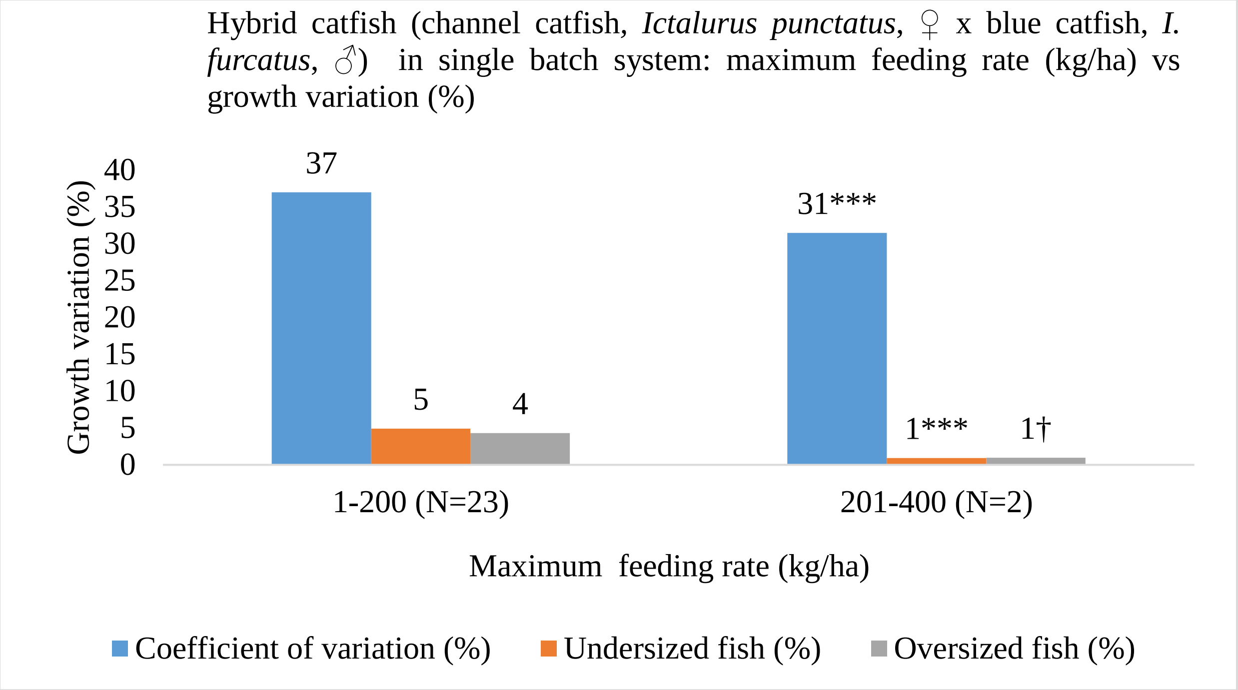

Figure 2.17. Effect of maximum feeding rate on the growth variation of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in single batch system

Significant differences at P< ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘†’ 0.1, t-test.

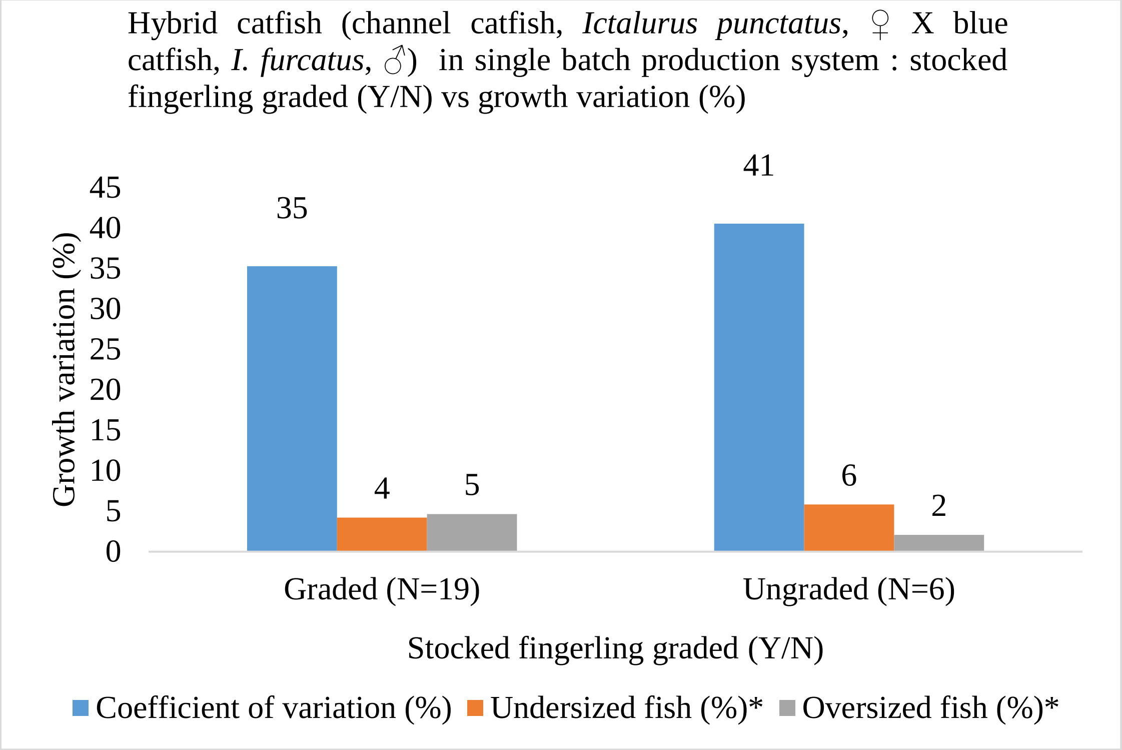

Figure 2.18. Effect of fingerling grading (Y/N) on the growth variation of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in single batch system

Significant differences at P< '***' 0.001 '**' 0.01 '*' 0.05 '†' 0.1, t-test.

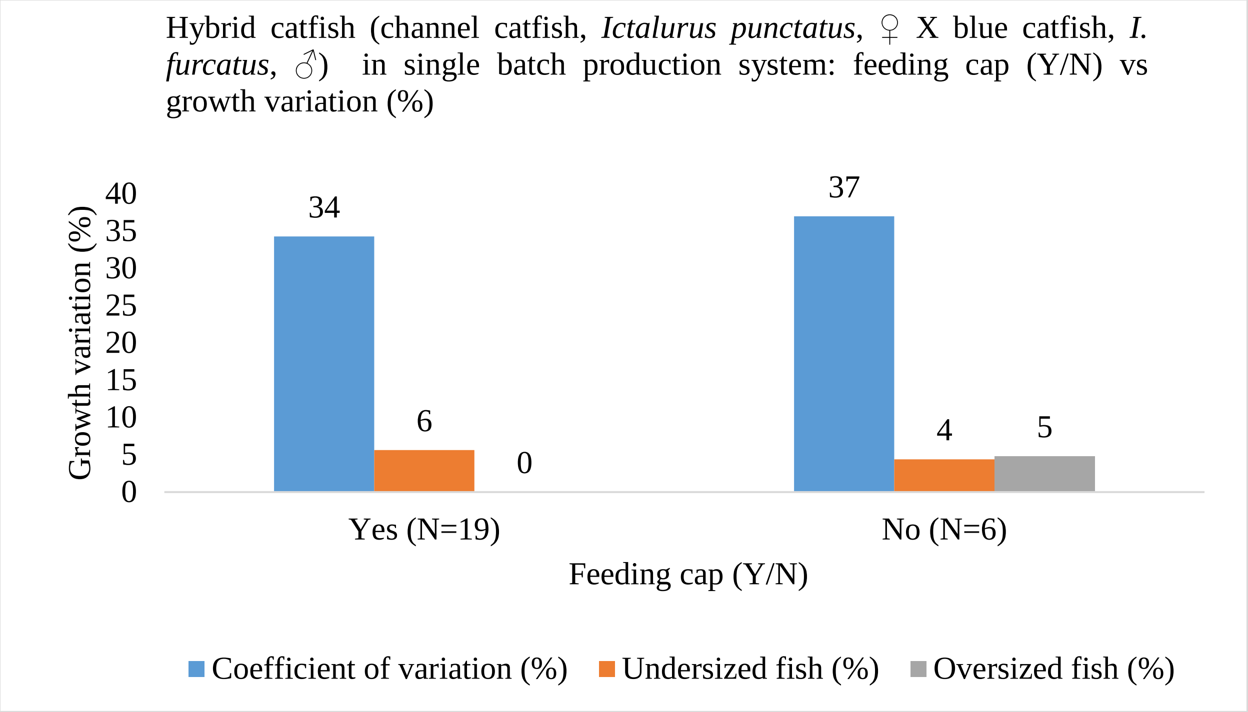

Figure 2.19. Effect of feeding cap (Y/N) on the growth variation of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in single batch system

Significant differences at P< '***' 0.001 '**' 0.01 '*' 0.05 '†' 0.1, t-test.

Multiple batch production system

Most of the variables under feeding and stocking management influenced the growth variability of hybrid catfish in multiple batch systems (Table 2.9). The undersized fish (%) was most heavily influenced by stocking density, FCR and pond area (Table 2.9; Figs. 2.20-2.21). Oversized fish (%) were caused by pond depth, weight/fingerling, FCR and stocking density. Using deeper ponds (2.1-3.0 m) reduced the proportion of oversized fish compared to pond depths of 0.1-2 m (Fig. 2.22). Using larger size fingerlings (0.03- 0.06) (kg) reduced the growth variation and production of oversized fish (%) (Fig. 2.23). Using higher stocking density reduced the percent of undersized and oversized fish (Fig. 2.20). Increasing the number of harvested fish (20,001-30,000) reduced the proportion of oversized fish (Fig. 2.24). FCR, however, had the inverse relationship with oversized fish production because increasing the FCR reduced the oversized fish (%) in this system (Fig. 2.21). Opposite result existed for premium size fish where increasing FCR increased the percentage of premium size fish (Table 2.9).

Table 2.9 Potential causative factors for growth variation in hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) of multiple batch production systems

System	Y[a]	Causative factors	Unit	Coefficients[b]	Std. error[c]	t value	Pr (>t) [d]	M. R^{2f}	Adj. R^{2g}	P[h]
Multiple batch	CV	Fingerling graded	Y/N	1.790e-01	8.064e-02	2.220	0.0572	0.7741	0.5764	0.03727
		Weight/ fingerling	kg	-7.731e+00	3.486e+00	-2.218	0.0573			
	Undersized Fish	Area	ha	-2.800e+00	1.288e+00	-2.173	0.0615	0.7161	0.4677	0.08057
		Stocking density	#/ha	-2.621e-04	9.966e-05	-2.630	0.0302			
	Oversized Fish	FCR	ratio	-1.339e+01	5.361e+00	-2.498	0.0371	0.6302	0.3067	0.185
	Premium size fish	FCR	ratio	1.158e+01	5.751e+00	2.014	0.0788	0.5442	0.1453	0.3344

Y[a]= dependent variable; Coefficients[b]= regression coefficients; Std. error[c]= standard error; Pr (>t) [d]= probability value> t value; M. R^{2g}= multiple r square; Adj. R^{2h}= adjusted r square; P[i]=probability value

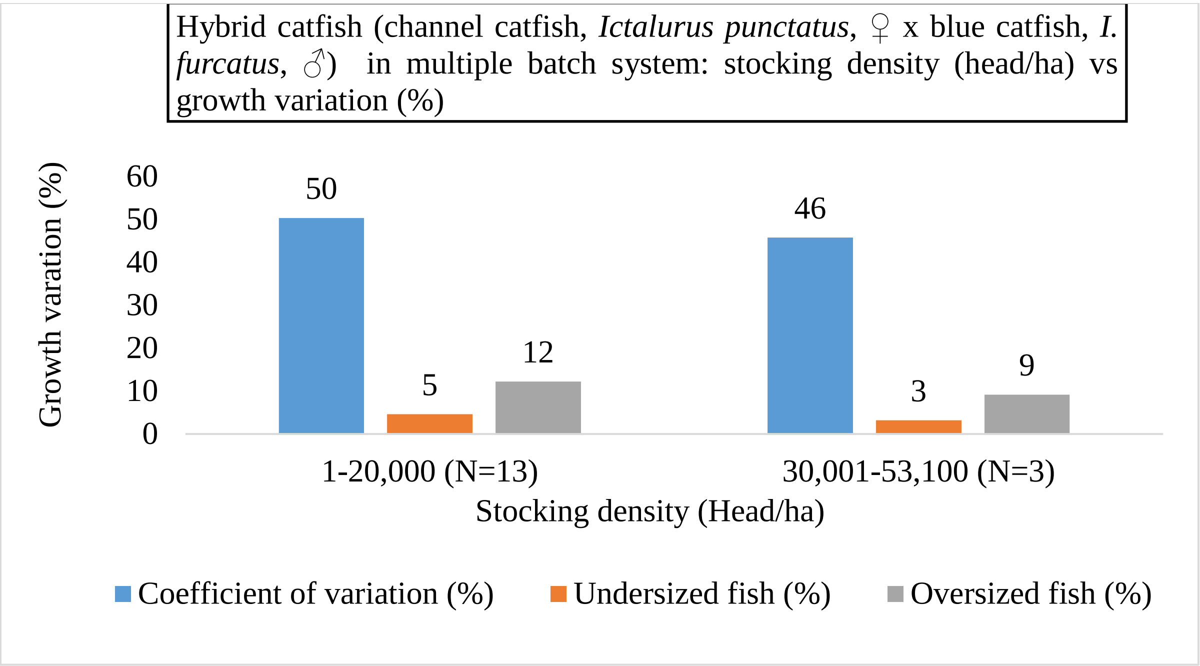

Figure 2.20. Effect of stocking density on the growth variation of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in multiple batch system

Significant differences at P< '***' 0.001 '**' 0.01 '*' 0.05 '†' 0.1, t-test.

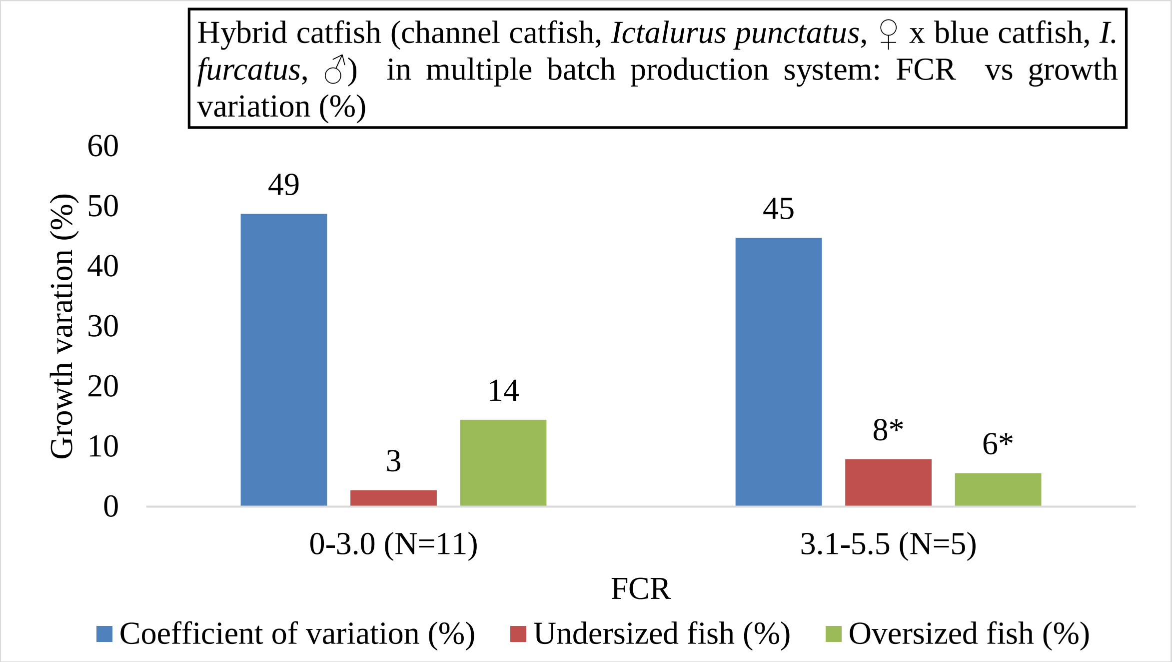

Figure 2.21. Effect of FCR on the growth variation of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in multiple batch system

Significant differences at P< '***' 0.001 '**' 0.01 '*' 0.05 '†' 0.1, t-test.

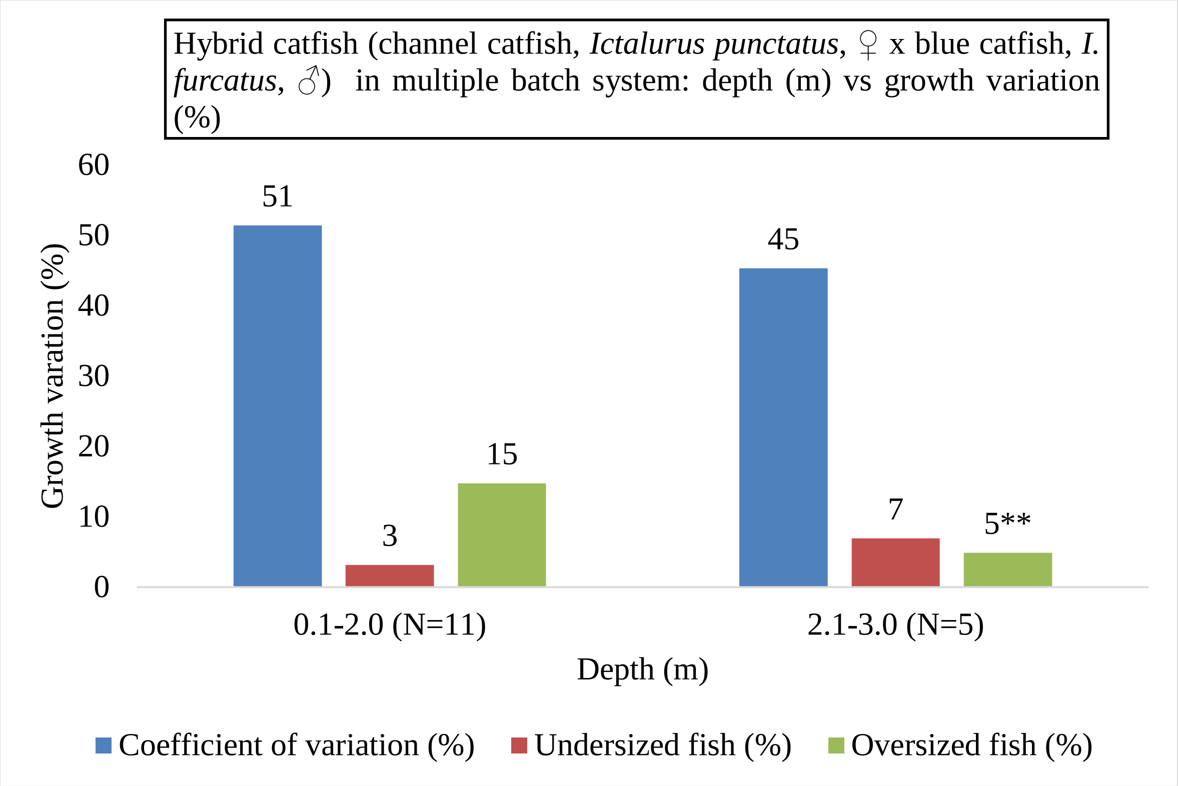

Figure 2.22. Effect of depth on the growth variation of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in multiple batch system

Significant differences at P< '***' 0.001 '**' 0.01 '*' 0.05 '†' 0.1, t-test.

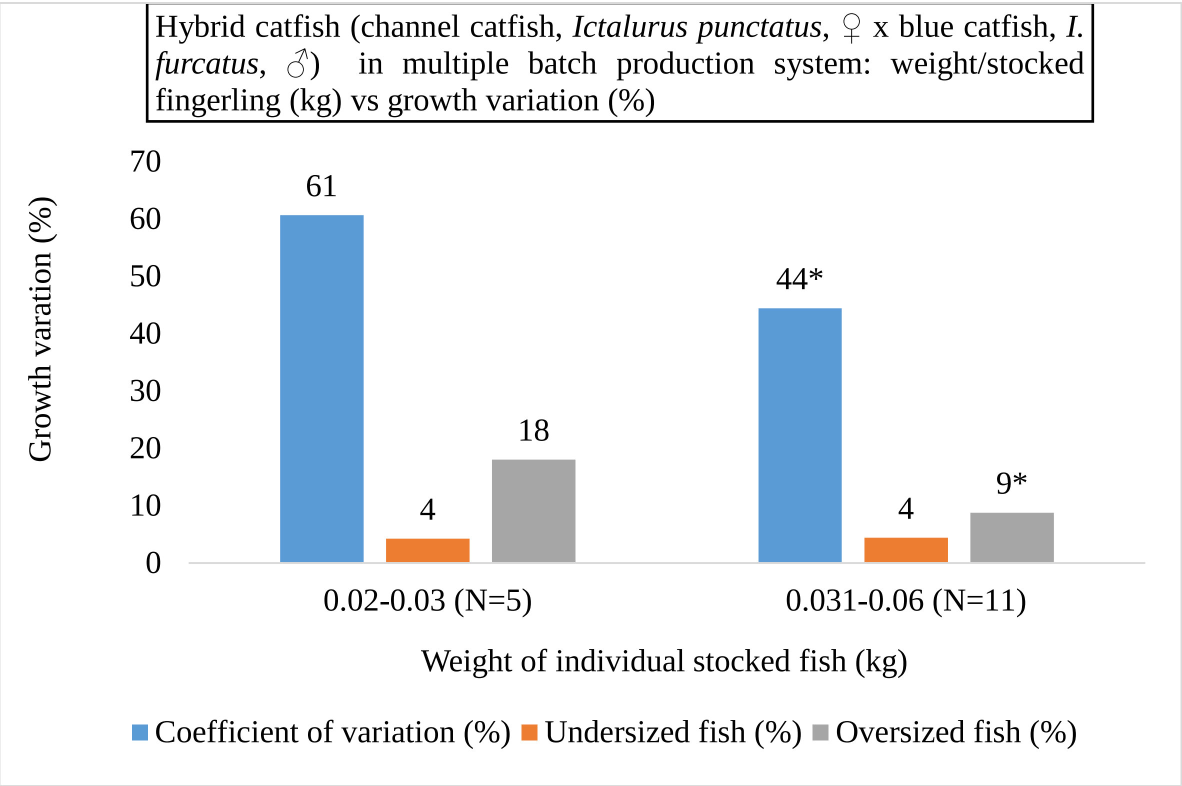

Figure 2.23. Effect of weight/fingerling (kg) on the growth variation of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in multiple batch system

Significant differences at P< '***' 0.001 '**' 0.01 '*' 0.05 '†' 0.1, t-test.

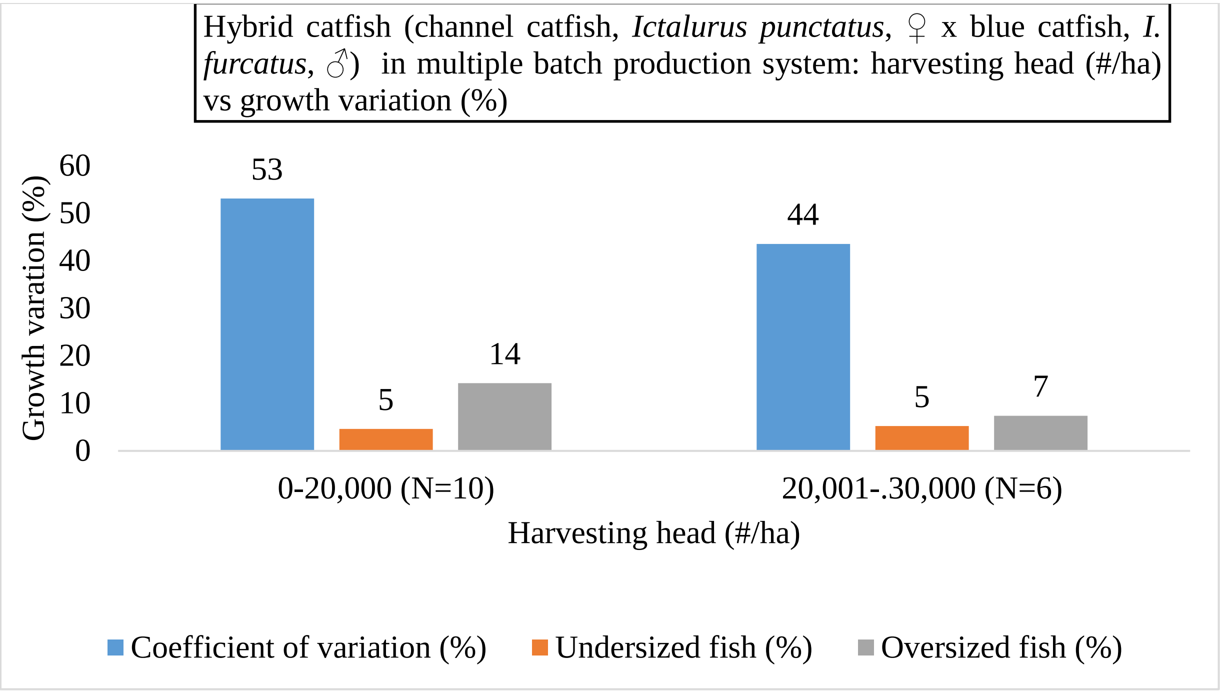

Figure 2.24. Effect of number of fish harvest (#/ha) on the growth variation of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in multiple batch system Significant differences at P< '***' 0.001 '**' 0.01 '*' 0.05 '†' 0.1, t-test.

Split pond production system

The growth variability of hybrid catfish in split pond system was correlated with fingerling grading ($P < 0.001$) (Table 2.10). Other variables such as stocking density and weight/ fingerling correlated with the incidence of undersized and oversized fish (%) ($P < 0.05$) (Table 2.10). Additionally, pond area and aeration correlated with the incidence of undersized and premium sized fish production (Fig. 2.25-2.27). Using larger sized ponds (4.6 -16 ha) could potentially decrease undersized fish (Fig. 2.25). High aeration rates increased the oversized fish (%) (> 11.1 hp/ha) ($P < 0.05$) (Figs. 2.26-2.27). Longer culture periods decreased the undersized and oversized fish production (%) (Fig.2.28). Graphical presentation showed that significant differences were present between total feed fed of 40,001 to 80,000 and 15,000 to 40,000 kg/ha with increased feeding reducing the percent of wrong sized fish (Fig. 2.29).

Table 2.10 Potential causative factors for growth variation in hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) of split pond production system

System	Y[a]	Causative factors	Unit	Coefficients[b]	Std. error[c]	t value	Pr (>t)[d]	M. R^2[f]	Adj. R^2[g]	P[h]
Split pond	CV	Graded fingerling	Y/N	2.905e-01	7.905e-02	3.675	0.0004	0.1760	0.1019	0.02283
	Undersized fish	Graded fingerling	Y/N	-1.027e+01	3.966e+00	-2.590	0.0112	0.4680	0.4198	1.21e-09
		Weight/ fingerling	kg	2.618e+01	1.019e+01	2.570	0.0118			
		Stocking density	#/ha	1.232e-04	5.686e-05	2.167	0.0329			
		Aeration	hp/ha	-4.621e-01	1.785e-01	-2.589	0.0112			
		Area	ha	-1.195e+00	4.250e-01	-2.812	0.0060			
	Oversized fish	Culture period	days	-7.269e-03	2.333e-03	-3.116	0.0024	0.7607	0.7391	< 2.2e-16
		Weight/ fingerling	kg	-6.573e+00	2.490e+00	-2.640	0.0097			
		Stocking density	#/ha	-3.726e-05	1.389e-05	-2.682	0.0087			
		Graded fingerling	Y/N	1.455e+01	9.692e-01	15.017	< 2e-16			
	Premium	Weight/ fingerling	kg	-1.961e+01	1.076e+01	-1.822	0.0717	0.3987	0.3446	1.739e-07
		Aeration	hp/ha	3.954e-01	1.885e-01	2.097	0.0388			
		Area	ha	1.226e+00	4.489e-01	2.731	0.0076			

Y[a]= dependent variable; Coefficients[b]= regression coefficients; Std. error[c]= standard error; Pr (>t)[d]= probability value> t value; M. R^2[g]= multiple r square; Adj. R^2[h]= adjusted r square; P[i]=probability value

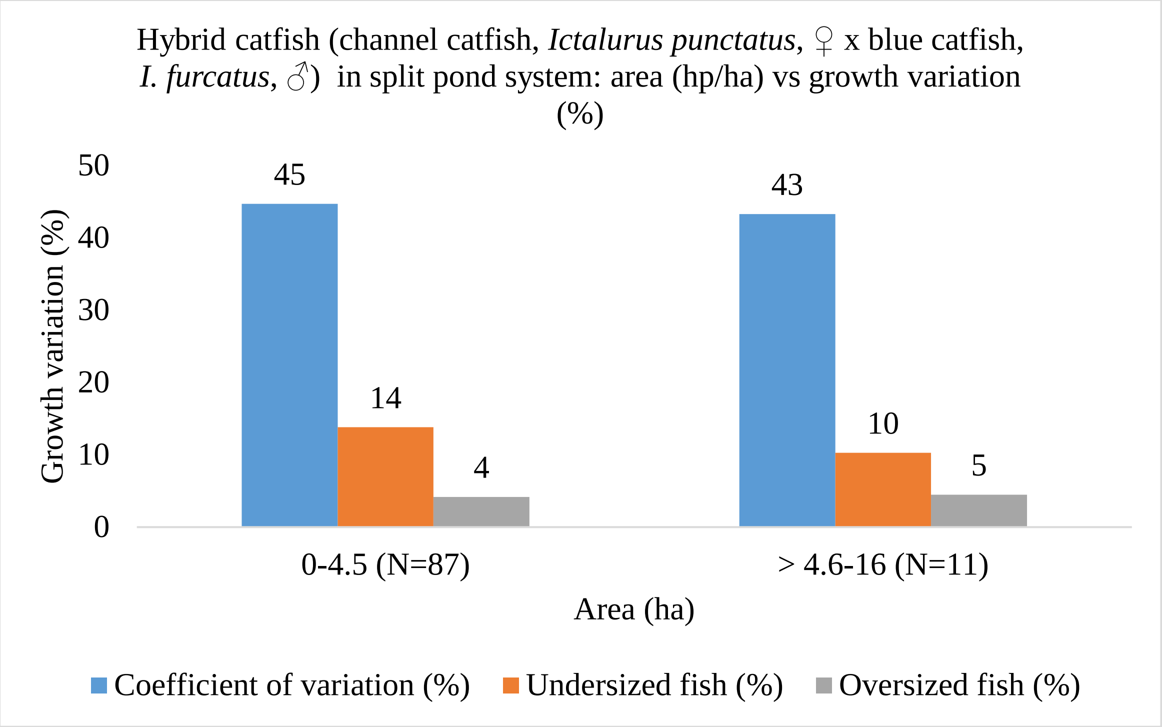

Figure 2.25. Effect of area on the growth variation of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in split pond system

Significant differences at P< '***' 0.001 '**' 0.01 '*' 0.05 '†' 0.1, t-test.

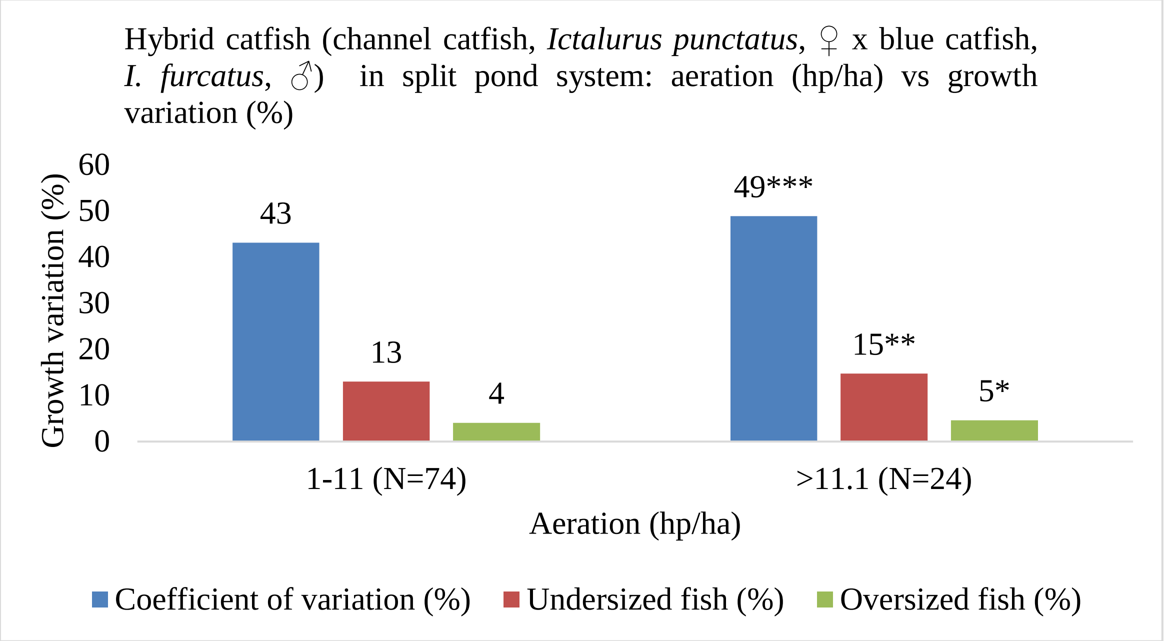

Figure 2.26. Effect of aeration on the growth variation of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in split pond system

Significant differences at P< '***' 0.001 '**' 0.01 '*' 0.05 '†' 0.1, t-test.

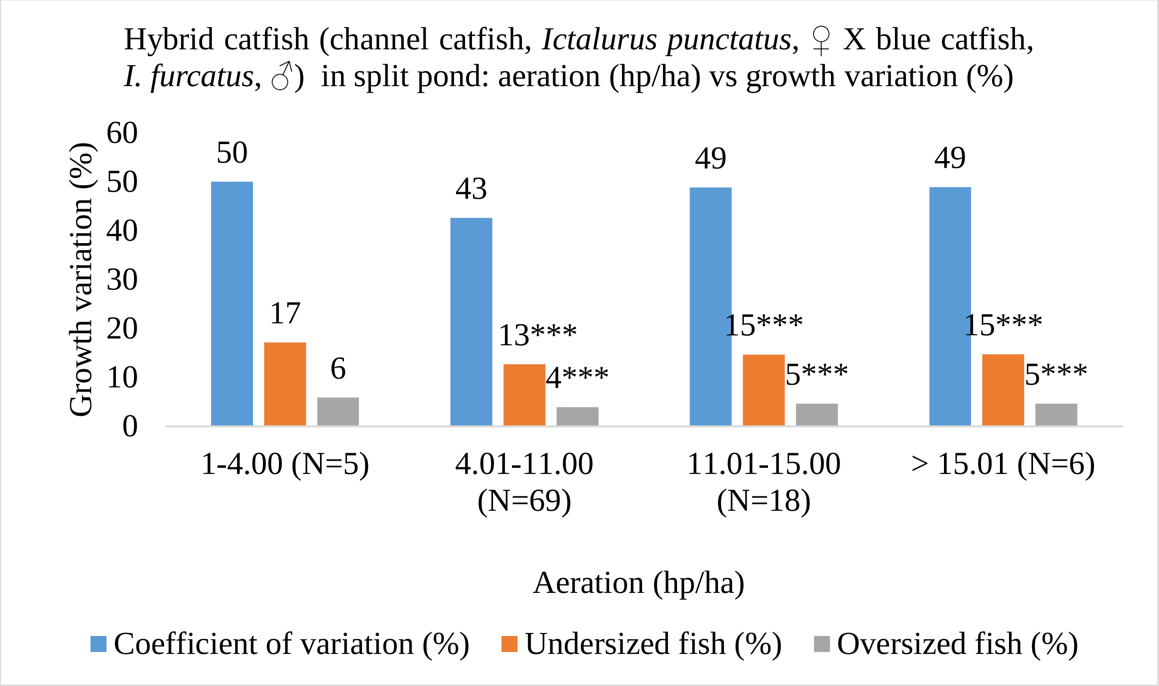

Figure 2.27. Effect of aeration (hp/ha) on the growth variation of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in split pond system

Significant differences at P< '***' 0.001 '**' 0.01 '*' 0.05 '†' 0.1, t-test.

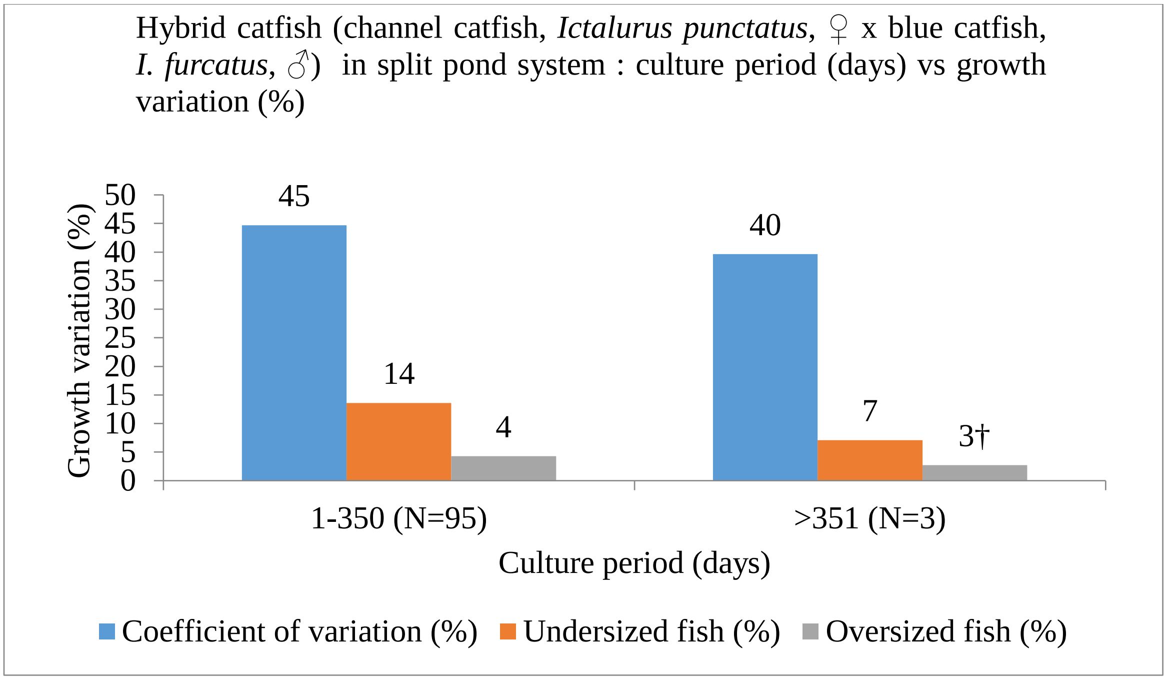

Figure 2.28. Effect of culture period on the growth variation of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in split pond system

Significant differences at P< '***' 0.001 '**' 0.01 '*' 0.05 '†' 0.1, t-test.

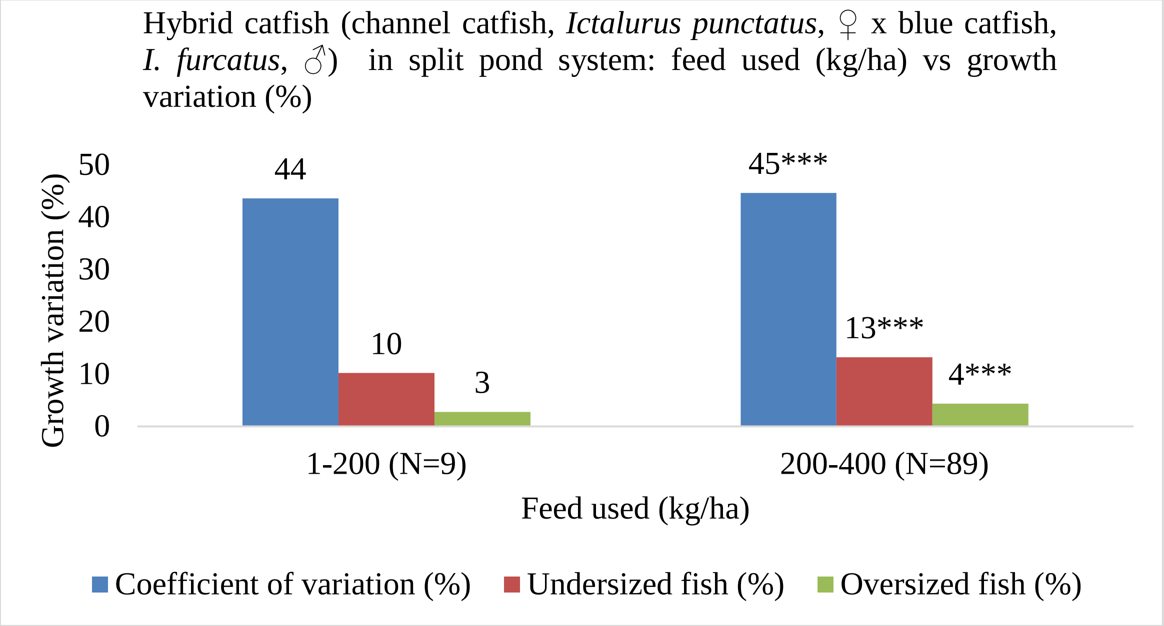

Figure 2.29. Effect of feed used on the growth variation of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in split pond system

Significant differences at P< '***' 0.001 '**' 0.01 '*' 0.05 '†' 0.1, t-test.

In-pond raceway system (IPRS)

In the IPRS system, variables relevant to stocking and feeding management affected the incidence of undersized fish (%) ($P<0.001$) (Table 2.11). Undersized fish (%) increased with increasing pond depth, feed usage and decreased stocking density (Figs. 2.30 - 2.32). Stocking rate of 150-300/cubic meter had the lowest growth variation in this system. Increasing feeding rate reduced the percent of CV and undersized fish while increasing the premium size fish production (%) ($P< 0.001$) (Table 2.11). Increasing FCR and production rate reduced the percent of undersized fish (Figs. 2.33 -2.34). Increasing the stocking weight/ fingerling reduced oversized hybrid catfish percentage and premium fish production (Table 2.9).

Table 2.11. Potential causative factors for growth variation in hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) of in-pond raceway system (IPRS) (research + commercial)

System	Y[a]	Causative factors	Unit	Coefficients[b]	Std. error[c]	t value	Pr(>t) [d]	M. R^{2e}	Adj. R^{2e}	P[f]
IPRS	Undersized fish	Stocking density	#/m^3	0.3027	0.0323	9.35	9.6e-09	0.865	0.839	1.8e-08
		Feed used	kg/ m^3	-0.2771	0.0396	-6.98	8.9e-07			
	Oversized fish	Weight/ fingerling	kg	-0.0514	0.0266	-1.92	0.0681	0.163	-0.003	0.4412
	Premium size fish	Weight/ fingerling	kg	-2.5e-01	4.4e-02	-5.58	1.8e-05	0.718	0.661	2.5e-05
		Feed used	kg/ m^3	2.2e-01	5.4e-02	4.14	0.0004			

Y[a]= dependent variable; Coefficients[b]= regression coefficients; Std. error[c]= standard error; Pr (>t) [d]= probability value> t value; M. R^{2g}= multiple r square; Adj. R^{2h}= adjusted r square; P[i]=probability value

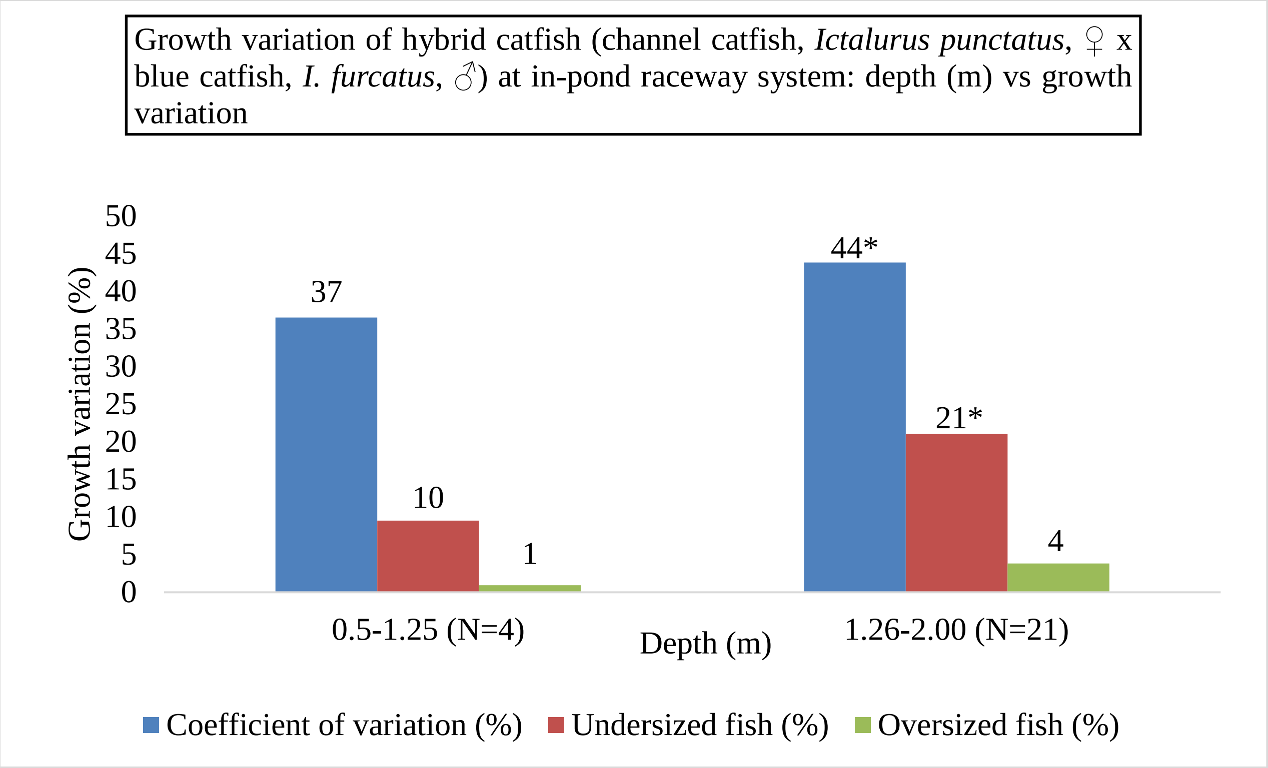

Figure 2.30. Effect of depth on the growth variation of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in in-pond raceway system

Significant differences at P< ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘†’ 0.1, t-test.

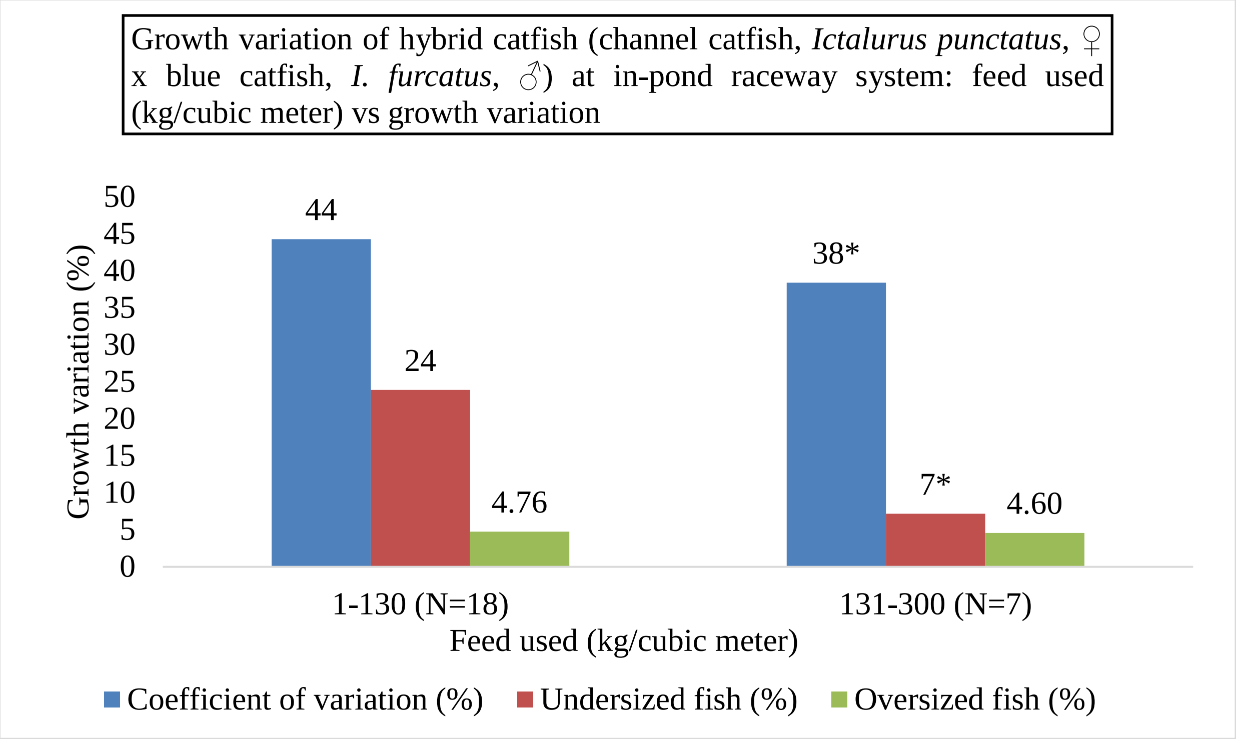

Figure 2.31. Effect of feed usage on growth variation of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in in-pond raceway system

Significant differences at P< '***' 0.001 '**' 0.01 '*' 0.05 '†' 0.1, t-test.

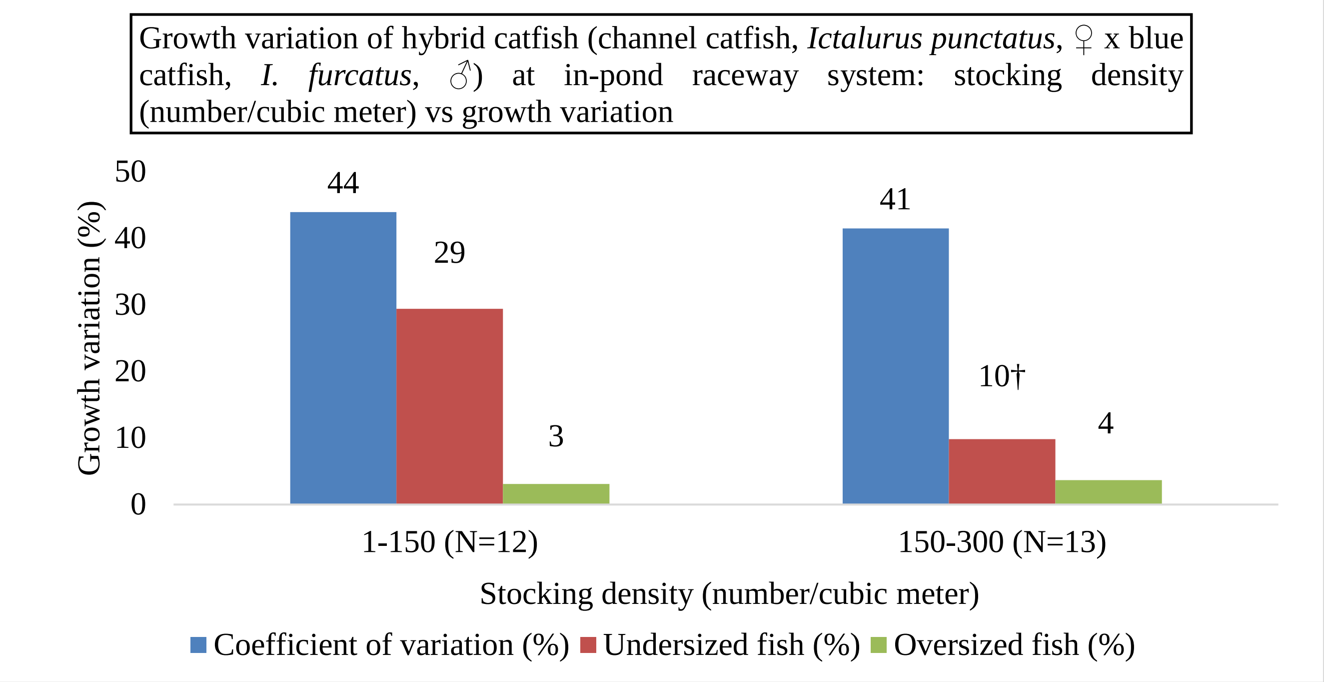

Figure 2.32. Effect of stocking density on the growth variation of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in in-pond raceway system

Significant differences at P< '***' 0.001 '**' 0.01 '*' 0.05 '†' 0.1, t-test.

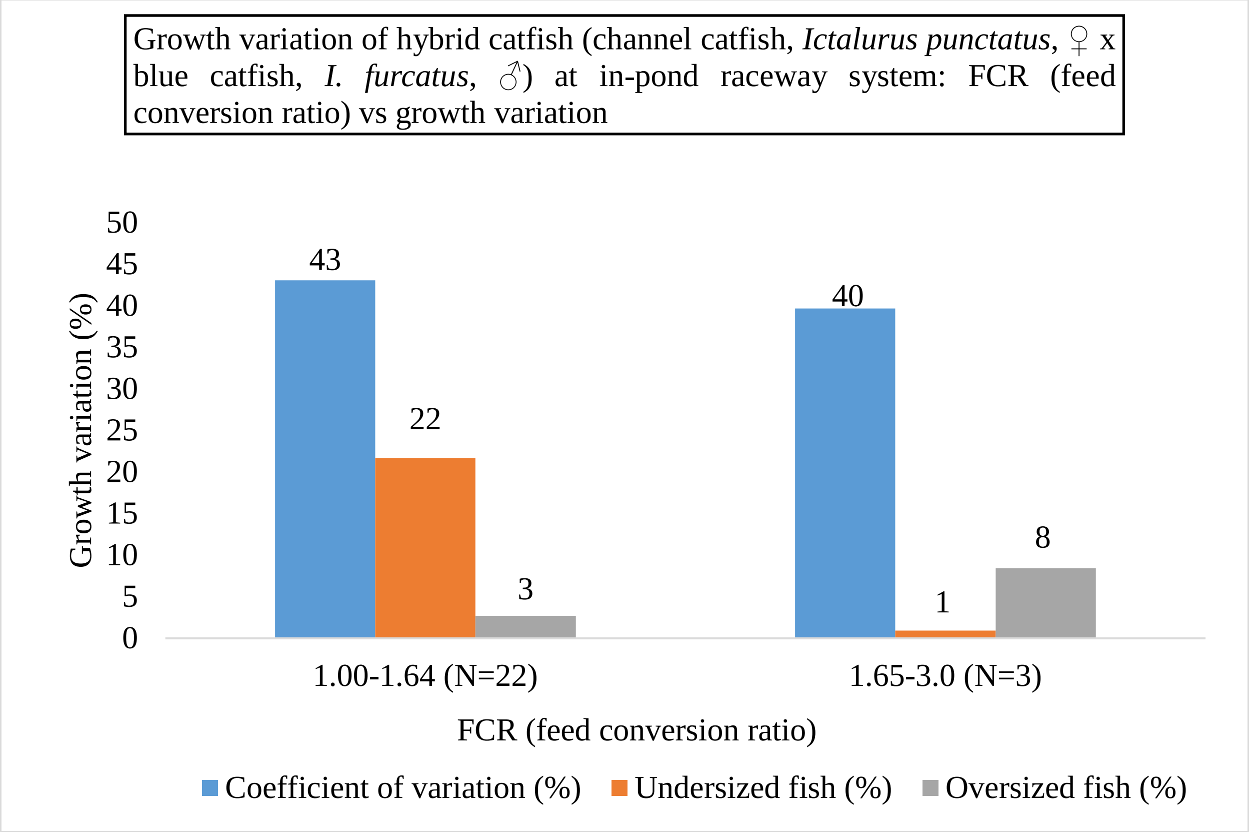

Figure 2.33. Effect of FCR (feed conversion ratio) on the growth variation of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in in-pond raceway system Significant differences at P< ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘†’ 0.1, t-test.

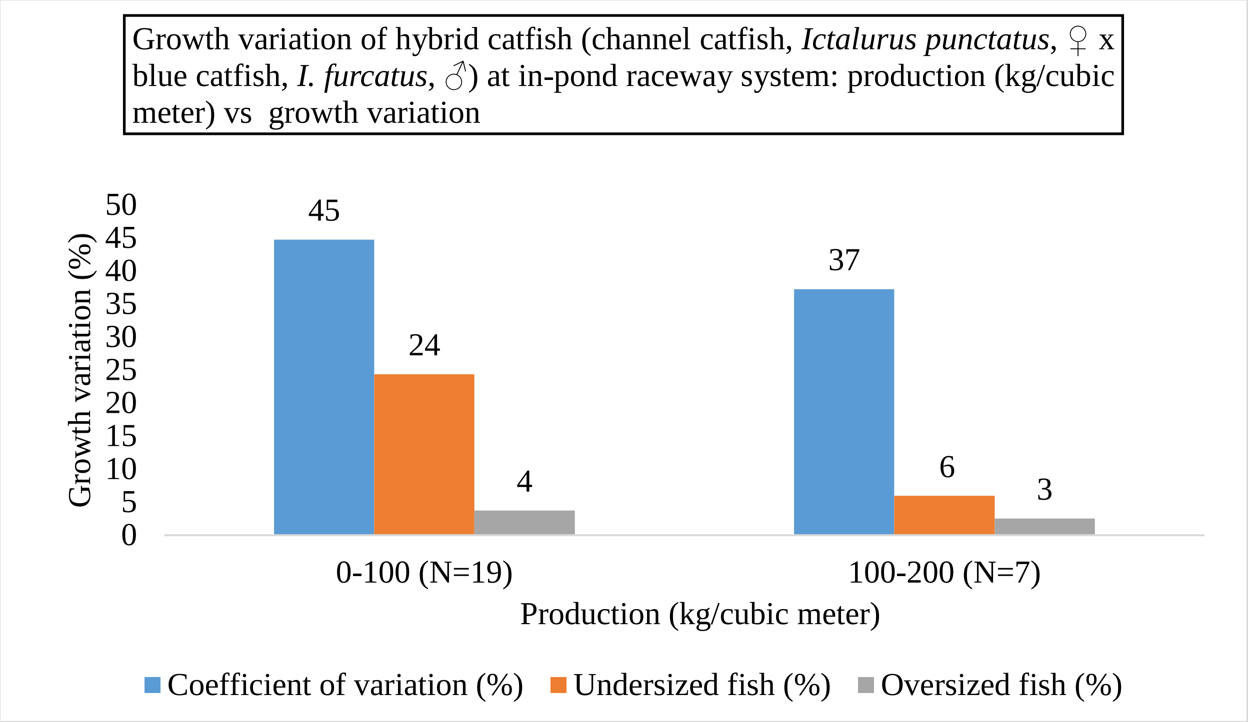

Figure 2.34. Effect of production (kg/cubic meter) on the growth variation of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in in-pond raceway system Significant differences at P< ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘†’ 0.1, t-test.

Discussion

Since the time of the data collection for this study, 2-4 years ago, the oversized catfish problem has become worse and is a large problem for both channel catfish and hybrid catfish culture due to an oversupply of food-sized fish. The fish producers are unable to sell their fish when they are ready to harvest as the processor has excess inventory in storage. The fish continue to grow, which is especially problematic with the faster growing hybrids. Some farmers try to cope with this situation by using restricted feeding, however, if done improperly, this can lead to poor FCR (Li et al. 2016), increased incidence of both oversized and undersized fish and more body weight variability (Li et al. 2012). This problem is further exacerbated by the inherent inefficiencies associated with traditional seining techniques, which leave 10-20% of fish in the pond, and the refusal of some producers to renovate pond bottoms that in some cases have not been addressed in decades. If stocking, harvesting and marketing were better coordinated, the wrong sized fish problems could be greatly diminished.

However, that is not the current state of the industry, and the comparative analysis of traditional (single and multiple batch), intensive (split pond and IPRS (research + commercial)) systems revealed many important parameters among these hybrid catfish production systems that, if properly managed, should reduce the undersized and oversized fish dilemma. Utilization of the information regarding these parameters could give guidance to the catfish farmer in terms of selecting the best management techniques that would help them to reduce the growth variability in hybrid catfish production.

Population distribution

The population distribution of hybrid catfish was near normal in the traditional (single/ multiple batch) and split pond systems. The mean skewness value for hybrid catfish populations in single batch, multiple batch, split pond and IPRS was 1.40, 0.59, 0.68 and 0.60, respectively. This was different from hybrid catfish fingerling production, where the mean skewness value was found -0.26 at low stocking density (150,000 fingerlings/ha) (Brooks et al. 1982). Another difference in population distribution of food-sized hybrid catfish grown at high density and fingerlings grown at low density was that hybrid fingerlings exhibited more uniformity in length than channel catfish fingerlings (Brooks et al. 1982). In general, the absolute value of skewness that is < 0.5 would be considered to be representative of a normally distributed population, while values of 1.5 to 2 were associated with moderate to highly skewed populations (Moav and Wohfarth 1973). Usually, skewness results from competition for food. Species with a relatively small mouth size in relation to body size are more prone to developing skewed populations. The largest individuals, shooters or jumpers, result from a combination of environmental and genetic factors (Dunham 2011). In general, skewness can be reduced by increasing the feeding rate and frequency, decreasing particle size and decreasing stocking rate, thus, reducing competition for food (McGinty 1980).

Undersized, oversized and premium sized fish

The intensive system (IPRS and split pond) had a higher frequency of undersized fish compared to traditional systems. Courtwright (2013) predicted that growth varaibiltiy could be reduced in IPRS system from the decreased competiton for feed since different year classes of fish are cultured in different cells. However, this could be counteracted by the high density of fish in the IPRS and split pond systems, and it may not be surprising that the percentage of undersized fish would increase due to competition in such high density environments. The increase in the small sized fish could be due to social interactions at these densities, unequal access to feed or underfeeding. Alternatively, most populations contain individuals that grow extremely slow due to genetic inferioirty, even though sufficient amount of food was avaiable (Brooks et al. 1982). However, this is not a likely explanation, as if this were the primary cause of the undersized fish. The percentage of such sized fish should be equal across all systems rather than having a preponderance of these fish in more confined systems, IPRS and split pond.

The multiple batch system had the highest amount of oversized fish as well as the highest CV (50 ± 11). This likely resulted from the repeated stocking and harvesting procedures associated with this system as the multiple year classes would increase individual variability and inefficient partial harvest would result in increasing numbers of oversized fish. Based on the report of Engle and Valderrama (2001), the percentage of small fish would also be expected to increase in multiple-batch systems due to slow growth of carry-over fish already present in the pond. Collier and Schwedler (1990) also suggested that the major drawback of multiple culture system was the food competition between larger and smaller fish sizes. However, the percentage of undersized fish from multiple batch systems in the current study was lower than that found in the IPRS and split ponds, and the same as in the single batch system, which is not consistent with reports from 9-18 years ago. The earlier studies addressed channel catfish culture. Thus, hybrid catfish may be better suited for multi-batch systems than channel catfish. Other potential explanations for the apparent decrease in size variation problems for the multiple batch system, although they are still significant, could be improvements in feeding, harvesting and grading technology.

However, the variability associated with the multiple batch systems and the increase of oversized fish could affect FCR. In the current analysis, the highest observed value of FCR was 2.75 for the multiple batch systems, a little higher compared to single batch system (2.47); even though almost similar stocking density was maintained in both of these traditional systems. Schwedler et al. (1989,1990) reported that the single batch system was beneficial in terms of reducing the size variability at harvest since the single cohorts of fish were cultured at a time in this system, and that was reflected by the least observed mean for wrong sized fish, 9%, for all systems in the current study, as well as slightly better observed FCR. However, problems with year-round availability of harvest ready fish were a major limitation for the single batch system when channel catfish were utilized (Terhune et al. 1997).

Overall, the coefficient of variation for body weight (%) of hybrid catfish was 43 in all production systems combined and ranged from 37 for the single batch system to 50 for the multiple batch systems. Dunham et al. (2014) found even higher CV (%) for hybrid catfish production (52.1-69.9 and 50.1-65.0) when comparing different genetic types of hybrids that had been grown at very high density during the fry/fingerling production stage. Jiang et al. (2008) observed a CV (%) of 41.8 and 30.3 for different genetic types of hybrid catfish fingerlings, which was similar to channel catfish (CV= 38.6 and 35.4) and blue catfish (CV= 29.9). Early experiments indicated that blue catfish had the most uniform growth rate, and paternal predominance was evident for this trait with the channel catfish female X blue catfish male hybrids being more uniform than parental channel catfish (Dunham et al. 1982). However, this study was conducted at relatively low densities compared to those currently used, and CV relationships among hybrid and channel catfish are evidently affected by environment, genetics and the genotype X environment interaction with strong density and culture effects.

Causative factors: growth variability

Most of the feeding and stocking management variables were the potential factors that influenced the CV, undersized and oversized fish production in hybrid catfish production. Among the stocking variables, stocking density, weight per fingerling, number of fish harvest and graded fingerling had the most impact. Bosworth et al. (2015) showed that hybrid body weight was unaffected and net production increased with the increasing density from 7,425 to 22,275 fish/ha, but additional production was not achieved when the stocking density was further raised above 22,275 /ha; under these conditions, instead the number of sub-marketable fish increased.

Individual weight of stocked fingerling had a significant impact on the frequency of undersized and oversized hybrid catfish production in all systems with the use of large fingerlings reducing oversized fish in all systems. Use of larger fingerlings reduced the occurrence of oversized fish by half in the multi-batch system and greatly reduced both oversized and undersized fish in the single batch system. For split ponds, again, large fingerlings resulted in decreased oversized hybrids, but increased the percentage of undersized hybrids. Stocking large hybrid fingerlings in the IPRS also decreased oversized fish, but oddly, also reduced premium sized fish. In contrast to these results, Mischke et al. (2017) suggested that stocking of larger size fingerling (> 0.054 kg) could yield a larger proportion of oversized fish that could affect the net returns. In the case of the multi-batch system, a larger fingerling should be able to compete better, preventing older larger fish from monopolizing the feed. In the case of the single batch system, stocking of larger fingerlings could reduce size variation (Schwedler et al. 1989; Schwedler et al. 1990), equalize access to the pellets, and reducing the magnification effect.

The effect of fingerling size on growth variation was different for the intensive systems but an increase in both undersized and oversized hybrid in the IPRS. There is a trend of opposite effects as the fish become increasingly crowded. This could be related to changes in social behavior as fish density changes. However, it would more likely be associated with underfeeding and access to feed as it would not be surprising to see a population gravitate to 2 subpopulations, oversized and undersized in an environment where feed is limiting and the fish are not satiated. Courtwright (2013) indicated that growth variability could be reduced by decreasing the feed competition among different year-class of fish in the IPRS system. Perhaps the competition within a cell has more impact than competition between different cohorts in the pond systems.

Increasing the number of fish harvest (#/ha) greatly reduced oversized fish in single batch and especially, multiple batch systems, but not split pond and IPRS systems. Efficient seining, grading and removal of harvestable and large catfish would be critical in the multiple batch system to prevent oversized fish, and this is likely reflected with the percent decrease of oversized hybrids as number of fish harvest (#/ha) increased. Harvestability would also be very important in the extensive single batch system, but less important in the intensive systems where the fish are already confined. Alternatively, but less likely, number of harvested fish should be correlated with stocking density, and perhaps if no stocking densities were reached that could change behavioral interactions and reduce the percentage of oversized fish. No fish production would trend to an optimum.

Initial fingerling body weight variation as well as the initial size could affect body size variation at harvest. Graded fingerlings are commonly utilized in aquaculture to reduce growth variability among harvested fish (Saoud et al. 2005). However, this practice has met with variable success. Saoud et al. (2005) found that grading resulted in populations with less growth variability at harvest in Nile tilapia, *Oreochromis niloticus*. However, Yousif (2002) found that grading Nile tilapia only temporarily resulted in lower growth variability, and that high stocking density and low feeding rates promoted growth variability. Additionally, Carmichael (1994) observed that grading appeared to result in repartitioning of variation and final coefficients of variation for size, and variability, ultimately, was not different in graded and ungraded channel catfish populations. In contrast, grading reduced body weight variation in paddlefish, *Polyodon spathula,* (Onders et al. 2011) and in yellow perch, *Perca flavescens* (Wallat et al. 2005).

Schwedler et al. (1990) reported that sub-populations of marked channel catfish (segregated based on discrete size) could reduce the size variability relative to the overall population (SD, 2.07-2.15 for the marked groups versus 2.82 for the total population). The authors also suggested that CV (%) for the total population declined from 12.4% at stocking to 8.8% at harvest, while it was 6.2-7.3% at harvest for the marked groups. Here the authors concluded that variability of channel catfish (at harvest) resulted from stocking variability and differential growth rates. Grading did not affect size variation in silver perch (*Bidyanus bidyanus*) (Barki et al. 2000), however, the densities were very low and the feeding restricted.

The overall effect of grading hybrid fingerlings in the current study was negative. In single batch and split pond systems, application of graded fingerlings increased the percentage of oversized fish, although grading reduced the number of undersized food fish in split ponds. However, grading increased the percentage of undersized fish in the single batch ponds as well as the oversized catfish, while reducing the CV. Grading increased the CV in the multiple batch and split pond systems. To fully understand the effects of grading, follow-up research is needed to determine if the fingerlings were graded to be larger or smaller, which could alter explanations for this result. It seems contradictory that grading would increase oversized fish while utilization of larger sized fingerlings would decrease frequency of oversized hybrid catfish. One or both of these variables could be correlated to a more explanatory variable such as genetics.

Among the variables under feeding management, feed usage and FCR were the most influential factors in terms of growth variability in hybrid catfish production in all four environments. When FCR was high in single batch systems, the undersized and oversized fish percentages increased. This is somewhat puzzling as a high FCR would be indicative of overfeeding, which would result in each fish being satiated and relatively even growth. However, this could also be a result of under feeding or improper use of restricted feeding. If underfed, the largest fish could dominate the feed with the smaller fish not having access to sufficient quantities of feed. This scenario would lead to high FCR and both undersized and oversized fish. Indeed, restricted feeding of channel-blue hybrid catfish results in higher FCR and an increase of undersized fish at harvest (Li et al. 2012, 2016).

However, the results were different in each system, high FCR in the IPRS also increased the oversized fish, but greatly reduced the percentage of undersized hybrids, perhaps indicating that providing enough feed in this highly intensive system is critical to allow all of the smallest fish to grow. A third scenario existed as high FCR reduced the oversized fish, but increased the undersized fish in the multiple batch system.

As expected, feed usage appeared to have significant impact on size variability. Although replication was very low, the ponds in the single batch system with maximum feeding rate more than 200 kg/ha had only 1% undersized fish and 1% oversized fish. Increasing the feeding rate could potentially reduce the undersized and oversized fish (%) resulting from the feed competition when culturing different year-classes of fish in the same environment, but in the case of single batch culture, this may be indicative of allowing all sizes of fish access to feed.

In contrast, no feeding had a signficantly reduced oversized fish production (%) in the single batch system only. Here the oversized fish production (%) would decrease if the operation impose any feeding cap during the feeding period. It appears contradictory that a high maximum feeding rate would decrease oversized fish, yet imposing a feeding cap would also result in fewer oversized fish. This needs further investigation to identify the relationship of these two variables. The absolute value of the feeding cap could help explain this apparent contradiction.

Increased feeding greatly reduced the number of undersized fish in the IPRS while it increased the percentage of premium size fish. Additionally, increased production, a reflection of feeding, in the IPRS greatly reduced out of sized fish, which was likely correlated to more or better feeding. Other studies indicated that feeding frequency and feed intake are likely main factors behind growth variability (Martins 2005; Zakęś et al. 2006). Hatlen et al. (2006) reported that restricted feeding increased growth variability in Atlantic cod, *Gadus morhua (L).* Feeding rate and stocking density affects variability and skewness (which leads to oversized fish) in common carp, *Cyprinus carpio* (Nakamura and Kasahara 1955, 1956, 1957, 1961; Moav and Wohfarth 1973; Wohlfarth 1977) and in channel catfish (McGinty 1980, Brooks et al. 1982). Increased feeding rate decreased size variability for hybrid sunfish (Wang et al. 1998). However, Zakes et al. (2006) did not observe any effect of feeding rate on size variability in pikeperch, *Sander lucioperca* with only minor growth variation if the fish were fed either in excessive or restricted settings. Feeding rate did not affect size variability in gibel carp, *Carassius auratus gibelio,* (Zhou et al. 2003) (Zhou et al. 2003) or pompano, *Trachinotus marginatus* (Da Cunha et al. 2013)

Other feeding variables had relatively minor impact on growth variation. Long feeding periods, actual days fed, would be expected to increase the amount of oversized fish, but paradoxically, there were slight decreases in single batch and split pond systems. Other factors during the period of feeding may explain this paradox. As expected longer culture periods increased the frequency of oversized hybrids in split ponds while undersized fish decreased, and reduced the frequency of undersized fish in split ponds. Dunham et al. (2014), reported that culture period did not have a significant impact on CV (%) in channel-blue hybrid catfish production, but they did not measure the percentage of undersized and oversized fish.

Pond depth had an impact on size variation and the percent of oversized fish was greatly reduced in deeper (2.1-3.0 m) multiple batch ponds compared to pond depths of 0.1-2 m. This could be related to social behavior or although the feeding is on the surface, large, dominant fish might have more difficulty controlling the feeding area in deeper ponds. This phenomenon was observed in multiple batch ponds where several age and size classes would result in a greater abundance of dominant and passive relationships and potentially greater numbers of large, dominant fish. As was the case for many variables, the opposite effect was observed in the IPRS and wrong sized fish was greatly reduced in shallow raceways. Different dynamics are at play in raceways.

Pond area was also important. The smallest ponds for single batch production had the least amount of wrong sized fish. This is logical as feeding and management should be more efficient in a small system, but capital construction costs would be higher. Contradictorily, larger split ponds and multiple batch ponds had reduced number of undersized hybrids compared to larger split ponds. Perhaps, the advantage is that once a pond reaches a certain size' feeding of the fish and spread of the fish is sufficient to reduce competition.

Aeration rate could also affect the growth variability of hybrid catfish, and this was the case in single batch ponds, but the relationship was not linear. As aeration increased, the wrong sized percentage of hybrids decreased until a plateau was reached, and size distribution remained constant as aeration increased. Aeration rates have increased over time from 2.50 in 1982 to 6.25 hp/ha in 2010 (Boyd 1998; USDA–APHIS 2010). Body weight of hybrid catfish increased by 44%, if dissolved oxygen concentration was maintained at the rate of 3.8 mg/L (total aeration rate maintained is 1.50 hp/ha) compared to 1.4 mg/L (Torrans et al. 2015). The increased aeration may have allowed better feeding and less competition decreasing the out of sized fish. Aeration levels at 22 hp/ha or higher altered the trend and wrong sized fish began to increase. This may be a result of other factors such as heavier stocking densities or water quality rather than direct effects of aeration.

Stocking density appears to be another key variable. Increased stocking densities for the intensive multiple batch system and the IPRS decreased the wrong sized fish problem. Increased stocking density also decreased the frequency of oversized hybrids in single batch and in split pond culture, but increased small fish in the split ponds. For the multiple batch system, this could be a reflection of efficient harvest and grading. Alternatively, social behavior and competition could be altered with changing density, leading to changes, this time positive, in population distribution.

Conclusion

The growth variability problem in hybrid catfish farming could be reduced by using the best management practices, particularly giving attention on the stocking and feeding management. The optimum values for the key variables should be included under the best management categories if a farmer would like to produce the highest amount of premium size fish from the production system. Intensive systems were a good option to produce considerably higher yield within a brief period as compared to traditional systems. The current study identified key factors to be included for best management practices. However, further study is needed to find the ideal values for these variables to best accomplish the goal of eliminating oversized and undersized hybrid catfish.

The best management practices may vary from one production system to another, and the results for the IPRS were the most unique compared to the pond systems. For example, deep ponds reduced oversized fish percentage, but deep raceways increased the oversized fish frequency. Some results could only be explained if the social behavior of hybrid catfish changes when certain environmental variables are altered, warranting more sophisticated behavioral studies. Surprisingly, grading aggravated the wrong size fish problem, but using large fingerlings alleviated the problem. It seems contradictory that grading would increase oversized fish while utilization of larger sized fingerlings would decrease frequency of oversized hybrid catfish. Follow-up research is needed to determine if the fingerlings were graded to be larger or smaller, which could impact the explanations for this result, and would determine if grading can be used in a positive manner to increase the premium sized fish.

It also appears contradictory that a high maximum feeding rate would decrease oversized fish, yet imposing a feeding cap would also result in fewer oversized fish. This needs further investigation of the relationship of these two variables. The absolute value of the cap could help explain this apparent contradiction. Feed conversion efficiency has a large impact on the frequency of wrong sized fish, but the exact cause is not clear and this needs further inveistgation.

Although, the factors affecting size distribution were not always exactly the same or of the same magnitude among the different production systems, some generalizations can be made regarding which variables, high stocking rates, stocking of large fingerlings, everyday feeding, relatively high feeding rates, adequate length of culture, use of small ponds, utilization of more than 4 hp/ha (aeration rate) and harvest of large numbers of fish (presumed efficient harvest and grading), had the most impact.

As part of it, the following best management practices are suggested to reduce oversized and undersized hybrid catfish in the following production systems.

Single batch systems

Oversized

- Use large fingerlings (50-70g), but this may actually have lesser net return compared to medium size fingerling (18 cm)
- Graded fingerlings slightly increases oversized fish, but reduces undersized fish

- Enacting a feeding cap greatly reduced oversized fish, but the ideal feeding cap needs to be identified (it is likely between 200-400 kg/ha)
- Stocking density should be increased
- Avoid overfeeding
- Three-hundred or more feeding days were needed to reduce oversized fish, probably meaning missed feeding days actually leads to oversized fish
- Culture period, however, should not exceed 400 days.
- Ponds less than 2.0 ha, but more than 4.0 ha should be used
- Ideal aeration rate should be 5-8 hp/ha, and likely due to correlations with other variables, aeration in excess of this value leads to an increase in oversized hybrids

Undersized

- Increase the number of culture days to allow more fish to reach harvestable size
- Decrease stocking density, which conflicts with reducing oversize fish, so we still must identify the ideal stocking rate
- Graded fingerling slightly reduces undersized fish
- Use large fingerlings (60g), but this may actually have lesser net return compared to medium size fingerling (18 cm)
- Avoid overfeeding
- Ponds less than 2.0 ha, but more than 4.0 ha should be used
- A minimum of 5 hp/ha should be used for aeration
- Maximum feeding rate should be more than 200 kg/ha/day

Multiple batch systems

<u>Oversized</u>

- Ponds should be at least 2 meters deep
- Stocking density should be more than 30,000 hybrids/ha
- Ungraded fingerlings should be used
- Fingerlings stocked should be a minimum of 30g each
- A minimum of 20,000 head/ha should be harvested annually so efficient harvest and grading are critical

<u>Undersized</u>

- Stocking density should be more than 30,000 hybrids/ha
- Ponds should be at least 4 surface-ha

Split pond systems

<u>Oversized</u>

- Use ungraded fingerlings, contradicts what is needed to prevent oversized fish
- Aeration should be between 4-11 hp/ha
- Culture period should be at least 350 days
- Average feeding rate should be no more than 200 kg/ha/day

<u>Undersized</u>

- Use graded fingerlings, contradicts what is needed to prevent oversized fish
- Pond should be larger than 4.5 ha

- Aeration should be between 4-11 hp/ha
- Average feeding rate should be no more than 200 kg/ha/day

In-pond raceway systems

Oversized

- Use ungraded fingerlings

Undersized

- Raceway depth should be 1.26m or less
- Feeding rate should be more than 130kg/cubic meter per day
- Stocking density should be at least 150 fish/cubic meter
- Fingerlings stocked should be 40g or less
- Satiation feeding should be used
- Production needs to exceed 100kg/cubic meter

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Appendix

Appendix 2.1: Survey questionnaire

Hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. Furcatus*, ♂) farming and growth variability: producer survey

Questions for fingerling to food size pond sampled	Answers
✓ Name of farm	
✓ Pond #	
✓ Date of sampling	
Source of fingerlings	
✓ What company did you buy your fingerlings from?	
✓ Which catfish strain or line did you use into this sampled pond?	
Pond type	
✓ Regular pond	
• Levee pond	
• Watershed pond	
• Split pond	
• In-Pond Raceway System	
✓ Size of pond (acre)	
✓ Total farm water acreage (acre)	
Stocking	
✓ What month did you stock this pond?	
✓ What month did you harvest this pond?	
✓ Stocking rate per acre	
✓ Number of understocking per acre	
✓ Stocking density (total)	
✓ Size of stocked fish (inch)	
✓ Were the fish stocked 'graded'? Yes or No	
Production system	
✓ Single batch	
✓ Multiple-batch	
Feeding Dates	
✓ What month did you begin feeding daily?	
✓ What month did you stop feeding daily?	
Feeding management	

✓ What was your maximum feeding rate? (lb./acre)	
✓ Did you have a feeding cap? Yes or No	
o If ‘Yes’, then what was your feeding cap (lb/acre/day)?	
✓ Did you feed fish all they would eat (to satiation)? Yes or No	
✓ Did you feed these fish during the winter months? Yes or No	
Feed types	
1. What protein level did you feed? (%)	
2. What protein level did you feed? (%)	
3. What protein level did you feed? (%)	
Feeding quantity total for:	
✓ Feed 1) above quantity fed? (lb/acre)	
✓ Feed 2) above quantity fed? (lb/acre)	
✓ Feed 3) above quantity fed? (lb/acre)	
Water quality management	
Was fixed aeration (Horse Power) available? Yes or No	
✓ What was your annual aeration electricity cost (total or per pond)?	
✓ Was your emergency aeration Horse Power (HP) available: Yes or No	
Primary method for monitoring dissolved oxygen (DO)	
a. automated sensor	
b. hand monitor (oxygen meter)	
c. other	
d. did not regularly monitor dissolved oxygen (DO) level	
Water quality testing	
a. at least once per month	
b. less than once per month	
c. in response to health problems only	
d. not tested	
Diseases losses	
✓ What were your estimated pounds of fish loss during this crop cycle?	
✓ Would you classify the quantity of fish loss in this pond as 'small', 'medium' or 'large'?	
✓ What were the primary causes of fish loss?	
✓ Was the primary cause from diseases or low dissolved oxygen?	
✓ Or, were the losses primarily from another cause?	
Harvesting	
Total quantity harvested	
✓ Average fish size (lb)	
✓ Total pounds harvested	
Method of harvest	
a. Complete harvest	

b. Partial harvest	
✓ Using seine net mesh	
✓ Using standard grading sock	
✓ Heikes or bar grader	
c. Other methods	

Appendix 2.2: Statistical procedure

Coefficient of variation (CV)

It is a standardized measure of dispersion from a probability/ frequency distribution. It is mainly a ratio of standard deviation (σ) relative to mean (μ), which is often expressed in percentage (%).

$$CV= \sigma/ \mu$$

Variance inflation factor (VIF)

VIF is the ratio of variance in a model with multiple terms, divided by the variance of a model with one term alone. It quantifies the severity of multicollinearity in an ordinary least squares regression analysis. It provides an index that measures how much the variance (the square of the estimate's standard deviation) of an estimated regression coefficient is increased because of collinearity.

Principal component analysis (PCA)

PCA is a statistical procedure that uses an orthogonal transformation to convert a set of observations of possibly correlated variables into a set of values of linearly uncorrelated variables called principal components

Linear regression

Linear regression is a linear approach for modelling the relationship between a scalar dependent variable, ‘Y’ and one or more explanatory variables (or independent variables) denoted as ‘X’. The case of one explanatory variable is called simple linear regression. For more than one explanatory variable, the process is called multiple linear regression

Model diagnostic test

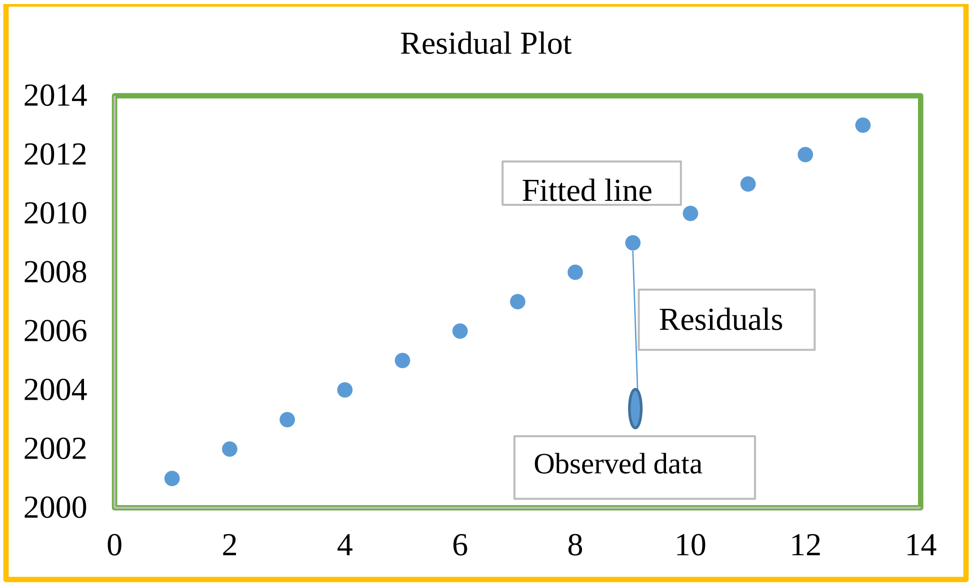
Adjusted R^2 (coefficient of determination)

It is a statistical method that estimates the proportion of the variability in the dependent variable (Y) that is predictable from the independent variables (X) (Watkins n.d.). Basically it measures how well the regression line approximates the real data points. For example, if the value of a adjusted R^2 is 0.6212, it means that the 62% of the variation between X and Y variables are explained, while the rest is not (Kerns 2010). Here an adjusted R^2 of 1 indicates that the regression line perfectly fits with the data points.

Residual analysis

Residuals are the differences between the fitted line and observed data at each combined values of the explanatory variables (Watkins n.d.). The can be defined by the following simple equation (Watkins n.d.)

$$\text{Residuals} = \text{Data-Fit} = Y_i - Y\hat{}_i$$



A hypothezised residual plot (concept adapted from Watkins n.d.)

Residual analysis (graphical)

Graphical analysis for residual is performed in between the residual and fitted data points to make sure that the selected model is best fitted. Such model usually shows an equally spread residuals around a horizontal line with distinct pattern, which means that a liner relationship exists in between the fitted and observed data points. If this type of line is not found, then the selected model can be considered as a bad model (Watkins n.d.).

Normality test

The normality test for the residual analysis can be performed by using a Q-Q (quantile-quantile) plot. This plot is basically a scatterplot, which incorporates two sets of quantiles (i.e., percentiles) against one another. If the plot forms a straight line, then it can be inferred that the residuals are normally distributed. If not, then it is assumed that the residuals are distributed in random manner. It is basically a visual check, which indicates the outlier in the data series and help to fix it (Watkins n.d.).

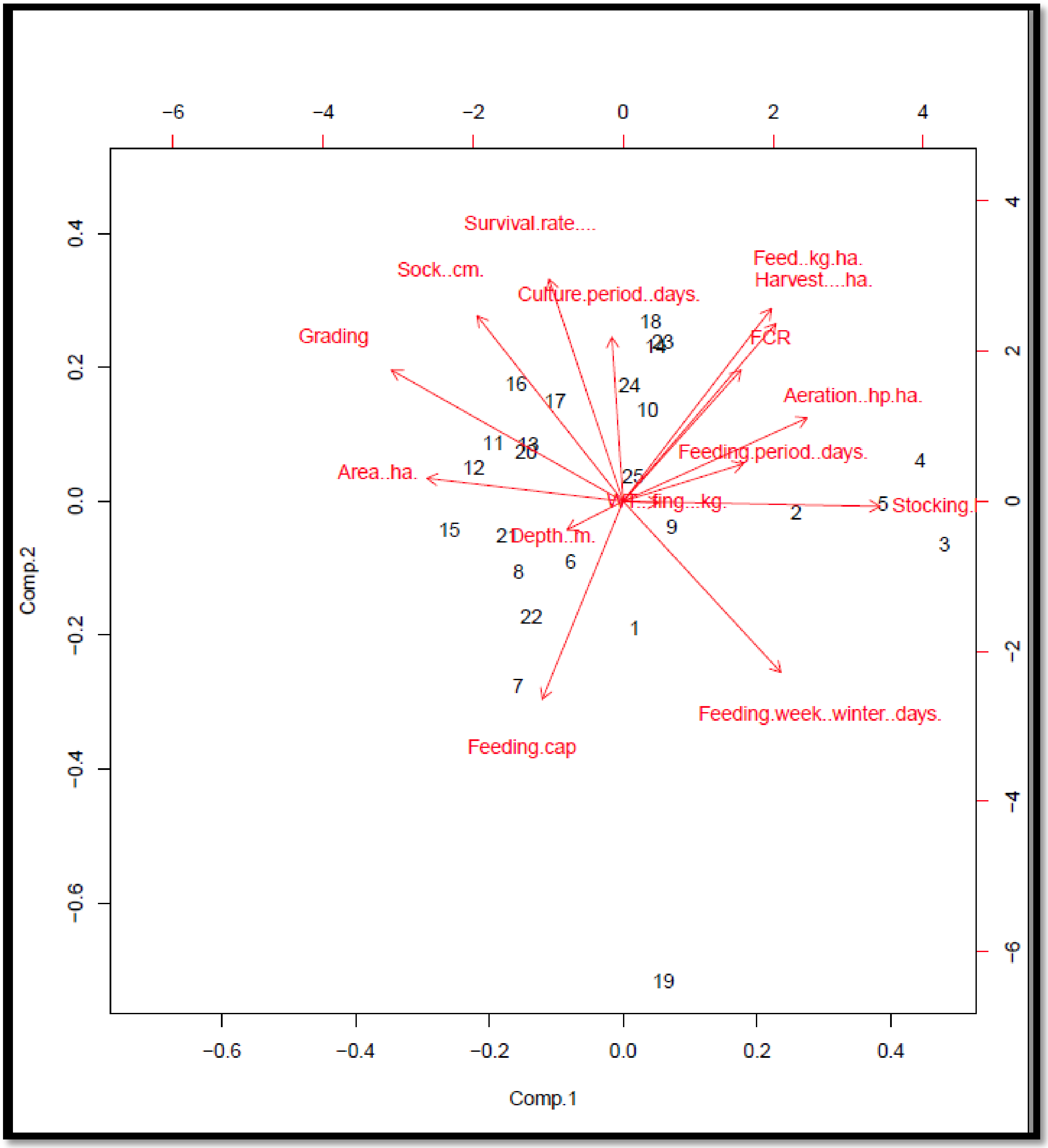
Scale location/Spread-Location plot

This plot shows how the residuals are spread equally along the ranges of predictors. This measurement is used to check the assumption of equal variance (homoscedasticity). A good indication of the measurement is to find out a horizontal line with equally (randomly) spread points in the plot.

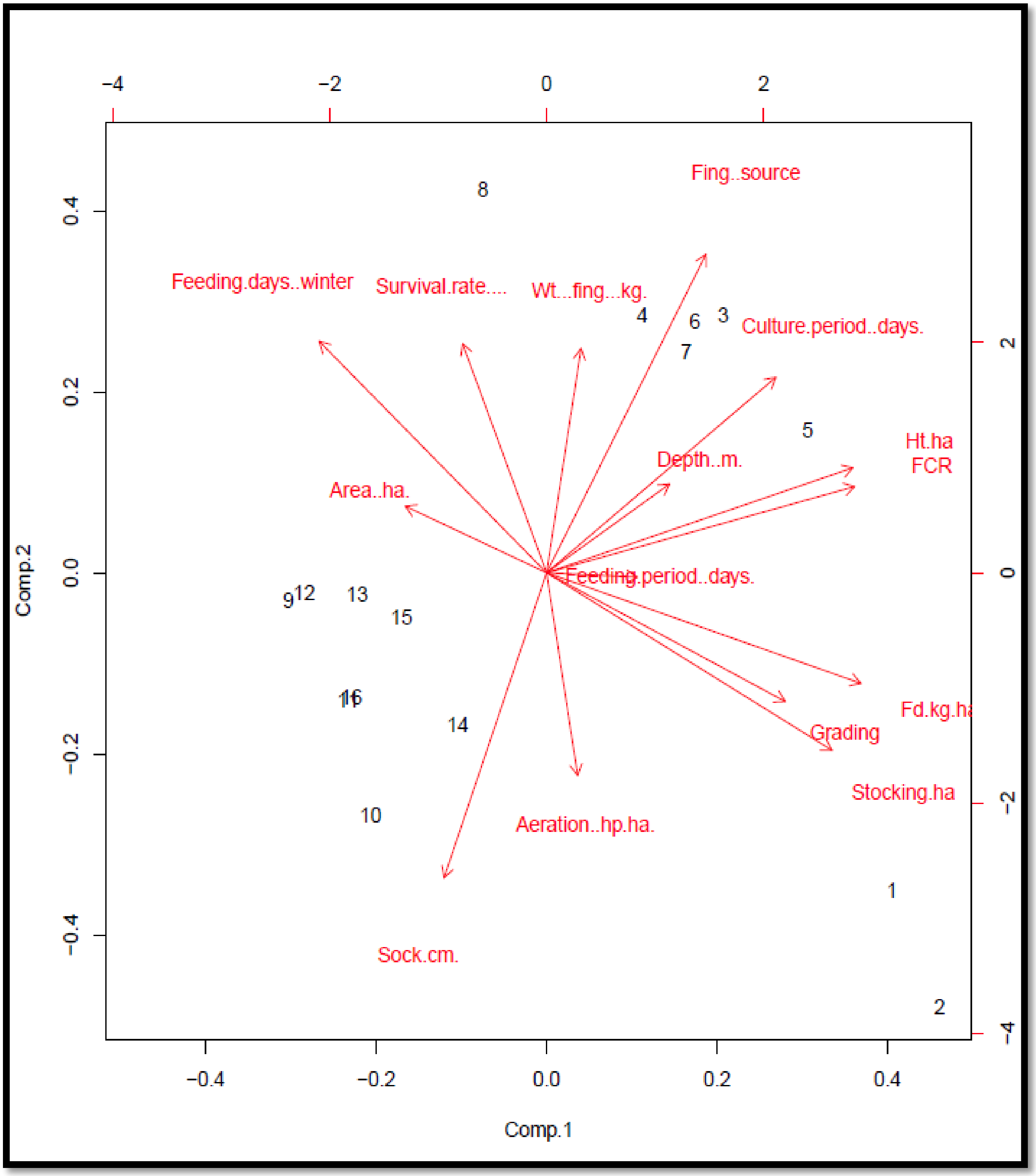
Residuals vs Leverage/ Cook's distance

This plot helps to find out the influential cases (i.e., subjects or outliers) that are present in linear regression analysis.

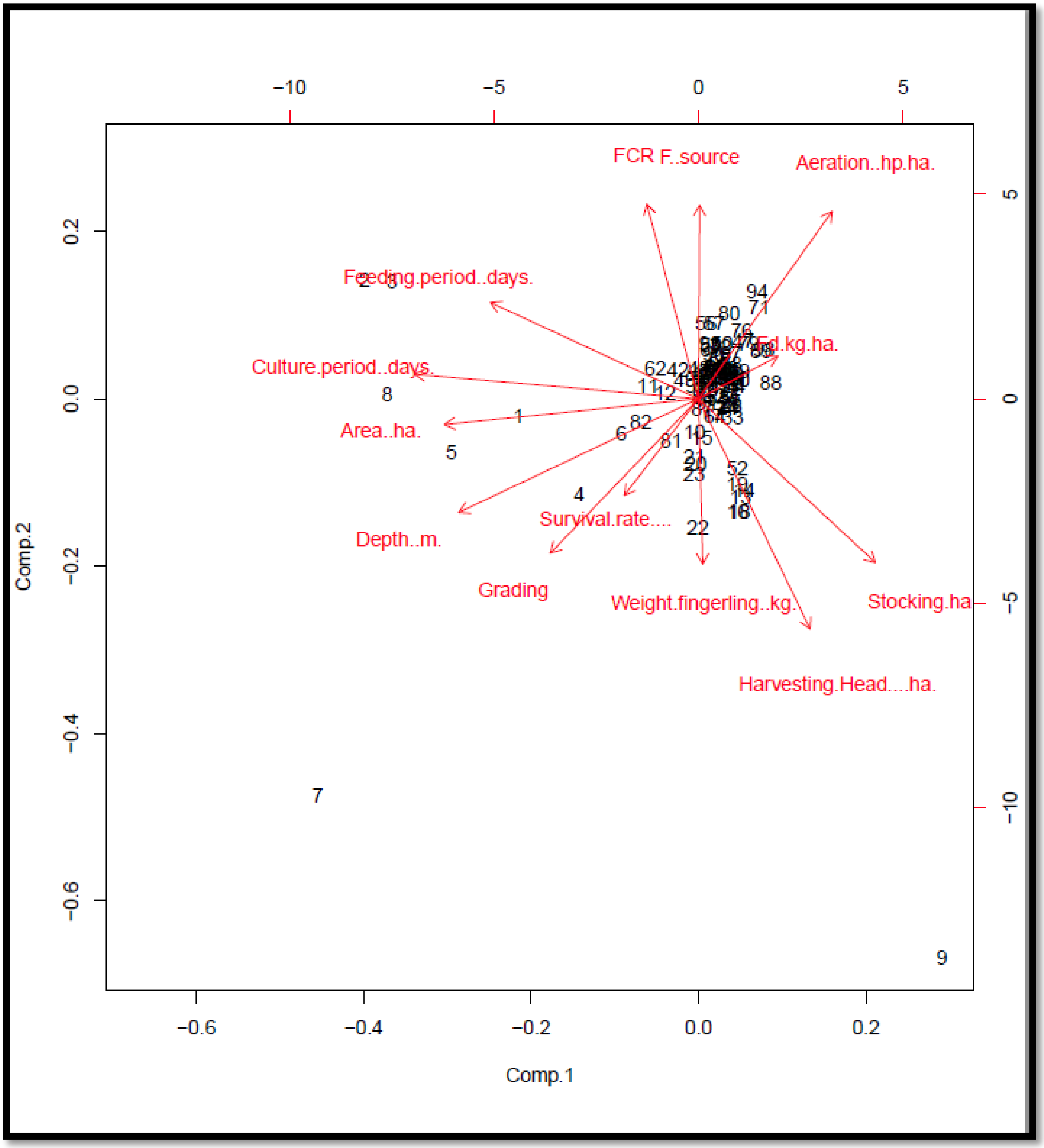
Appendix 2.3: Results for PCA bi-plots



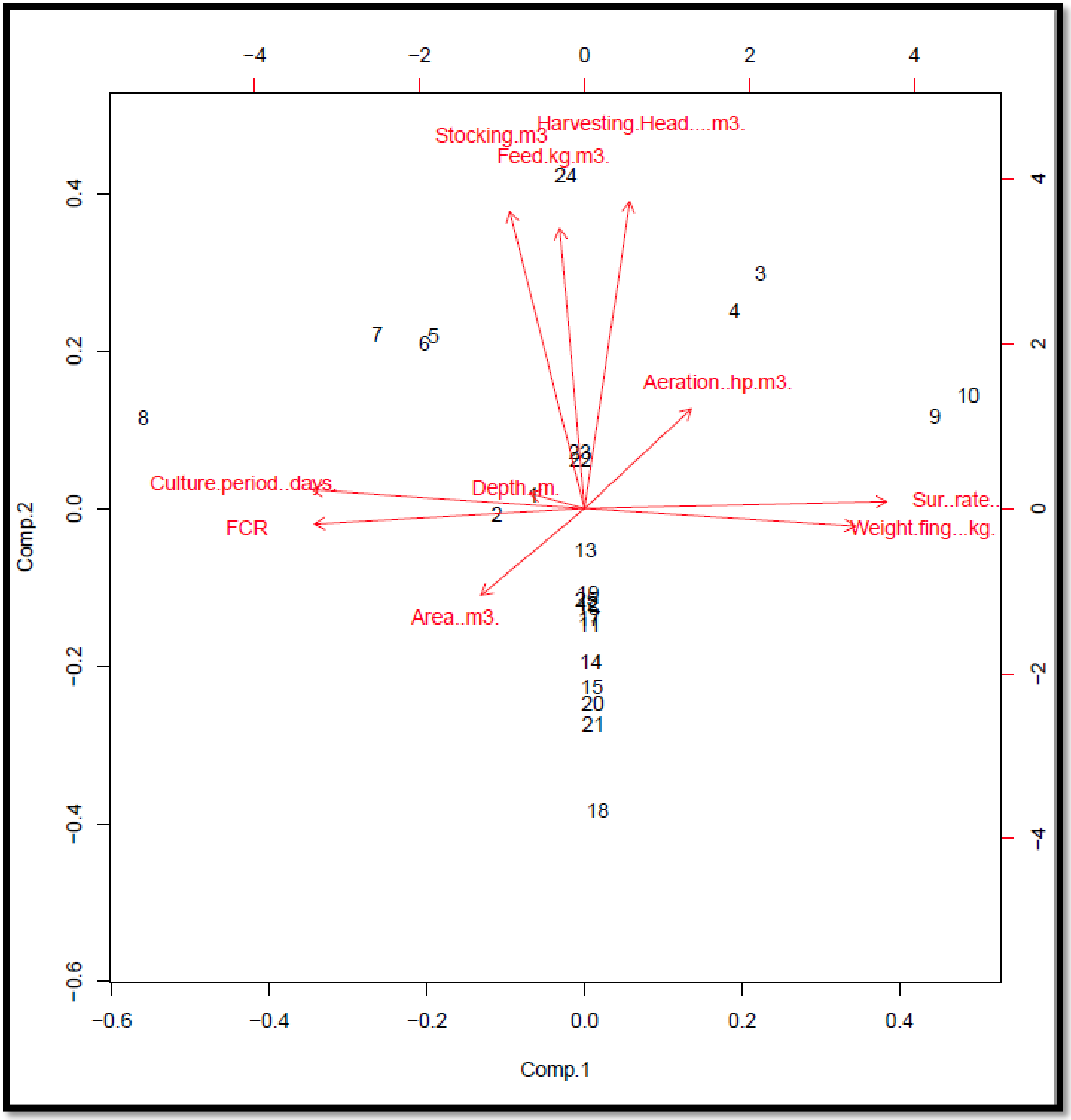
PCA bi-plots of growth variability study of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in single batch systems (includes Xi, numeric + categorical variables) (wt. fing. = weight/fingerling, kg)



PCA bi-plots of growth variability study of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in multiple batch systems (includes Xi, numeric + categorical variables) (wt. fing. kg= weight/fingerling (kg); fing. Source=fingerling sources, Ht. ha= Harvested head/ha); Fd.kg.ha=Feed used (kg/ha)

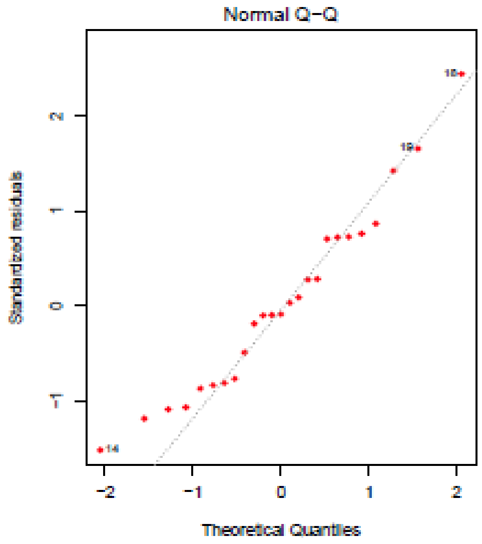
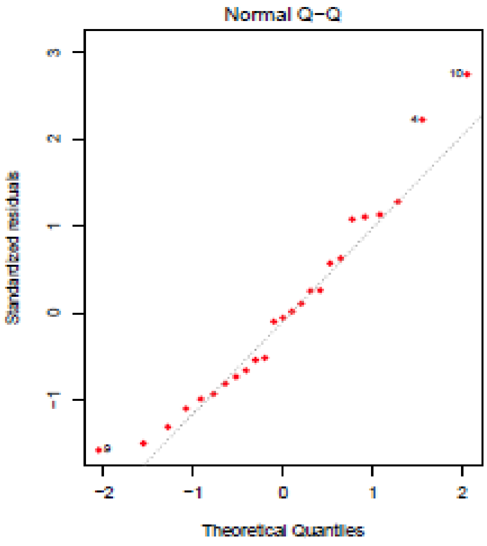
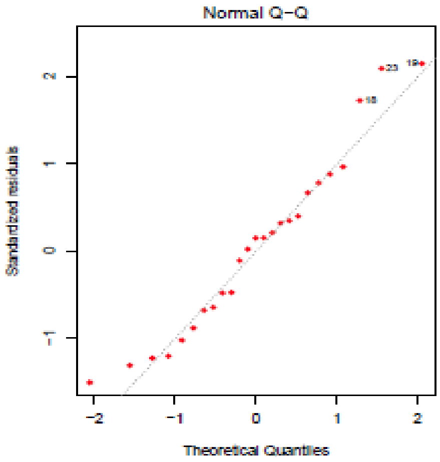
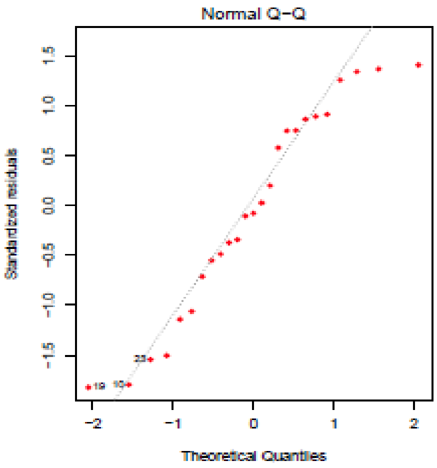


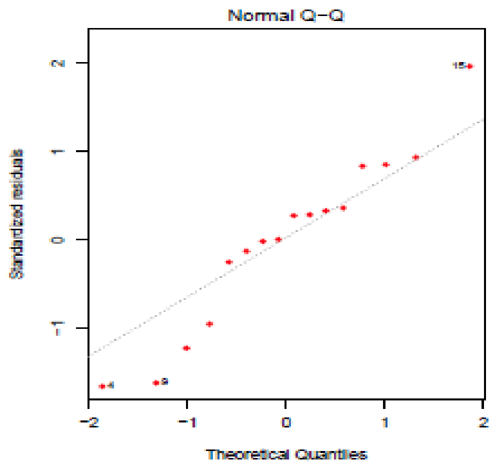
PCA bi-plots of growth variability study of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in split pond (includes Xi, numeric + categorical variables) (F. Source=fingerling sources)



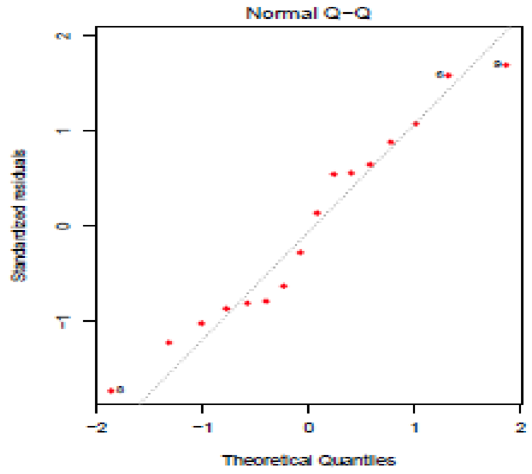
PCA bi-plots of growth variability study of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in IPRS (includes Xi, numeric + categorical variables) (Sur. Rate=Survival rate, %; m3= cubic meter)

Appendix 2.4: Results for model diagnostics test

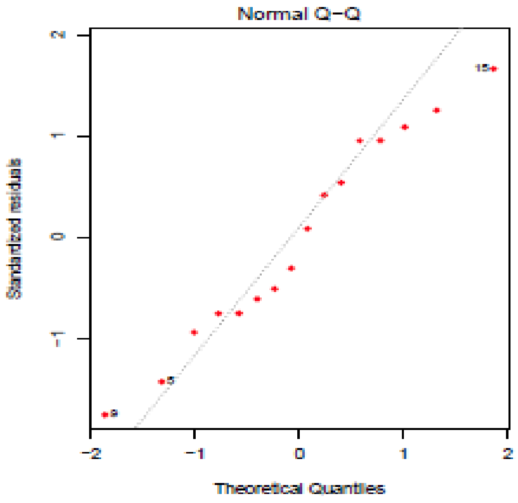
	
Testing the normality (QQ plot) for the best fitted model in growth variability study of hybrid catfish farming (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in single batch system (Y=CV (%) and X= production variables)	Testing normality (QQ plot) for the best fitted model in growth variability study of hybrid catfish farming (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in single batch system (Y= undersized fish (%) and X= production variables)
	
Testing normality (QQ plot) for the best fitted model in growth variability study of hybrid catfish farming (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in single batch system (Y= oversized fish (%) and X= production variables)	Testing normality (QQ plot) for the best fitted model in growth variability study of hybrid catfish farming (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in single batch system (Y= premium size fish (%) and X= production variables)



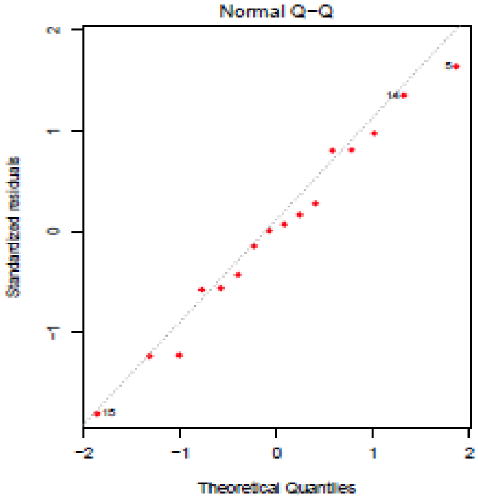
Testing normality (QQ plot) for the best fitted model in growth variability study of hybrid catfish farming (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in multiple batch system (Y= CV (%); X= production variables)



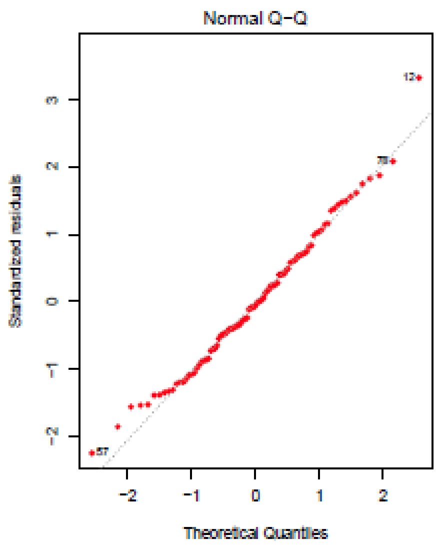
Testing normality (QQ plot) for the best fitted model in growth variability study of hybrid catfish farming (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in multiple batch system (Y= undersized fish (%); X= production variables)



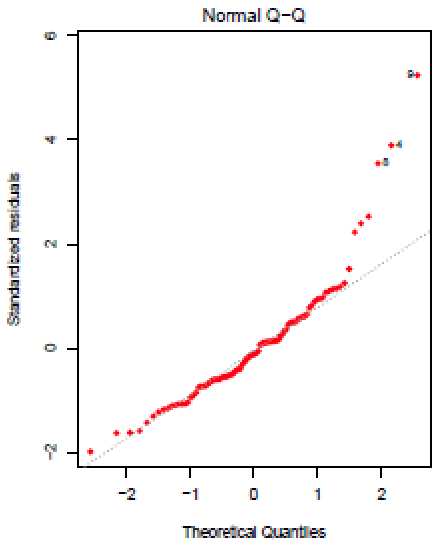
Testing normality (QQ plot) for the best fitted model in growth variability study of hybrid catfish farming (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in multiple batch system (Y= oversized fish (%) and X= production variables)



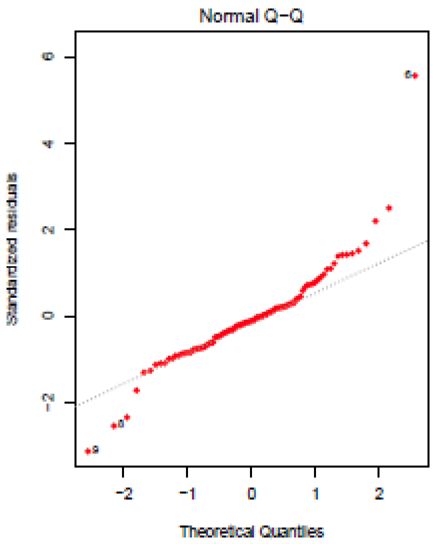
Testing normality (QQ plot) for the best fitted model in growth variability study of hybrid catfish farming (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in multiple batch system (Y= premium size fish (%) and X= production variables)



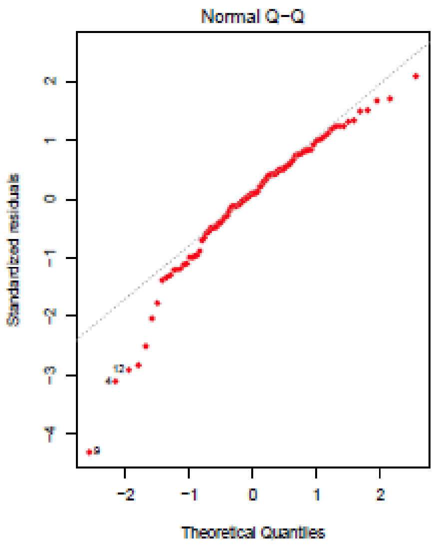
Testing normality (QQ plot) for the best fitted model in growth variability study of hybrid catfish farming (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in split pond system (Y= CV (%) and X= production variables)



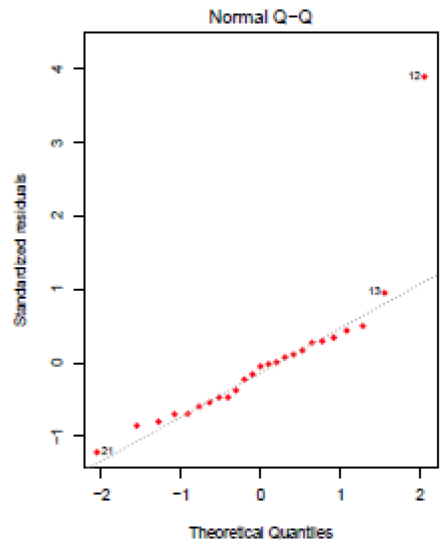
Testing normality (QQ plot) for the best fitted model in in growth variability study of hybrid catfish farming (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in split pond system (Y= undersized fish (%) and X= production variables)



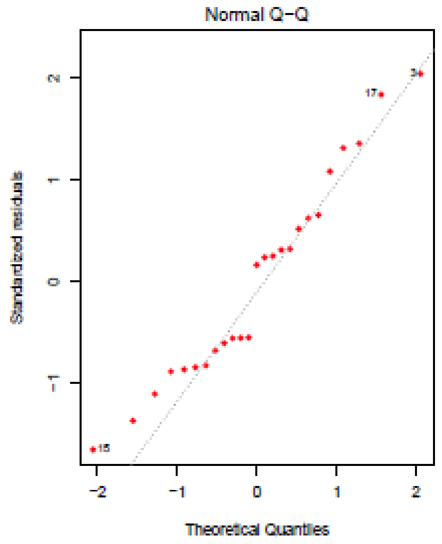
Testing normality (QQ plot) for the best fitted model in growth variability study of hybrid catfish farming (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in split pond system (Y= oversized fish (%) and X= production variables)



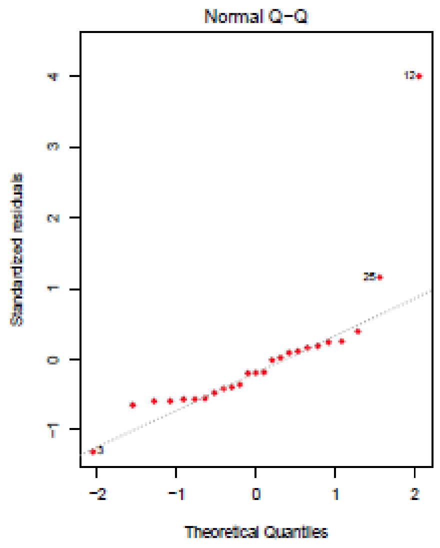
Testing normality (QQ plot) for the best fitted model in growth variability study of hybrid catfish farming (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in split pond system (Y= premium size fish (%) and X= production variables)



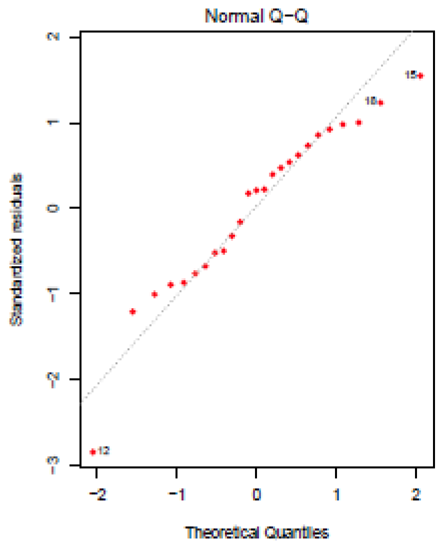
Testing the normality (QQ plot) for the best fitted model in growth variability study of hybrid catfish farming (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in in-pond raceway system (Y= CV (%) and X= production variables)



Testing normality (QQ plot) for the best fitted model in growth variability study of hybrid catfish farming (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in in-pond raceway system (Y= undersized fish (%) and X= production variables)



Testing normality (QQ plot) for the best fitted model in growth variability study of hybrid catfish farming (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in in-pond raceway system (Y= oversized fish (%) and X= production variables)



Testing normality (QQ plot) for the best fitted model in growth variability study of hybrid catfish farming (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in in-pond raceway system (Y= premium size fish (%) and X= production variables)

CHAPTER 3

ECONOMIC IMPACT OF HYBRID CATFISH (CHANNEL CATFISH, *ICTALURUS PUNCTATUS*, ♀ X BLUE CATFISH, *I. FURCATUS*, ♂) GROWTH VARIABILITY ON PRODUCTION

Abstract

The production cost of hybrid catfish farming (channel catfish, *Ictalurus punctatus,* ♀ x blue catfish, *I. furcatus,* ♂) has been increasing due to rising input costs. Production intensification may result in lower per unit cost. Hybrid catfish production is one way toward production intensification, but the business has experienced a growth variability problems resulting in undersized and oversized fish. Analyzing the economic impact of this problem is critical to understanding how a fish farm's profitability is affected by fish processors demand for certain premium sized fish and alternative production systems. Comparative economic analyses were conducted by using standard enterprise budgeting, partial budgeting and sensitivity analysis for single batch (N=25), multiple batch (N=16), split-pond (N=98) and IPRS (research) (N=4) systems. Results showed that split pond system had greater economic benefits than traditional systems (single and multiple batch) and IPRS (research). This was evidenced from the higher net returns ($8,578/ha) resulting from the highest availability of premium sized fish (0.45-1.81 kg in weight and sales price = $2.46/kg). Current analyses also showed that variations in dockage rates for the price of undersized (sales price = $2.34/kg) and oversized fish (sales price = $2.08/kg) resulted in revenue loss and had a significant economic impact on net returns. This loss, in total, was $1,712/ha for undersized and oversized fish, regardless of the production system. Partial budget analyses showed that using 18 or 20 cm fingerlings were economically feasible but 18 cm fingerling resulted in greater benefits. Sensitivity analyses showed that split pond system could be the most profitable enterprise compared to the traditional and IPRS (research) systems, because it

produced a greater net return in all dockage price scenarios for undersized and oversized fish at 25%, 50%, and 75% reductions to the base sales price.

Introduction

The U.S catfish industry is one of the prime sources of economic activity and employment in many southern counties in the U.S (Kaliba and Engle 2004). However, this industry has been contracting due to increasing input prices (Hanson and Sites 2015), availability of inexpensive basa, *Pangasius bocourti*, and tra catfish, *P. hypophthalmus*, and the additional costs of regulatory compliance (Engle and Stone 2013). In such a situation, adopting productivity-enhancing measurements is likely to be the main solution, which has already begun in the U.S. to produce higher output at a lower per unit cost (Engle 2003).

Hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) farming is a prime example of such a measurement as it shows certain unique characteristics that are evident in commercial settings such as better growth, feed conversion ratio (FCR) and disease resistance in comparison to channel catfish production (Dunham and Masser 2012; Li and Robinson 2012). Moreover, hybrids represent a profitable enterprise as it can generate four times higher net returns in comparison to channel catfish production (Ligeon et al. 2004). This aligns well with economics of scale concept, where the total fixed cost is spread over the entire production output (Kay et al. 2016). However, a potential disadvantage of hybrid catfish is that they show considerable growth variation (Brooks et al. 1982; Jiang et al. 2008; Dunham et al. 2014), which can affect producers profitability as fish processor's demand certain sizes and if fish are outside of desired sizes, they receive lower prices according to each processor's dockage policy (Wiese et al. 2006). Reduced quantities of premium sized fish are likely to reduce net returns and needs to be analyzed. Catfish farmers have identified oversized and undersized hybrid catfish at harvest as a major problem in the catfish industry and should be a research priority (Southern Regional Aquaculture center (SRAC), personal communication). The evaluation of selling undersized, premium and oversized fish's effect on net profit is needed.

Each processor has adopted a dockage policy to eliminate fish that do not meet their standards and impose a monetary penalty on the total sale receipts. The policies are complicated and varies across processing plant (Wiese et al. 2006). In general, the policy has two components. The first component deals with the out-of-size fish that includes the undersized (<0.45 kg) and oversized (>1.81 kg) fish. (Wiese et al. 2006). Monetary penalties are imposed by reducing the prices for out-of-size fish, and are deducted from the total sale proceeds. A review study found that a producer could lose $0.066/ kg due to supplying out-of-size fish to the fish processors (survey period: 1997-2002) (Wiese et al. 2006). This loss is increasing over time and at present, the dockage loss has reached $0.09/kg and $0.22/kg for undersized and oversized fish, respectively (calculated from 2014-2016, Terry Hanson, personal communication). The second component includes fish rejected after arriving at the processing plant and all diseased, deformed, dead on arrival, ‘’trash species’’, shorts, excessively fed, low dress-out weights and/or other shapes that are unacceptable to the plant. This component does not have any tolerance limit. This docking incident is the second most common, leading to a monetary penalty of $0.11/kg (survey period: 1997-2002) (Wiese et al. 2006). Off flavored fish are not included in the dockage policy as this judgement occurs prior to harvest, and is a different problem (Wiese et al. 2006).

In general, the farmer has no financial option to combat the docking rate due to their lack of market power and control in the catfish supply chain (Neira 2007). Additionally, the availability of less expensive imported basa and tra catfish into the U.S market from Vietnam and/or other Asian countries aggravates these marketing problems. The U.S. imports 80% of its catfish and catfish-like fillet products from Asian countries (Hanson and Sites 2015). Moreover, according the International Trade Administration, governments provides a subsidy to their catfish industry, which assists in exporting the catfish to the U.S. at a lower price than the true cost of production (ITA 2012). Hence, domestic U.S. catfish producers can face a negative net return created by high fish inventories and excessive imports. This high fish inventories are, perhaps aligned with the supply shift, where fish remained unsold due to relatively low market price and demand for them.

While several studies have assessed the economic performance of the hybrid catfish production systems (Ligeon et al. 2004; Rees 2013; Courtwright 2013; Johnson et al. 2014; Bott et al. 2015; Fullerton 2016; Holland 2016; Kumar et al. 2016; Mischke et al. 2017; Engle et al. 2017; Kumar and Engle 2017), none have evaluated the economics of hybrid catfish size categories (undersized, premium and oversized) resulting from alternative production systems (single batch, multiple batch, split pond and IPRS). Here an economic analysis is developed under a common set of assumptions related to prices of inputs and market prices with a uniform set of economic indicators, essential for farmers to understand the relative advantages, disadvantages and trade-offs among the different production systems. An integral part of this project was to develop a complete economic analysis to provide the necessary financial/economic guidance to make recommendations to farmers. In general, the enterprise budget, sensitivity analyses and partial budgets were developed to analyze the objectives of determining the economic impact of the undersized and oversized catfish problem, and the economic impact of employing production systems.

The specific objectives of this study were to estimate and compare the: 1) net returns to operator's labor and management that would be received from different production systems and resulting fish size categories (via enterprise budgeting) 2) net returns to operator's labor and management after changing the price of undersized and oversized catfish from the base premium sized sales price (via sensitivity analyses), and 3) net benefit after adopting either medium, or large size fingerlings (18 and 20 cm) in hybrid catfish production (via partial budget analyses).

Literature Review

Economics of existing catfish production systems

Gross receipts and yield

Gross receipts are dependent on fish farming systems, particularly on the gross yield occurring from different sized catfish. Different farm management systems have been followed in the U.S. catfish industry to increase gross receipts and therefore, reduce the breakeven price. Review studies have shown that a producer could grossly earn at the rate of $12,039/ha (gross yield 7,818 kg/ha) from hybrid catfish farming in single batch system (Ligeon et al. 2004). In a multiple batch system, the gross receipt likely to be higher, in one study, it was found to be $33,893/ha/year (gross yield 14,110 kg/ha) (Bott et al. 2015). But the highest gross receipts have been achieved from the split pond system, which Kumar et al. (2016) found to be $44,058/ha (gross yield 16,816 ± 2,932 kg/ha). IPRS methods carried out at a commercial West Alabama farm, yielded a gross receipt of $27,415/ha (gross yield 11,010 kg/ha) (Fullerton 2016). Dockage rates were not considered in any of these gross receipt calculations. Wiese et al. (2006) reported that dockage rates have a substantial economic impact on gross receipts and net returns in catfish production. The average revenue loss was 7 cents/kg due to the presence of such dockage rates for undersized and oversized fish (Wiese et al. 2006).

Prices-food fish

The catfish price received by the producer from the processor often varies, as it is determined by the market demand and supply. A review study showed that a shortage of catfish during 2014 resulted in a higher price ($2.62/kg for premium size fish) paid by fish processors to the producers (Fig. 3.1) (Hanson and Sites 2015). This value, along with the 2016 price ($2.63/kg) were the highest prices ever paid to producers, which reflected the shortage of fish available during those years (Hanson and Sites 2015; Terry Hanson, personal communication). The prices for undersized and oversized fish also varies, and averaged for $2.05 to $2.54/kg (2014-2016) (Terry Hanson, personal communication). The lowest price ($1.23/kg) for oversized fish was seen in 2017, which was likely due to low market demand and oversupply of oversized fish. In Fig. 3.1, the average price received by the producers from 2008-2017 are provided and until recently, the oversized to undersized fish prices did not vary from the premium sized fish. Here in 2015 and 2017, the oversized fish price diverged greatly from the premium sized fish price. Undersized fish diverged to a lesser degree.

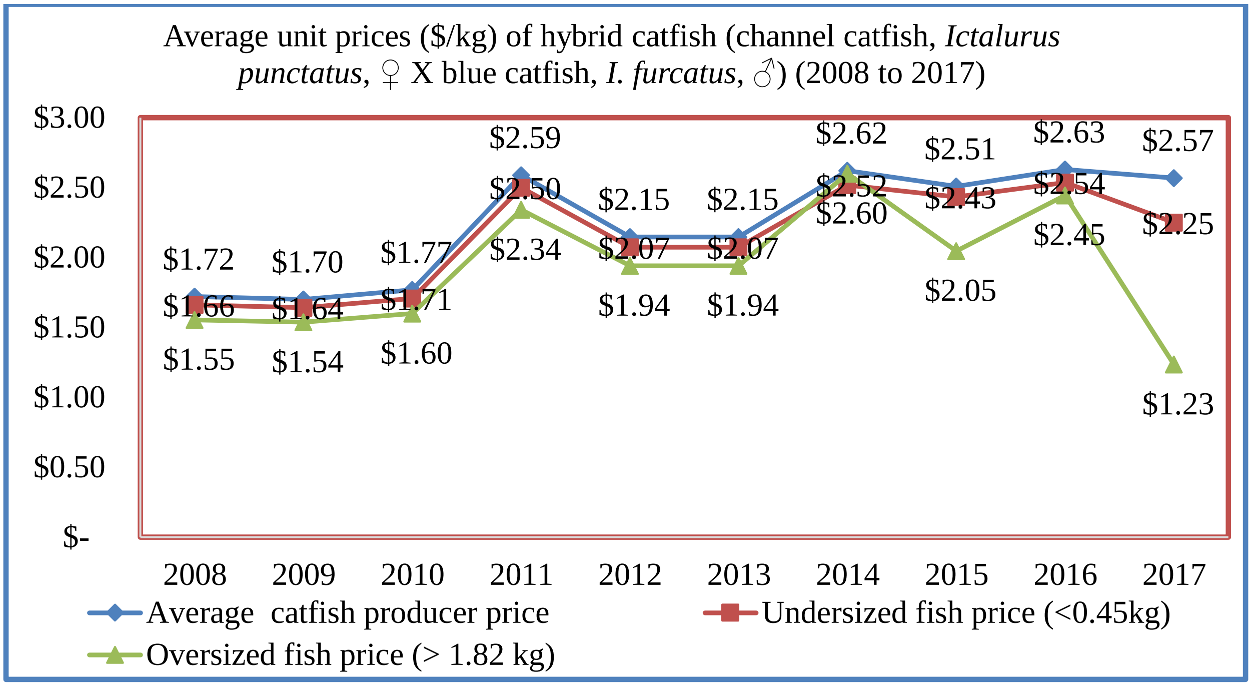


Figure 3.1 Average unit prices ($/kg) of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) based on average, undersized and oversized range (2008-2017*)

*The prices of undersized and oversized fish for the years of 2008-2013 were calculated based on the average price data of 2014-2015 after estimating the average changes (%) of under/oversized fish prices from the base price (changes of undersized and oversized fish prices from the base price in 2014-2015 were -3.46% and -9.61%, respectively) (Terry Hanson, personal communication)

Prices-fingerlings/stockers

Catfish producers consider the fingerling price as an important criterion in deciding whether they will stock fingerling or larger sized stockers at their operations for food fish production. This was indicated by 33.9% of operations, followed by hatchery producer's reputation (28.8% operations), and growth characteristics (15.0% of operations) in a USDA survey (USDA–APHIS 2010). In general, the terms and definitions used in catfish production are based on size and/or length. Fingerlings usually pertains to small fish weighing 0.91-27 kg per 1,000 fish (2-60 pounds per 1,000 fish) or 5-15 cm (2-6 inches) in length (USDA 2017). Stockers, either large or medium, weigh between 82-340 kg per 1,000 fish (180 pounds to 750 pounds per 1,000 fish) and over 27-82 kg per 1,000 fish (over 60 pounds to 180 pounds per 1,000 fish) or over 15 cm in length (over 6 inches), respectively (USDA 2017). Foodsize fish of large, medium and small sizes are considered greater than 1.36 kg (>3 lb.), 0.45-0.68 kg (1-1.5 lb.) and over 0.22 kg (over 0.5 lb.), respectively (USDA 2017).

Hybrid catfish fingerlings are sold by length (cm) in the U.S. rather than weight (Brown et al. 2016). In general, with ictalurid catfish culture, several samples of fish are batch weighed and counted and the results scaled to represent the average weight of 1000 fish, and that value is compared to a standardized length-weight table to predict the average fish length (Brown et al. 2016). For example, 100,000 hybrid catfish fingerlings with an average total length of 16.5 cm (~6.5 inches) would cost about $0.165 each at $0.01 per cm (~$0.025 per inch) or $16,500 for the entire fingerling cohort (Brown et al. 2016). Usually, the price of 19 cm (7.5 inch) size fingerlings was approximately 46% higher compared to smaller sized fingerlings (13 cm) (5 inch) (Kumar and Engle 2010). Currently, the price of hybrid catfish fingerlings (15 to 18 cm or 6-7 inch in size or the total weight of 26.72 kg/1,000 fingerling) is 1.0236 cents/cm (2.6 cents/inch) in Mississippi (Wilson Holland, personal communication). The cost of stockers (18 to 20 cm or 7-8 inch in size or the total weight of 58.32 kg/1000 fingerling) is higher, which is sold at the rate of 1.0826 cents/cm (2.75 cents/inch) (Wilson Holland, personal communication). The cost of larger stockers (> 20 cm or > 8 inch in size or the total weight of 85kg/1000 fingerling) is considerably higher, 1.1220 cents/cm (2.85 cents/inch) (Wilson Holland, personal communication) and this size is more difficult to routinely acquire. Most fingerling producers are selling ungraded fingerlings, as the cost of graded fingerling is higher due to additional time and labor for grading, and additional handling losses (Nagaraj Chatakondi, personal communication).

Prices-feed

In terms of selecting the fish feed with certain protein percentage, fish producers were influenced by feed price (51 percent of respondents) followed by the past performance of feed (17 percent) (USDA–APHIS 2010). Catfish feed prices have significantly increased, especially from 2010 (Fig. 3.2), when 32% protein in feed peaked during August 2012 at 584/metric ton. The highest annual feed price for 32% and 28% protein were \$533 and \$499/metric ton in 2013, respectively (Hanson and Sites 2015).

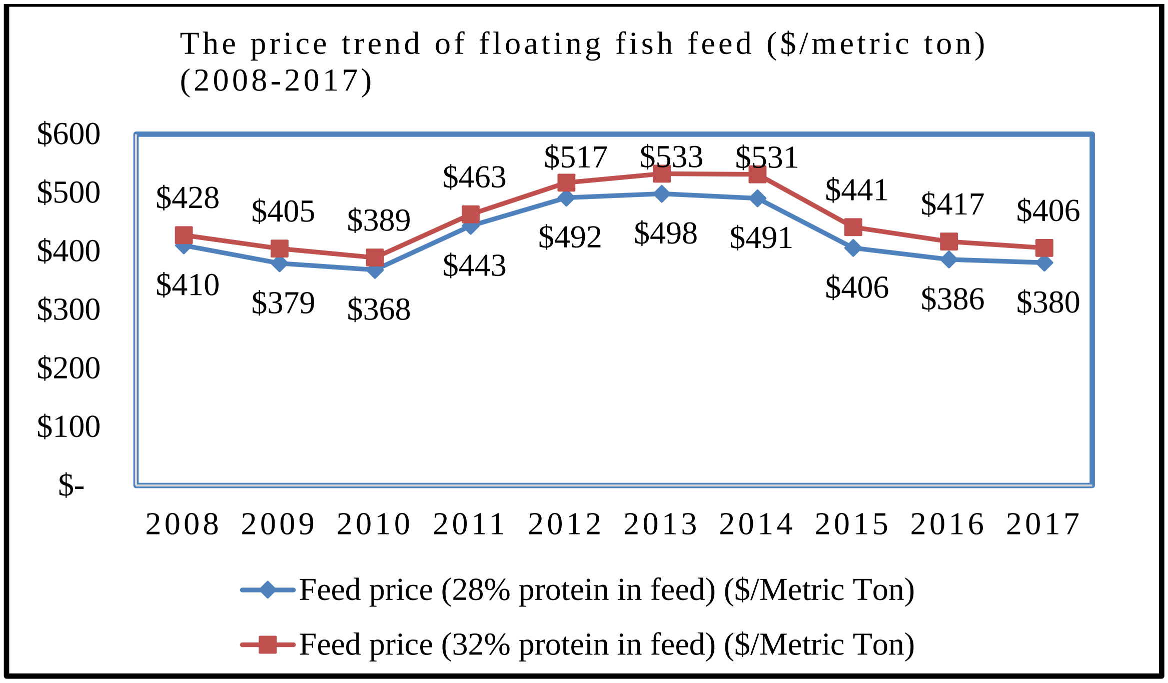


Figure 3.2. The price trend of floating fish feed ($/metric ton) (2008-2017) (Terry Hanson, personal communication)

Variable costs

Variable costs include resources that depend on and vary with the volume of production (Engle 2010). In hybrid catfish production, the annual variable costs ranged from $6,965/ha in single batch system (Ligeon et al. 2004), while it could be $30,396/ha in split pond systems (Kumar et al. 2016). Among these variable costs, feed followed by fingerling and labor costs were the greatest expenses in hybrid catfish farming. Rees (2013) and Ligeon et al. (2004) also indicated that feed cost constituted between 47 and 51% of the total variable cost in hybrid catfish production using a single batch system. Similarly, Bott et al. (2015) found feed cost constituted approximately 58% to the total variable cost (TVC) using a multiple batch system, while in split ponds, it constituted approximately 56% to the TVC in hybrid catfish production (Kumar et al. 2016). However, in in-pond raceway systems, feed costs comprised only 36% of the TVC in hybrid catfish production (Davis et al. 2017). Other variable costs, such as fingerling and labor cost accounted for 8% (Rees 2013) to 18% (Kumar et al. 2016) in traditional (single batch) and intensive system (split pond), respectively. Labor cost is higher for intensive systems, because extra labor is needed for greater feeding purposes. Usually, it accounted for 4% in traditional systems (single batch) (Rees 2013) and 9% in intensive split pond systems (Kumar et al. 2016).

Fixed costs

The investment cost in catfish production system has increased over time. For example, a small size 102-ha farm required $2.8 million to purchase equipment, land, facilities, buildings, ponds and machineries as part of the capital investment cost (Engle 2010). The major additional cost for more intensive systems involve purchasing aerators and generators, which may increase the fixed cost and therefore, make catfish farming a capital-intensive business (Engle 2010). These investment costs were, however, 42-44% higher for the partitioned aquaculture system (PAS) compared to the traditional farm pond system (Goode et al. 2002). The annual fixed cost for the PAS was five times higher than that of the traditional catfish farming system (Masser and Lazur 1997). Kumar et al. (2016) also calculated that approximately $8,375 to $17,938/ha was needed to convert traditional catfish ponds into split pond systems.

Net returns

Ligeon (2000) calculated the catfish net returns using linear programming model on three different farm sizes to evaluate the profitability of switching from channel catfish to hybrid catfish. The net income of the farmers increased when they switched from channel catfish to hybrid catfish. Under the constraints of a 61-ha farm size, net returns, however, decreased, but the total net cash income was greater than that of a similar-sized channel catfish farm. More capital was required in multiple-batch systems, but sensitivity analyses showed that the cash income was higher. Lastly, introducing 20 or 60% hybrid catfish to the farm reduced the income variations to farmers (Ligeon 2000).

Ligeon et al. (2004) reported that the net returns to land, labor and management in the single batch production system was four times higher for hybrid catfish ($15,020/ha) compared to channel catfish production ($ 3,710/ha). Rees et al. (2014) also suggested that hybrid catfish farming could generate a net return of $2,993/ha (after stocking 13 cm size fingerlings) or $2,114/ha (after stocking 19 cm size fingerlings) in single batch system (research setting). Significant net returns could also be achieved in multiple batch production systems, which could average $12,797/ha/year (Bott et al. 2015). Net returns could, however, be higher in split pond production systems based on the higher gross fish yields from greater input usage (Kumar et al.

2016). For in-pond raceway systems (IPRS), a net return of $7,450/ha in hybrid catfish production (Davis et al. 2017) was achieved for an experimental setting. This was evident when hybrid catfish was cultured in a research setting. However, negative net returns to operator's labor and management would occur for this IPRS if best management practices were not followed in hybrid catfish production (Holland 2016). Review studies showed that hybrid catfish farming would result in a negative net return of -$3,621/ha (Fullerton 2016) or -$281/ha (Holland 2016) for the IPRS system if the farmer does not follow the appropriate farming protocol (commercial settings) or best management practices (BMP).

Breakeven price and yield above total cost

The breakeven price (BEP) is the selling price for which total income will just equal to total costs for a given level of production (Engle 2010). Alternatively, the breakeven yield (BEY) is the yield level at which total income will just equal to total expenses at a given selling price (Engle 2010). Both of these variables are important parameters that are calculated from the enterprise budget analysis. Johnson et al. (2014) reported that BEP and BEY above total cost were in the range of $1.96 to $2.84/kg and 10,285 to 18,944 kg/ha for hybrid catfish using single and multiple batch production system, respectively. Rees et al. (2014) also found a comparatively higher BEP and BEY above total cost in the range of $1.57 to $1.72/kg and 11,301 to 17,023 kg/ha for hybrid catfish employing the single batch system, respectively. Similarly, Engle et al. (2017) found BEP was $1.84/kg for single size (13 cm) and $1.48/kg for mixed size fingerlings in hybrid catfish for the single batch system. Courtwright (2013) found a slightly higher BEP (above total cost) of $2.44/kg in hybrid catfish for the multiple batch system. Almost similar BEP were found for cage culture, split pond system and IPRS of hybrid catfish production ranging from $1.72 to

$1.96/ kg (Masser and Lazur 1997), $1.72 to $2.05/kg (Kumar et al. 2016) and $2.08/kg for IPRS (Davis et al. 2017), respectively.

Sensitivity analysis

Ligeon et al. (2004) found fish price had the largest effect on net profits followed by feed conversion and feed price. Fingerling price, however, had the smallest effect on the net profits in hybrid catfish production. This was similar to the split pond production system, for which the production cost of hybrid catfish was sensitive to yield, fish price, and feed price (Kumar et al. 2016). Posadas (2000) also reported that the average production cost was sensitive to several factors, such as mortality rate, off flavor, feed cost and feed efficiency, which were the most important variables in the single batch production system. Kumar and Engle (2010) assumed that fluctuation in feed prices could negatively affect the net return in hybrid catfish production. They suggested that variation in fingerling prices could, however, reverse the net return if the price of all sized fingerlings were available at or below $0.006/cm of fingerling ($0.015/inch of fingerling) (Kumar and Engle 2010).

Partial budget

Partial budget analysis previously showed that the fingerling cost of hybrid catfish ($0.0076/cm or 0.019/inch of fingerling) would result in an additional cost of $653/ha as compared to NWAC-103 channel catfish fingerlings ($0.0050/cm) (i.e., NWAC-103 is a strain of channel catfish, formerly known as USDA 103, which was released on February 06, 2001 by USDA) (Kumar and Engle 2010). Though the hybrid catfish farmer could save $172/ha from the feed cost ($0.30/kg) resulting from the improved feed conversion ratio (FCR), the net benefit due to the higher fingerling cost might not change (Kumar and Engle 2010). Comparing the production parameters of hybrid catfish (channel x blue) with NWAC-103, channel catfish strains produced conflicting results, depending on the size of fingerling stocked and maternal genetic inheritance.

Methods

Economic analysis was performed by developing a standard enterprise budget (Kay et al. 2016; Engle 2012) to estimate the cost and return of hybrid catfish production in 4 systems: 1) single batch (N=25); 2) multiple batch systems (N=16); 3) split pond (N=98) and 4) in-pond raceways (research) (N=4), where N is the number of farms sampled. Specific production data were collected with a producer questionnaire survey (Table 2.5, Chapter 2). A uniform set of prices and costs were used to ensure consistency in comparisons among culture systems. These data were mainly derived from secondary (producer) sources and expert opinion. The average prices of different sizes of hybrid catfish such as premium size (0.45-1.81 kg), undersized (<0.45 kg) and oversized (> 1.81 kg) fish along with the feed prices (28% and 32% protein percentage) were calculated from the average annual price data of 2011-2017 (Table 3.1) (Hanson and Sites 2015; Terry Hanson, personal communication). The average fingerling price was calculated based on two years of annual prices, 2010 and 2017 (Table 3.1) (Kumar and Engle 2010; Nagaraj Chatakondi, personal communication). Labor cost (full time/seasonal) was calculated from the employees' annual salary that was provided by catfish farm owners in Arkansas, Mississippi and Alabama (Table 3.1) (Ganesh Kumar, personal communication; Terry Hanson, personal communication). An additional labor cost was added for the split pond system because extra labor is required for feeding (Table 3.1) (Ganesh Kumar, personal communication). The methods of calculation and the assumptions used in enterprise budget analysis are listed in Table 3.2.

Table 3.1. Unit prices used in enterprise budgets for hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ X blue batfish, *I. furcatus*, ♂) production in traditional (single and multiple), split pond and in-pond raceway systems and their sources

Item	Description	Unit	Price/Cost	Notes and Sources
Gross receipts				
Premium size	0.45-1.81 kg	$/kg	2.24	Avg. price (2011-2017)
Undersized fish	<0.45 kg	$/kg	2.14	Terry Hanson*
Oversized fish	> 1.81 kg	$/kg	1.92	
Operating costs				
Feed	28% protein	$/MT	425	Avg. price (2011-2017)
	32% protein	$/MT	453	Terry Hanson*
Fingerlings	size: 18 cm (7 inch)	$/cm	0.0101	Avg. price (2010 and 2017) Kumar and Engle (2010); Chatakondi Nagaraj*
	size 20 cm (8 inch)	$/cm	0.0112	
Labor	Hourly rate	$/hr.	12	Terry Hanson*
	Annual salary/ labor	$/year	25,000	Ganesh Kumar*
	Seasonal labor	$/half yearly	12,500	Ganesh Kumar*
	Extra feeding	hr./ha	83	Kumar et al. (2016)
	Raceway (research)	$/ha	6,818	Davis et al. (2017)
Catfish farm size	Average: MS/AL/AR	ha	32	Ganesh Kumar*

* Personal communication; AL=Alabama; AR= Arkansas; MS= Mississippi, MT=metric ton; Avg.= Average

Table 3.2 Method of calculating total cost/values in enterprise budget analysis for hybrid catfish production (channel catfish, *Ictalurus punctatus*, ♀ X blue batfish, *I. furcatus*, ♂)

Item	Method of calculation
Gross receipts	
• Premium sized fish	Total production*premium size fish (%)* 7-year annual average sales price
• Undersized fish	Total production*undersized fish (%)* 7-year annual average sales price
• Oversized fish	Total production*oversized fish (%)* 7-year annual average sales price
• Inventory of sub-marketable fish	Total number of sub-marketable fish* breakeven price above total cost (food fish)
Operating costs	
• Feed	Total feed fed (28 or 32%)* 7-year average feed price (annual)
• Fingerlings	Total stocking density* average size of fingerlings* individual fingerling price ($/cm)
• Owner supplied labor	(Annual salary/average catfish farm size in AR/MS/AL)* average pond size
• Seasonal labor	(Salary for six months*average catfish farm size in AR/MS/AL)*average size of sampled pond
• Extra Feeding labor	[a]Empirical average price($/ha)* average size of sampled pond
• Plankton control	Empirical average price ($/ha)* average size of sampled pond
• Gas and diesel	Empirical average price ($/ha)* average size of sampled pond
• Electricity	Empirical average price ($/ha)* average size of sampled pond
• Repairs and maintenance	Empirical average price ($/ha)* average size of sampled pond
• Bird depredation supplies	Empirical average price ($/ha)* average size of sampled pond
• Seining and hauling	Total harvested fish (kg)*empirical average price harvested fish ($/kg)
• Telephone	Empirical average price ($/ha)* average size of sampled pond
• Office supplies	Empirical average price ($/ha)* average size of sampled pond
• Interest on operating capital	Total variable cost* interest rate
• Total variable costs	Sum of all variable costs above
• Income above operating costs	Gross receipts – total variable costs
Fixed costs	
• Farm insurance	Empirical average price ($/ha)* average size of sampled pond
• Legal/accounting	Empirical average price ($/ha)* average size of sampled pond
• Interest on investment	
• Land	Empirical average price ($/ha)* interest rate* average size of sampled pond
• Wells	Empirical average price ($/ha) for single well* interest rate

• Pond construction	Empirical average price ($/ha)* interest rate
• Equipment	Empirical average price ($/ha)* interest rate
• Annual depreciation	
• Equipment	Empirical average price ($/ha)* average size of sampled pond
• Total fixed costs	Sum of all the fixed costs above (sub-categorized)
• Total costs	Total variable costs+ total fixed costs
• Net returns to operator's labor, and management	Gross receipts – total costs
• Breakeven price above variable costs	Total variable costs/total kg of fish produced (includes premium/under/oversized fish) (excludes sub-marketable fish)
• Breakeven price above total cost	Total costs/total kg of fish produced (includes premium/under/oversized fish) (excludes sub-marketable fish)
• Breakeven yield above variable costs	Total variable costs/weighted average selling price ($/kg) (includes premium/under/oversized fish) (excludes sub-marketable fish)
• Breakeven yield above total cost	Total costs/ weighted average selling price ($/kg) (includes premium/under/oversized fish) (excludes sub-marketable fish)

*=multiplication; AL=Alabama; AR= Arkansas; MS= Mississippi; [a]Empirical average price means it was the numbers derived either from investigation, observation, experimentation, or experience.

Baseline assumptions for enterprise and partial budgets analyses

- The price of sub-marketable fish ($/kg) was assumed to be the BEP above TC (i.e., the total costs divided by the fish produced (premium, oversized and undersized fish). This BEP above TC is used, as money had already been spent in producing the total population even though the size of fish was in the sub-marketable stage (100-300 gm in weight). This outcome is common in multiple batch production systems.
- While feed price varies over time because of availability of raw materials, demand and supply conditions of the market, such variation is not included in the current analysis and an average annual feed prices is used. Moreover, this price did not include any advanced feed booking or timing of feed deliveries adjustments.
- The area (ha) represents the size of the grow-out pond used for hybrid catfish production only. It did not include other pond areas such as hatchery, fish-out operations, or production of other species.
- The unit prices of plankton control, gas and diesel, electricity, repairs and maintenance, bird depredation supplies, telephone, office supplies, interest on operating capital and investment cost varied among the production systems (Table 3.3). These assumed prices were the empirical average price ($/ha) taken from secondary enterprise budget sources.

Table 3.3 Empirical unit prices used in enterprise budgets analysis for hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ X blue batfish, *I. furcatus*, ♂) production in traditional and intensive systems and their sources.

Item	**Description**	**Unit**	**Price/Cost**		
			Traditional (single/multiple)	Split pond*	IPRS* (research)
Plankton control	Empirical average	$/ha	322[a]	38[e]	665[f]
Gas and diesel	Empirical average	$/ha	365[a]	228[e]	333[g]
Electricity	Empirical average	$/ha	486[a]	1,445[e]	1,524[f]
Repairs and maintenance	Empirical average	$/ha	308[b]	268[e]	1,498[g]
Bird depredation supplies	Empirical average	$/ha	15[c]	15[e]	16[g]
Seining and hauling	Food fish	kg	0.13[d]	0.11[e]	0.11[h]
Telephone	Empirical average	$/ha	42[c]	26[e]	26[g]
Office supplies	Empirical average	$/ha	27[c]	28[e]	28[g]
Interest on operating capital		%	10[c]	10[e]	10[g]
Fixed costs					
Pond insurance	Empirical average	ha	108[c]	63[e]	63[g]
Legal/accounting	Empirical average	ha	46[c]	15[e]	15[g]
Interest on Investment					
Land	Empirical average	$/ha	2,030[c]	2,055[e]	2,900[g]
Wells	Empirical average	$/ha	2,015[c]	1,880[e]	2,015[c]
Pond construction	Empirical average	$/ha	2,141[b]	3,495[e]	920[i]
Equipment	Empirical average	$/ha	8,923[b]	12,125[e]	15,583[f]
Annual depreciation					
Equipment	Empirical average	$/ha	665[b]	1255[e]	1,572[f]

[a]Courtwright (2013); Hanson et al. 2005); Hanson (2005); [b]Hanson (2015); Hanson et al. 2005); Hanson (2005); [c]Engle (2012a); [d]Hanson (2015); Bott (2015); [e]Kumar et al. (2016); [f]Kubitza et al. (2017); [g]Kumar et al. (2017); [h]Fullerton (2016); [i]Hanson (2005)

*IPRS (in-pond raceway system). IPRS is comprised of two units; a) fish culture unit b) oxygen production/waste treatment unit. Economic analysis was based on data collected from research raceways only. * A split pond includes two basins; a) fish culture basin b) oxygen production/waste treatment lagoon

- The fuel price used does not account for price fluctuations and/or timing of purchases.
- Electricity price was also assumed to be the empirical average price ($/ha) and it did not account for the 'peak' and 'off-peak' rate plans regardless of State or electrical agency. This assumption was made to create consistent, comparable budget for all production systems. These 'peak' and 'off-peak' plans were, however, available in certain rural areas of the surveyed states, but not all.
- All production systems used custom seining and hauling crews during the harvesting period. Larger farms might, however, use on-farm labor, but was not considered in the current analysis.
- The surveyed pond was either owned by farmers and/or leased (i.e., signed a contract to rent a land for certain period)/sub-leased (i.e., a lease by a tenant or lessee of part or all of leased premises to another person but with the original tenant retaining some right or interest under the original lease).
- Gross receipts, total costs, net returns, breakeven price and yield were calculated in four ways. 1) Total: which included all inputs and outputs for a specific crop duration; 2) Total per ha: taking 1) total and dividing by area to get a common area value; 3) Annualized total: taking 1) total and dividing by the number of crop duration days and multiplying by 365 to get an annualized total; 4) Annualized per ha: taking 3) annualized total and dividing by area to get a common area value
- The annualized scenarios were calculated as the culture period varied among production systems. The calculated annualized scenario represented the geometric average that could be reached/earned over a given period of time, more specifically, within one year (365 days). The average culture period for producing premium size hybrid catfish in single

batch (N=25), multiple batch (N=16), split pond (N=98) and in-pond raceway systems (N=4) were 372, 383, 221, and 268 days, respectively.

- An interest rate of 10% per annum was used for calculating interest on operating and investment capital in the current analysis.
- The annual depreciation cost for equipment was calculated based on the straight line method with a salvage value of zero for traditional (single and multiple batch) (Hanson (2015); Hanson et al. 2005; Hanson 2005) and split pond systems (Kumar et al. 2016), but for IPRS, a salvage value of 13% was considered (Kubitza et al. 2017). The calculation was on an annual basis.
- Missing data were observed during the data compilation stage and were replaced by imputing them from the average data that were available at other surveyed ponds or secondary sources.

Sensitivity analysis

Sensitivity analyses were developed for both traditional systems, split pond and IPRS (research) systems to assess the economic effects of reducing the prices of undersized and oversized fish by 25%, 50%, and 75% from their base sales price. These analyses were conducted on the annualized per ha gross receipt, income above variable cost, and net returns to operator's labor and management.

Partial budget analysis

A partial budget analysis was conducted to compare the net benefit of increasing hybrid catfish production after changing the fingerling size from medium (18 cm) to large (20 cm) for all four production systems. Partial budgeting is a useful tool to compare the benefits and costs that would result from a relatively small change on a farm (Kay et al. 2016). As part of this, seven other enterprise budgets were developed (Appendices 3.1-3.7), which were based on the baseline assumptions. Original production data were used for enterprise budget development and was collected from the producer harvest surveys. Collected data were split into two units. One unit included the farmers that used 18 cm fingerlings, while the rest were included in another unit that used 20 cm size fingerling in their hybrid catfish farming. In terms of IPRS (research) system, an added assumption was made since the sample size was quite low (N=4). The assumption was that the production parameters did not significantly vary in the IPRS (research) system after changing the fingerling size from 18 to 20 cm. This assumption was derived from the split pond system, another example of an intensive system, where only minor changes were found in the production parameters after changing the fingerling size from 18 to 20 cm. After finishing the enterprise budget analysis, the partial budget was formatted by quantifying the benefits that could be obtained either from additional revenue or reduced cost after making the proposed changes from using 18 cm fingerlings to using 20 cm fingerlings. Costs were quantified in an opposite manner by adding the additional costs or reduced revenue in the analysis. The bottom line of partial budget analysis is to calculate the net benefit, which can be obtained by subtracting the total additional cost from the total additional benefit. If the value of the net benefit is positive, then the change is profitable; if negative, the change is not recommended for the farm (Engle 2010).

Results

Gross receipts (annualized per ha)

Results from the “Annualized ($/ha)” column of the enterprise budget are presented in this section as they represent the receipts, costs, and returns for all production systems on a common area and common time frame (one year, 365 days). Comparing enterprise budgets among the traditional single batch, multiple batch, split pond and in-pond raceway system (IPRS, research) (Tables 3.4- 3.7) systems showed that split pond production systems had the highest annualized gross receipts ($76,704/ha/yr) compared to other farming systems. This resulted from its higher total yield (68,900 kg/ha/yr) (Fig. 3.3). Even though the percent of undersized fish in split pond systems (13%) was the highest compared to the other systems (Table 3.8), but it’s revenue had a minor impact on the total gross receipt resulting from the large yield contribution of its premium sized fish (Fig. 3.4). IPRS (research) had the second highest gross receipts followed by the multiple and single batch systems. Besides these, the multiple batch production system had the most potential contribution from the inventory of sub-marketable fish ($6,743/ha/yr) (Table 3.5; Fig. 3.4) resulting from the repeated stocking and harvesting procedures. In terms of the specific gross receipts from premium/under/oversized fish categories, split pond system had the greatest quantity of premium sized fish and therefore, the highest receipts (Fig. 3.4). Multiple batch production systems had the second highest annualized gross receipts ($/ha/yr) from the oversized fish category, which was followed by single batch and IPRS (research) systems (Fig. 3.4). In similar manner, IPRS (research) had the second highest monetary contribution from undersized fish, followed by single and multiple batch production systems (Fig. 3.4). Economic analysis also showed that the dockage rates played an influencing role on gross receipts for each production system. In general, the total revenue loss, regardless of the production system, was $1,712/ ha due to dockage rate for undersized and oversized fish (Table 3.9).

Table 3.4 Enterprise budget for the hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) production in SINGLE BATCH system (area 3.47 ha; stocking density 24,433/ha; fingerling size 18 cm, feed 32 [a]MT /ha, yield 13,821 kg/ha, culture period 372 days)

Item	**Description**	**Unit**	**Quantity**	**Price/Cost ($)**	**Total ($)**	**Total ($/ha)**	**Annualized total ($/yr)**	**Annualized ($/ha/yr)**
1. Gross receipts	Premium size	kg	43,867	2.46	107,867	31,051	105,933	30,494
	Undersized fish	kg	2,206	2.34	5,164	1,486	5,071	1,460
	Oversized fish	kg	1,939	2.08	4,030	1,160	3,958	1,139
Total Gross receipts		kg	48,012	2.44	117,061	33,698	114,962	33,094
2. Operating costs								
Feed	28% protein floating	MT	110	442	48,507	13,963	47,637	13,713
Fingerlings	Size: 18 cm	Each	84,878	0.18	15,467	4,452	15,190	4,373
Labor	Owner supplied	$/ha	3.47	772	2,682	772	2,634	758
	Seasonal labor	$/ha	3.47	386	1,341	386	1,317	379
Plankton control	Empirical average	ha	3.47	322	1,119	322	1,099	316
Gas and diesel	Empirical average	ha	3.47	365	1,270	365	1,247	359
Electricity	Empirical average	ha	3.47	486	1,690	486	1,659	478
Repairs and maintenance	Empirical average	ha	3.47	308	1,071	308	1,051	303
Bird depredation supplies	Empirical average	ha	3.47	15	54	15	53	15
Seining & hauling	Empirical average	kg	48,012	0.13	6,242	1,797	6,130	1,765
Telephone	Empirical average	ha	3.47	42	146	42	143	41
Office supplies	Empirical average	ha	3.47	27	94	27	93	27
Interest on operating capital		$	66,401	0.10	6,640	1,911	6,521	1,877
Total variable costs	Per pond				86,322	24,849	84,774	24,403
3. Income above variable costs					30,739	8,849	30,188	8,690
4. Fixed costs								
Farm insurance	Empirical average	ha	3.47	108	374	108	368	106
Legal/accounting	Empirical average	ha	3.47	46	161	46	158	46
Interest on Investment								-
Land	Empirical average	$	7,052	0.10	705	203	693	199
Wells	Empirical average	$	2,015	0.10	202	58	198	57
Pond construction	Empirical average	$	2,141	0.10	214	62	210	61
Equipment	Empirical average	$	8,923	0.10	892	257	876	252
Annual depreciation								
Equipment	Empirical average	ha	3.47	665	2,309	665	2,268	653
Total Fixed costs	Per pond				4,858	1,398	4,771	1,373
5. Total costs	Per pond				91,180	26,247	89,545	25,777

6. Net returns to operator's labor, and management	Per pond		25,881		25,417	
	Per Ha		7,450	7,450	7,317	7,317
Breakeven Price	Above variable costs	$/kg	1.80		1.80	
	Above total costs	$/kg	1.90		1.90	
Breakeven Yield	Above variable costs	kg	35,405	10,192	34,770	10,009
	Above total costs	kg	37,397	10,765	36,727	10,572

[a]MT= metric ton

Table 3.5 Enterprise budget for the hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) production in MULTIPLE BATCH systems (area 3.42 ha; stocking density 24,302 /ha; fingerling size 18 cm, feed 39 [a]MT/ha, yield 15,766 kg/ha, inventory of sub-marketable fish 3,795 kg/ha, culture period 383 days)

Item	**Description**	**Unit**	**Quantity**	**Price/ Cost**	**Total ($)**	**Total ($/ha)**	**Annualized total ($/yr)**	**Annualized ($/ha/yr)**
1. Gross receipts	Premium size	kg	34,407	2.46	84,604	24,722	80,523	23,530
	Undersized fish	kg	1,778	2.34	4,162	1,216	3,961	1,158
	Oversized fish	kg	4,782	2.08	9,940	2,905	9,461	2,765
	Inventory of Sub-marketable fish	kg	12,987	1.87	24,245	7,085	23,076	6,743
Total Gross receipts		kg	53,954	2.28	122,951	35,928	117,021	34,195
2. Operating costs								
Feed	28% protein floating	MT	135	442	59,516	17,391	56,645	16,552
Fingerlings	Size: 18 cm	Each	83,164	0	14,828	4,333	14,113	4,124
Labor	Owner supplied	$/ha	3.42	772	2,643	772	2,515	735
	Seasonal labor	$/ha	3.42	386	1,321	386	1,258	367
Chemicals	Empirical average	ha	3.42	322	1,102	322	1,049	307
Gas and diesel	Empirical average	ha	3.42	365	1,251	365	1,190	348
Electricity	Empirical average	ha	3.42	486	1,664	486	1,584	463
Repairs and maintenance	Empirical average	ha	3.42	308	1,055	308	1,004	293
Bird depredation supplies	Empirical average	ha	3.42	15	53	15	50	15
Seining and hauling	Empirical average	kg	40,967	0	5,326	1,556	5,069	1,481
Telephone	Empirical average	ha	3.42	42	144	42	137	40
Office supplies	Empirical average	ha	3.42	27	93	27	89	26
Interest on operating capital		$	74,162	0.10	7,416	2,167	7,059	2,063
Total variable costs	Per pond				96,411	28,173	91,761	26,814
3. Income above variable costs	Per pond				26,540	7,755	25,260	7,381
4. Fixed costs								
Farm insurance	Empirical average	ha	3.42	108	369	108	351	103
Legal/accounting	Empirical average	ha	3.42	46	159	46	151	44
Interest on Investment								
Land	Empirical average	$	2,030	0.10	203	59	193	56
Wells	Empirical average	$	2,015	0.10	202	59	192	56
Pond construction	Empirical average	$	2,141	0.10	214	63	204	60
Equipment	Empirical average	$	8,923	0.10	892	261	849	248
Annual depreciation								

Equipment	Empirical average	Ha	3.42	665	2,275	665	2,165	633
Total Fixed costs	Per pond				4,313	1,260	4,105	1,200
5. Total costs	Per pond				100,725	29,433	95,866	28,014
6. Net returns to operator's labor, and management	Per pond				22,227	6,495	21,155	6,182
	Per ha				6,495		6,182	
Breakeven Price	Above variable costs	$/kg			1.79		1.79	
	Above total costs	$/kg			1.87		1.87	
Breakeven Yield	Above variable costs	kg			42,308	12,363	40,267	11,767
	Above total costs	kg			44,201	12,916	42,069	12,293

[a]MT= metric ton

Table 3.6 Enterprise budget for the hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) production in SPLIT POND system (pond area 3.60 ha; stocking density 32,433/ha; 20 cm fingerling size, total feed fed 42 [a]MT/ha, yield 19,122 kg/ha kg, culture period 221 days)

Item	**Description**	**Unit**	**Quantity**	**Price /Cost**	**Total ($)**	**Total ($/ha)**	**Annualized total ($/yr)**	**Annualized ($/ha/yr)**
1. Gross receipts	Premium size	kg	56,753	2.46	139,553	38,729	230,654	64,012
	Undersized fish	kg	9,240	2.34	21,627	6,002	35,745	9,920
	Oversized fish	kg	2,907	2.08	6,042	1,677	9,986	2,771
Total Gross receipts		kg	68,900	2.43	167,222	46,408	276,385	76,704
2. Operating costs								
Feed	28% protein floating	MT	152	442	67,405	18,707	111,407	30,918
Fingerlings	Size: 20 cm	Each	116,864	0.23	26,603	7,383	43,969	12,203
Labor	Owner supplied	$/ha	3.60	772	2,782	772	4,599	1,276
	Extra Feeding labor	hr./ha	3.60	83	3,589	996	5,932	1,646
Chemicals	Empirical average	ha	4	38	137	38	226	63
Gas and diesel	Empirical average	ha	4	228	822	228	1,358	377
Electricity	Empirical average	ha	4	1445	5,207	1,445	8,606	2,388
Repairs and maintenance	Empirical average	ha	4	268	966	268	1,596	443
Bird depredation supplies	Empirical average	ha	4	15	56	15	92	26
Seining & hauling	Empirical average	kg	68,900	0.11	7,579	2,103	12,527	3,476
Telephone	Empirical average	ha	4	26	94	26	155	43
Office supplies	Empirical average	ha	4	28	101	28	167	46
Interest on operating capital		$	96,116	0.10	9,612	2,667	15,886	4,409
Total variable costs					124,951	34,677	206,519	57,314
3. Income above variable costs					42,271	11,731	69,866	19,390
4. Fixed costs								
Farm insurance	Empirical average	ha	3.60	63	228	63	377	105
Legal/accounting	Empirical average	ha	3.60	15	55	15	91	25
Interest on Investment								
Land	Empirical average	$	7,405	0.10	740	206	1,224	340
Wells	Empirical average	$	1,880	0.10	188	52	311	86
Pond construction	Empirical average	$	12,593	0.10	1,259	350	2,081	578
Equipment	Empirical average	$	43,690	0.10	4,369	1,213	7,221	2,004
Annual depreciation								
Equipment	Empirical average	ha	3.60	1,255	4,522	1,255	7,474	2,074

Total Fixed costs			11,362	3,153	18,779	5,212
5. Total costs			136,312	37,830	225,298	62,526
6. Net returns to operator's labor, and management		Per pond	30,910	8,578	51,088	14,178
		Per ha	8,578		14,178	
Breakeven Price	Above variable costs	$/kg	1.81		1.81	
	Above total costs	$/kg	1.98		1.98	
Breakeven Yield	Above variable costs	kg	51,483	14,288	85,092	23,615
	Above total costs	kg	56,165		92,829	25,762

[a]MT= metric ton

Table 3.7 Enterprise budget for hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) production in IN-POND RACEWAY SYSTEM (research) (pond area 0.40 ha; stocking density 9,505/ha; 18 cm fingerling size, total feed fed 9 [a]MT/268 day/cycle, yield 5,985 kg, culture period 268 days)

Item	Description	Unit	Quantity	Price/ Cost	Total ($)	Total ($/ha)	Annualized total ($/yr)	Annualized ($/ha/yr)
1. Gross receipts	Premium size	kg	5,357	2.46	13,173	32,551	17,941	44,333
	Undersized fish	kg	570	2.34	1,335	3,299	1,818	4,493
	Oversized fish	kg	57	2.08	119	294	162	400
Total Gross receipts		kg	5,985	2.44	14,627	36,144	19,921	49,226
2. Operating costs								
Feed	32% protein floating	MT	9	473	4,189	10,350	5,705	14,096
Fingerlings	Size: 18 cm	Each	9,505	0.18	1,674	4,137	2,280	5,634
Labor	Owner supplied labor	$/ha	0.40	6,818	2,759	6,818	3,758	9,286
	Seasonal labor	$/ha	0.40	0	0	0	0	0
Chemicals	Empirical average	ha	0.40	665	269	665	367	906
Gas and diesel	Empirical average	ha	0.40	333	135	333	184	454
Electricity	Empirical average	ha	0.40	1524	617	1,524	840	2,075
Repairs and maintenance	Empirical average	ha	0.40	1498	606	1,498	826	2,040
Bird depredation supplies	Empirical average	ha	0.40	16	6	16	9	22
Seining and hauling	Empirical average	kg	5985	0.11	658	1,627	897	2,216
Telephone	Empirical average	ha	0.4	26	11	26	14	35
Office supplies	Empirical average	ha	0.40	28	11	28	15	38
Interest on operating capital	Empirical average	$	9113	0.1	911	2,252	1,241	3,067
Total variable costs					11,847	29,273	16,134	39,868
3. Income above variable costs					2,781	6,871	3,787	9,358
4. Fixed costs								
Farm insurance	Empirical average	ha	0.40	63.3	26	63	35	86
Legal/accounting	Empirical average	ha	0.40	15.0	6	15	8	20
Interest on Investment								
Land	Empirical average	$	1,174	0.10	117	290	160	395
Wells	Empirical average	$	2,015	0.10	202	498	274	678
Pond construction	Empirical average	$	372	0.10	37	92	51	125
Equipment	Empirical average	$	15,583	0.10	1,558	3,850	2,122	5,244
Annual depreciation								
Equipment	Empirical average	$	0.40	1,571.85	636	1,572	866	2,141

Total Fixed costs			2,582	6,380	3,517	8,690
5. Total costs			14,429	35,653	19,651	48,557
6. Net returns to operator's labor, management, and risk		Per raceway	199	491	271	669
Breakeven Price	Above variable costs	$/kg	1.98		1.98	
	Above total costs	$/kg	2.41		2.41	
Breakeven Yield	Above variable costs	kg	4,847	11,977	6,602	16,312
	Above total costs	kg	5,904	14,588	8,040	19,868

[a] MT= metric ton

Table 3.8 Effect of fingerling size (cm) on the production variables and outputs of growing hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in single batch, multiple batch, split pond and in-pond raceway systems

Production system	**N**	**Fingerling size (cm)**	**Stocking density**	**Feed**	**Undersized fish**		**Premium size fish**		**Oversized fish**		**Total**	
Unit		cm	#/ha	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha
Single batch	16	≤ 18	21,530	21,530	4	592	91	12,001	5	663	100	13,256
	8	≥ 20	28,689	29,907	5	726	92	13,204	3	374	100	14,304
	1	≥ 23	36,841	56,018	3	528	97	18,464	-	-	100	18,992
Multiple batch	14	≤ 18	25,049	40,320	4	696	83	13,517	12	2,022	100	16,236
	2	≥ 20	19,073	32,350	5	587	89	11,120	6	774	100	12,480
Split pond system [a]	38	≤ 18	33,552	45,259	14	2,642	82	15,615	4	824	100	19,081
	42	≥ 20	31,724	40,422	13	2,515	83	15,836	4	796	100	19,147
	18	≥ 23	33,661	37,699	14	2,795	82	16,084	4	688	100	19,566
Raceway (research) [b]	4	≤ 18	23,489	21,905	10	1,410	90	13,238	1	141	100	14,789
	4	≥ 20	23,489	21,905	10	1,410	90	13,238	1	141	100	14,789

[a] Split pond includes two basins; a) fish culture basin b) oxygen production/waste treatment lagoon. Pond size of 3.60 ha is the summation of two basins (a + b), but production data are obtained from the a) basin only

[b] Raceway also includes two units; a) fish culture unit b) oxygen production/waste treatment unit. Pond size of 0.4 ha is the summation of two units (a+ b), but production data are obtained from a) unit only; avg.=average

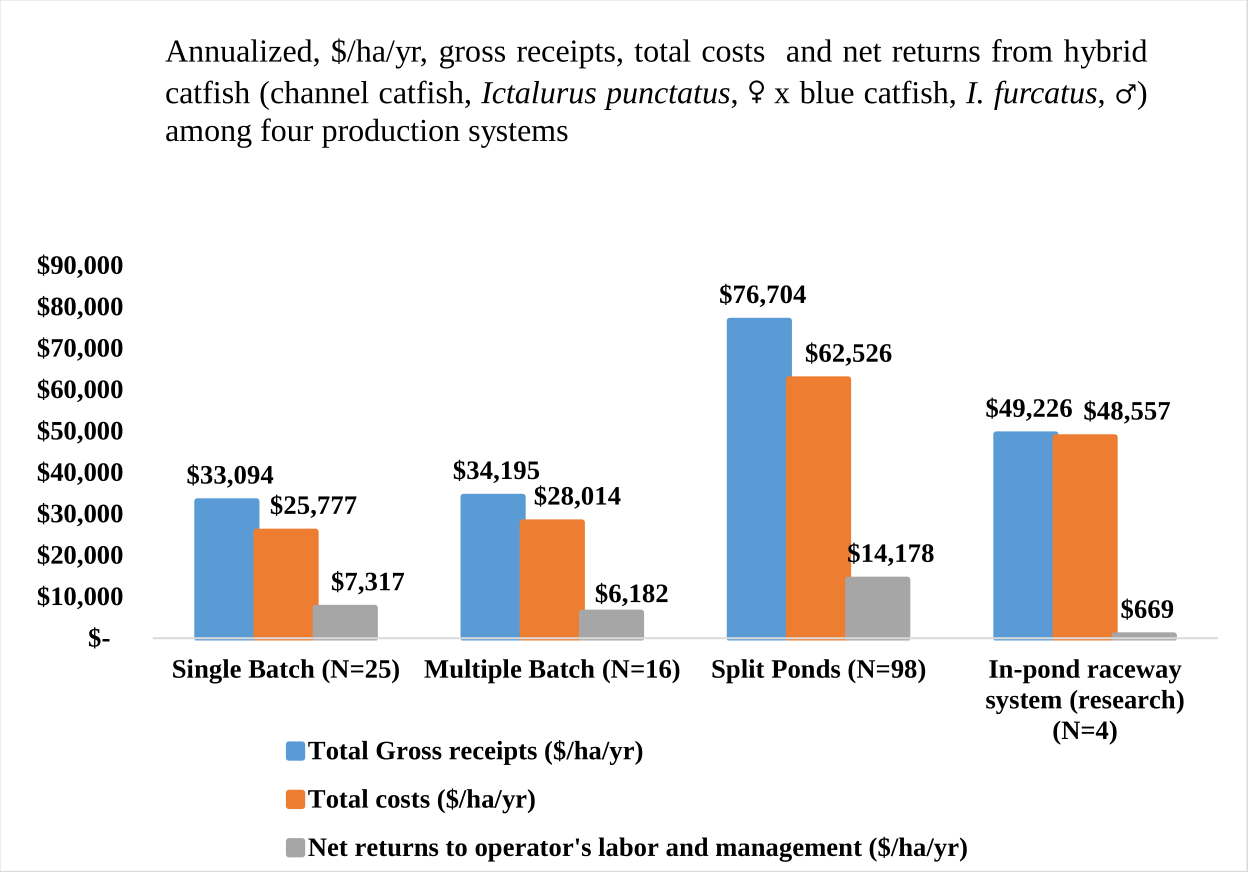


Figure 3.3: Annualized, $/ha/yr, gross receipts, total cost and net returns operator’s labor and management ($/ha/yr) of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) farming from different production systems

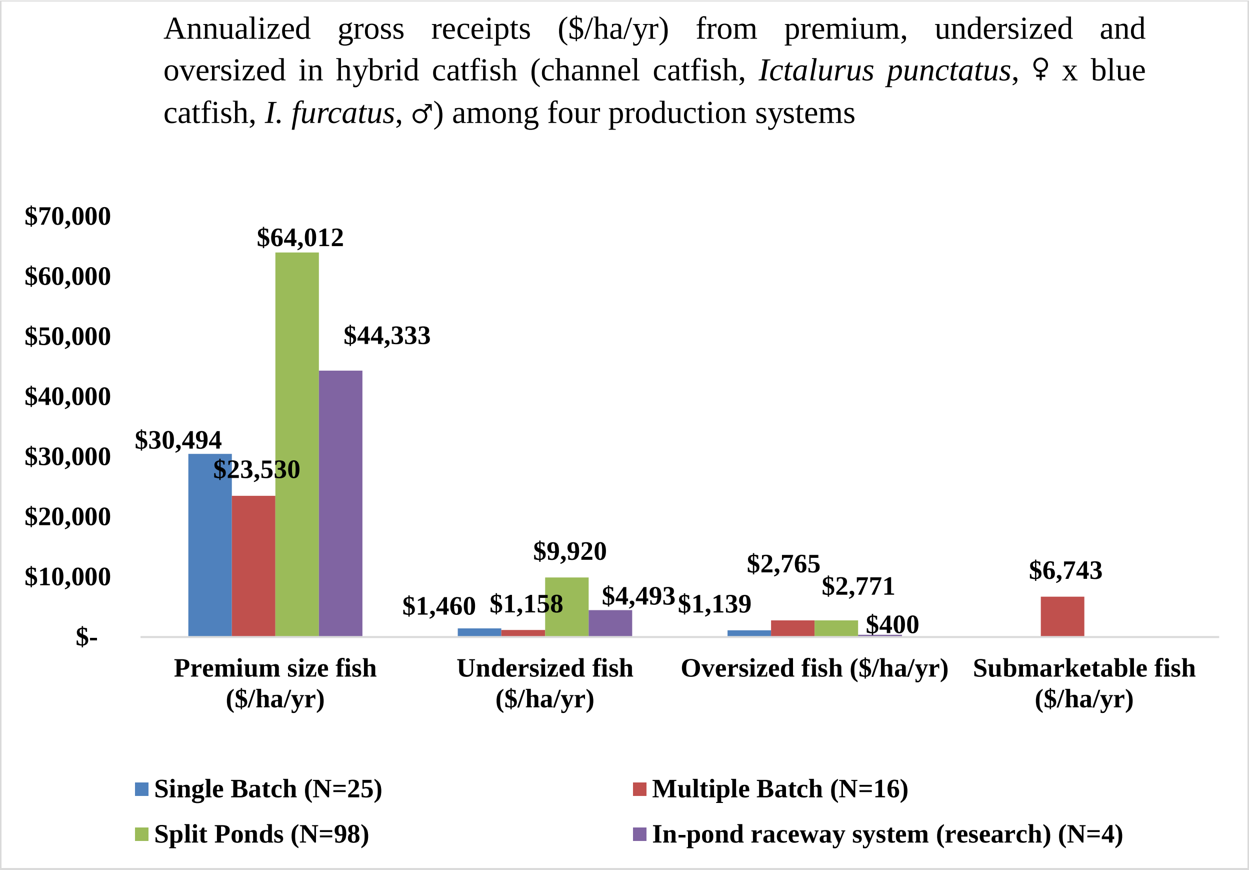


Figure 3.4 Annualized gross receipts ($/ha/yr) from hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) production (premium/undersized/ oversized categories) from different production systems

Table 3.9: Average revenue loss ($/ha) due to growth variation in hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) production (with and without scenario) (un-annualized, $/ha)

			Receipts: Undersized fish			**Receipts: Oversized fish**		
Production System	N	Unit	*with dockage rate	**without dockage rate	Difference	with dockage rate	without dockage rate	Difference
Single batch	25	$/ha	1,486	1,562	75	1,160	1,373	212
Multiple batch	16	$/ha	1,216	1,278	62	2,905	3,436	532
Split pond	98	$/ha	6,002	6,306	304	1,677	1,984	307
IPRS (research)	4	$/ha	3,299	3,466	167	294	347	54
Total revenue loss	164	$/ha			607			1,104
								1,712

*with dockage rate= total production (under/oversized fish) (kg/ha) * 7 year's average selling price of under/oversized fish ($/kg)

** Without dockage rate= total production (under/oversized fish) (kg/ha) * 7 year's average selling price of premium size fish ($/kg)

Variable, fixed and total costs (annualized, $/ha/yr)

Results from the variable cost analysis suggested that feed cost contributed the highest percentage to the total variable cost (TVC) in all four production systems of hybrid catfish farming (Fig 3.5). Specifically, feed cost accounted for approximately 56%, 62%, 54% and 35% of TVC in single batch and multiple batch, split pond and IPRS (research) systems, respectively (Fig. 3.5). The lowest feed cost ($/ha/yr) was found in the single batch system. In comparison, both the single and multiple batch systems were stocked with almost similar fish densities, but slightly higher feed costs were reported for the multiple batch system, resulting from higher feed inputs as compared to the single batch system. Fingerling and labor variable costs (to TVC) were the second and third highest costs in traditional and split pond systems, respectively (Fig. 3.5). But in IPRS, labor cost was much greater than the other systems (Fig. 3.5).

In general, the split pond was the greatest intensification by using greater inputs of feed, fingerlings, labor and management compared to IPRS and traditional systems. The average stocking density of hybrid catfish fingerlings (number/ha) in split pond and IPRS (research) system were 32,432 ± 7,901 (N=98) and 23,486 ± 3,845 (N=4), respectively, while the single batch and multiple batch were stocked with 24,433 ± 12,441 (N=25) and 24,301± 11,949 (N=16), respectively ($P < 0.05$). Moreover, this split pond was stocked with medium to large sized fingerlings (average size 20 cm) (split pond, 60 ± 20g) while traditionally managed system and IPRS (research) were often stocked with small to medium and to some extent, large sized hybrid catfish fingerlings (average size 13 to 20 cm) (single batch, 50 ± 20g; multiple batch, 40 ± 20g; IPRS, 40 ± 0 g) ($P < 0.05$). The protein percentage in feed also varied among these production systems. Traditional and split pond systems often used 28% protein, while the IPRS (research) used 32% protein in the feed as part of their feeding management strategy. The FCR of the single and multiple batch, split pond and IPRS (research) systems were 2.47 ± 0.50, 2.75 ± 0.66, 2.48 ± 0.55, and 1.58 ± 0.05, respectively ($P < 0.05$).

The cost of labor was potentially higher in the IPRS compared to traditional and split pond systems. Comparative analysis showed that labor cost ($/ha/yr) of single batch ($758), multiple batch ($735), split pond ($1,276) and IPRS (research) ($9,286) systems were different among these production systems.

Gross yields (kg/ha) for hybrid catfish production were highest in split pond system (19,122 ± 5,237), followed by multiple batch (15,766 ± 5,025), single batch (13,821 ± 4,149) and IPRS (research) (14,789 ± 1,256) systems ($P < 0.05$). Net yields (total production minus initial weight of the stocked fingerlings) followed the same pattern. The gross yields were used for economic analysis as the fish were sold on gross yield basis. Comparative analysis also showed that survival rate (%) of single batch (84 ± 15), multiple batch (87 ± 10), split pond (80 ± 11) and IPRS (research) (86 ± 7) systems were different among these production systems ($P < 0.05$).

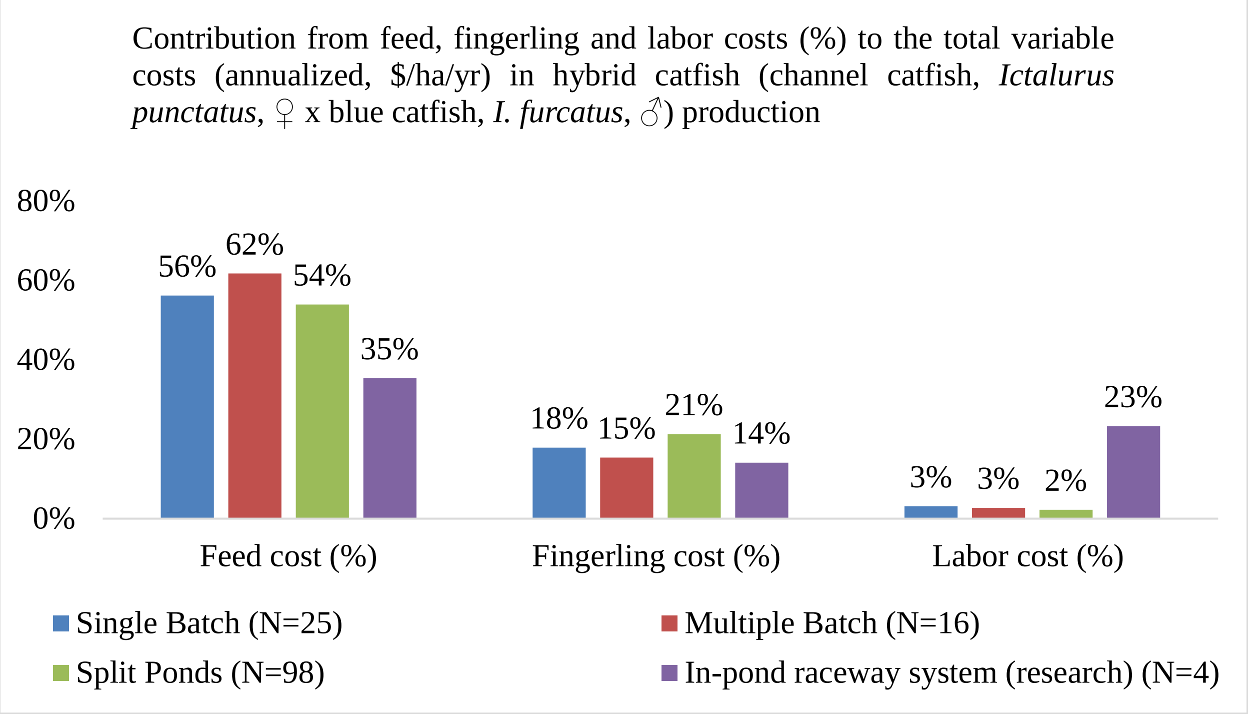


Figure 3.5: Contribution of feed and fingerling cost (%) to the total variable costs of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) farming (annualized, $/ha/yr) in different production systems

Overall, the total variable cost (TVC) was highest for the split pond system, followed by the IPRS (research), multiple batch and single batch systems, which was primarily due to the greater stocking densities and feed cost (Fig. 3.6). TVC accounted for approximately 82 to 95% of the total cost (TC) in all four production systems. The total variable cost of IPRS (research) accounted for the lowest percentage (82%), while multiple batch systems accounted for the highest percentage (96%) towards the total cost (TC). The single batch and split pond systems accounted for 95% and 92% to TC, respectively.

The total fixed cost (TFC) (annualized, $/ha/yr) was the highest (18%) for the IPRS (research) system, which was primarily due to the additional investment cost that was initially needed to set up the infrastructure (Fig 3.6). This was followed by the split pond, single batch and multiple batch production systems. This cost accounted for 4 to 18% of the total cost in all four systems of hybrid catfish production.

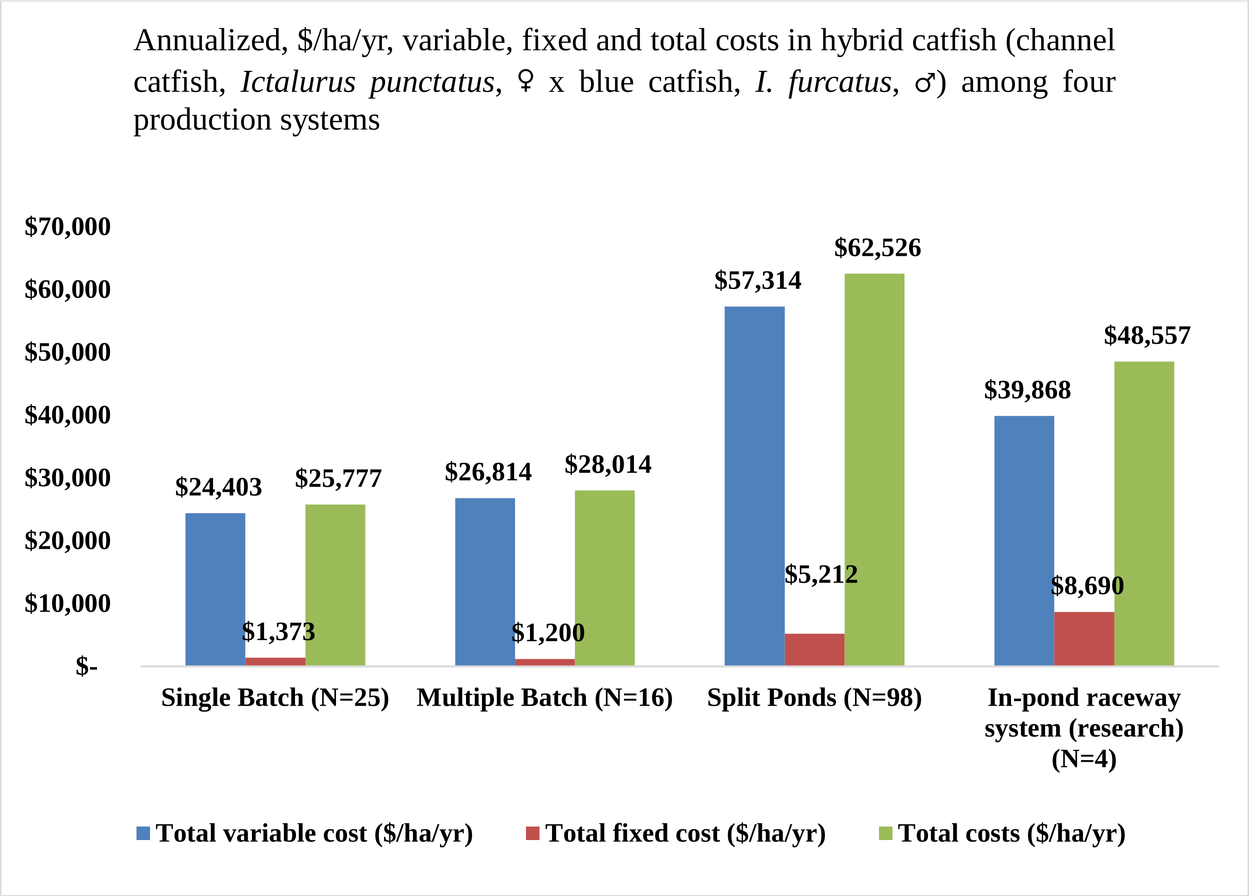


Figure 3.6 Annualized, $/ha/yr, variable, fixed and total costs of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in traditional (single/multiple batch), split pond and in-pond raceway systems

Income above variable cost and net returns (annualized, $/ha/yr)

The income above variable cost and net returns to operator's labor and management was the highest in the intensive split pond system (Fig. 3.7). Potential reasons behind that outcome were the greater stocking densities resulting higher yield and gross receipts. This trend was followed by single and multiple batch systems (Fig. 3.7). In IPRS, income above variable cost was higher but the net returns were the lowest compared to other systems (Fig. 3.7). The additional investment cost had a substantial impact, particularly on the intensive systems, which was evident after calculating the deviation between income above variable cost and net returns to operator's labor and management (annualized, $/ha/yr) (Fig. 3.7).

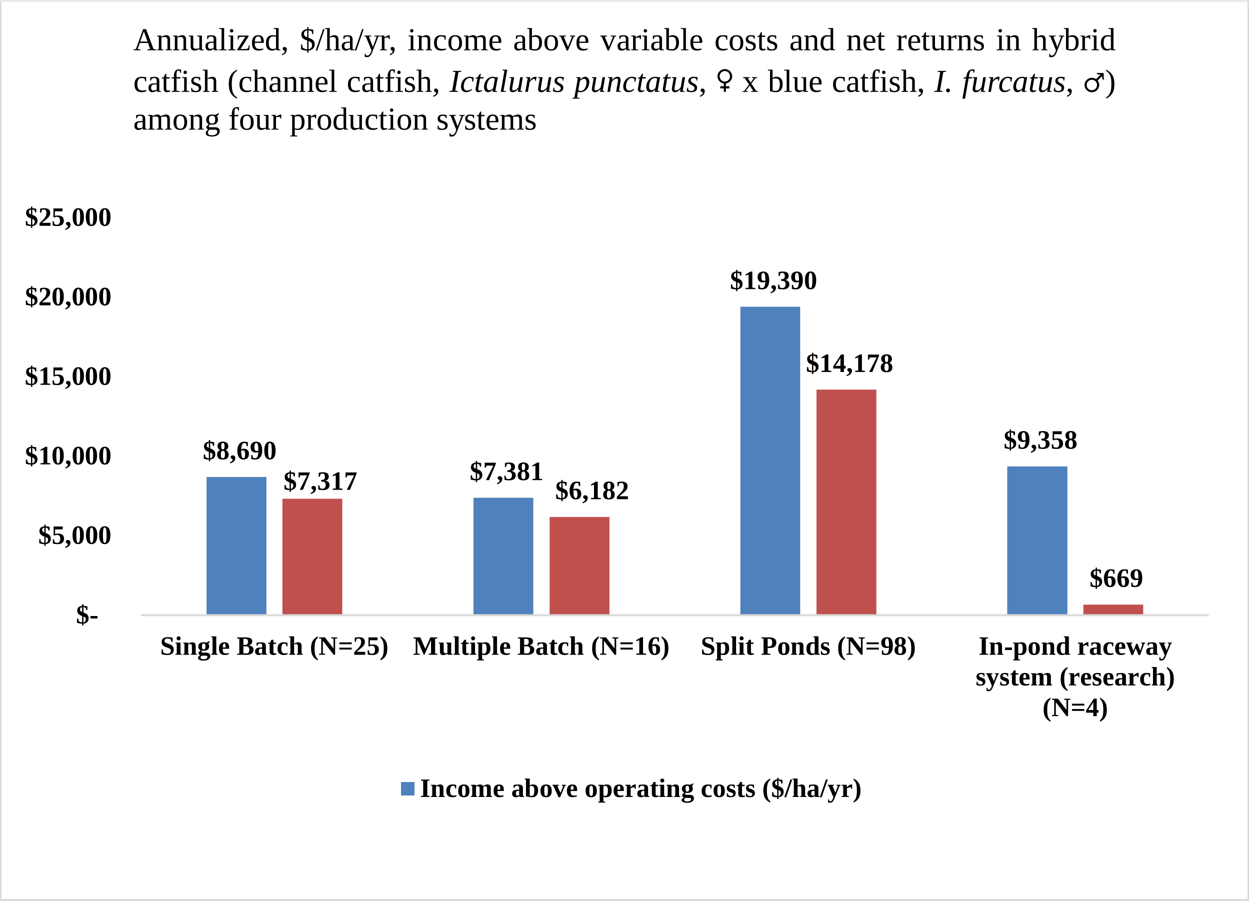


Figure 3.7 Annualized, $/ha/yr, income above variable costs and net returns to operator's labor and management of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) farming of traditional (single/multiple batch), split pond and in-pond raceway systems

Breakeven price and yield (annualized, $/ha/yr)

The breakeven prices (BEP) above annualized per ha variable and total costs (i.e., the price that was needed to cover the fixed and variable costs in $/kg of catfish produced) were highest for the IPRS (research) and lowest for the multiple batch production system (Tables 3.4-3.7 and Fig. 3.8). This trend was not evident in the case of breakeven yield (BEY) above total cost (variable plus fixed cost on a $/ha/yr basis) (i.e., the catfish yield, kg/ha/yr, that was needed to cover the per ha per year fixed and variable costs) as the highest and lowest BEY above TC and TVC was found for split pond and single batch systems, respectively (Fig. 3.9).

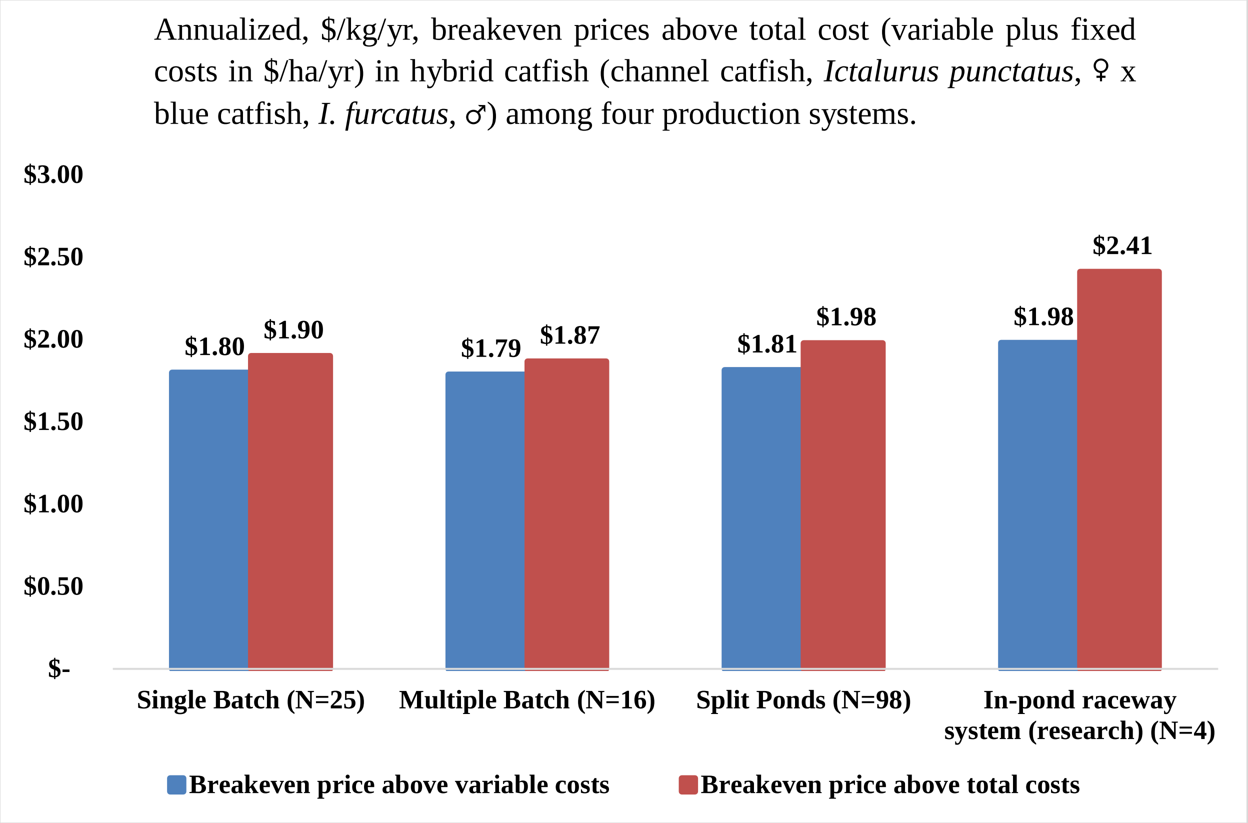


Figure 3.8 Annualized, $/kg/yr, breakeven prices above total cost (variable plus fixed costs in $/ha/yr) of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) farming in traditional (single/multiple batch), split pond and in-pond raceway systems

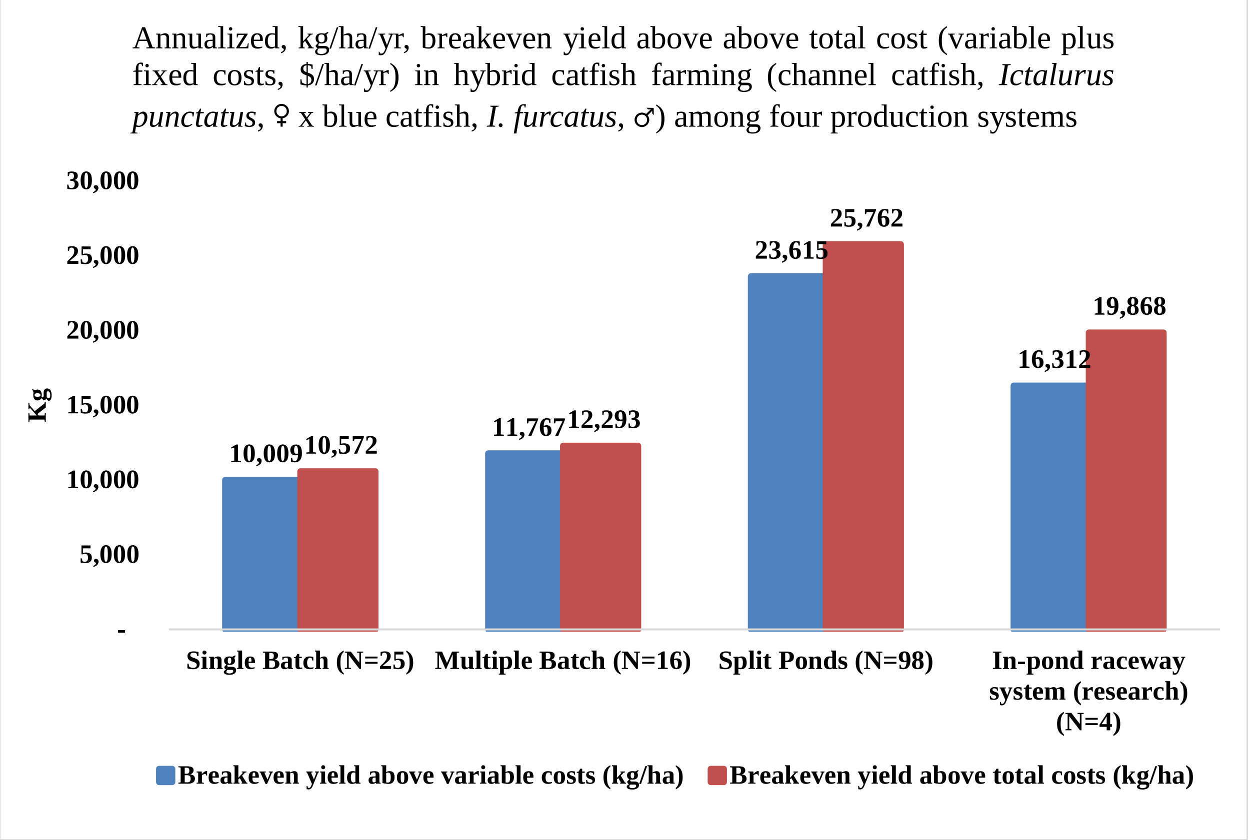


Figure 3.9 Annualized, kg/ha/yr, breakeven yield above total cost (variable plus fixed costs in $/ha/yr) of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) farming in traditional (single/multiple batch), split pond and in-pond raceway systems

Sensitivity analysis

Sensitivity analyses for all four production systems showed that the income above variable cost ($/ha/yr) and the net returns to operator's labor and management ($/ha/yr) were very sensitive to price changes for undersized and oversized fish (Table 3.10 and Figs. 3.10- 3.11). These two financial parameters were substantially decreased after reducing the dockage price by 25% (from the base price), and was particularly evident for undersized/oversized fish prices. The IPRS (research) system showed the highest sensitivity to price changes by projecting a negative net return to operator's labor and management (Table 3.10 and Fig. 3.11).

Table 3.10: Sensitivity analysis for hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) of single and multiple batch, split pond and IPRS systems after decreasing the prices of undersized and oversized fish by 25%, 50%, and 75% from the base sales price and its potential economic impact on the annualized, $/ha/yr, gross receipt, income above variable cost, and net returns to operator's labor and management

% decreases from base price (0%)	Premium size fish ($/kg)	Undersized fish ($/kg)	Oversized fish ($/kg)	Premium size fish ($/ha)	Undersized fish ($/ha)	Oversized fish ($/ha)	Gross receipts ($/ha)	Total costs ($/ha)	Income above variable costs ($/ha)	Net returns ($/ha)
Single batch										
0%	2.46	2.34	2.08	$30,494	$1,460	$1,139	$33,094	$25,777	$8,690	$7,317
25%	2.46	1.76	1.56	$30,494	$1,095	$855	$32,444	$25,777	$8,040	$6,667
50%	2.46	1.17	1.04	$30,494	$730	$570	$31,794	$25,777	$7,390	$6,017
75%	2.46	0.59	0.52	$30,494	$365	$285	$31,144	$25,777	$6,741	$5,367
Multiple batch										
0%	2.46	2.34	2.08	$23,530	$1,158	$2,765	$34,195	$28,014	$7,381	$6,182
25%	2.46	1.76	1.56	$23,530	$868	$2,073	$33,215	$28,014	$6,401	$5,201
50%	2.46	1.17	1.04	$23,530	$579	$1,382	$32,234	$28,014	$5,420	$4,221
75%	2.46	0.59	0.52	$23,530	$289	$691	$31,254	$28,014	$4,440	$3,240
Split pond system										
0%	2.46	2.34	2.08	$64,012	$9,920	$2,771	$76,704	$62,526	$19,390	$14,178
25%	2.46	1.76	1.56	$64,012	$7,440	$2,079	$73,531	$62,526	$16,217	$11,005
50%	2.46	1.17	1.04	$64,012	$4,960	$1,386	$70,358	$62,526	$13,044	$7,832
75%	2.46	0.59	0.52	$64,012	$2,480	$693	$67,185	$62,526	$9,871	$4,659
In-pond raceway system (research)										
0%	2.46	2.34	2.08	$44,333	$4,493	$400	$49,226	$48,557	$9,358	$669
25%	2.46	1.76	1.56	$44,333	$3,370	$300	$48,003	$48,557	$8,135	$(555)
50%	2.46	1.17	1.04	$44,333	$2,247	$200	$46,780	$48,557	$6,912	$(1,778)
75%	2.46	0.59	0.52	$44,333	$1,123	$100	$45,556	$48,557	$5,689	$(3,001)

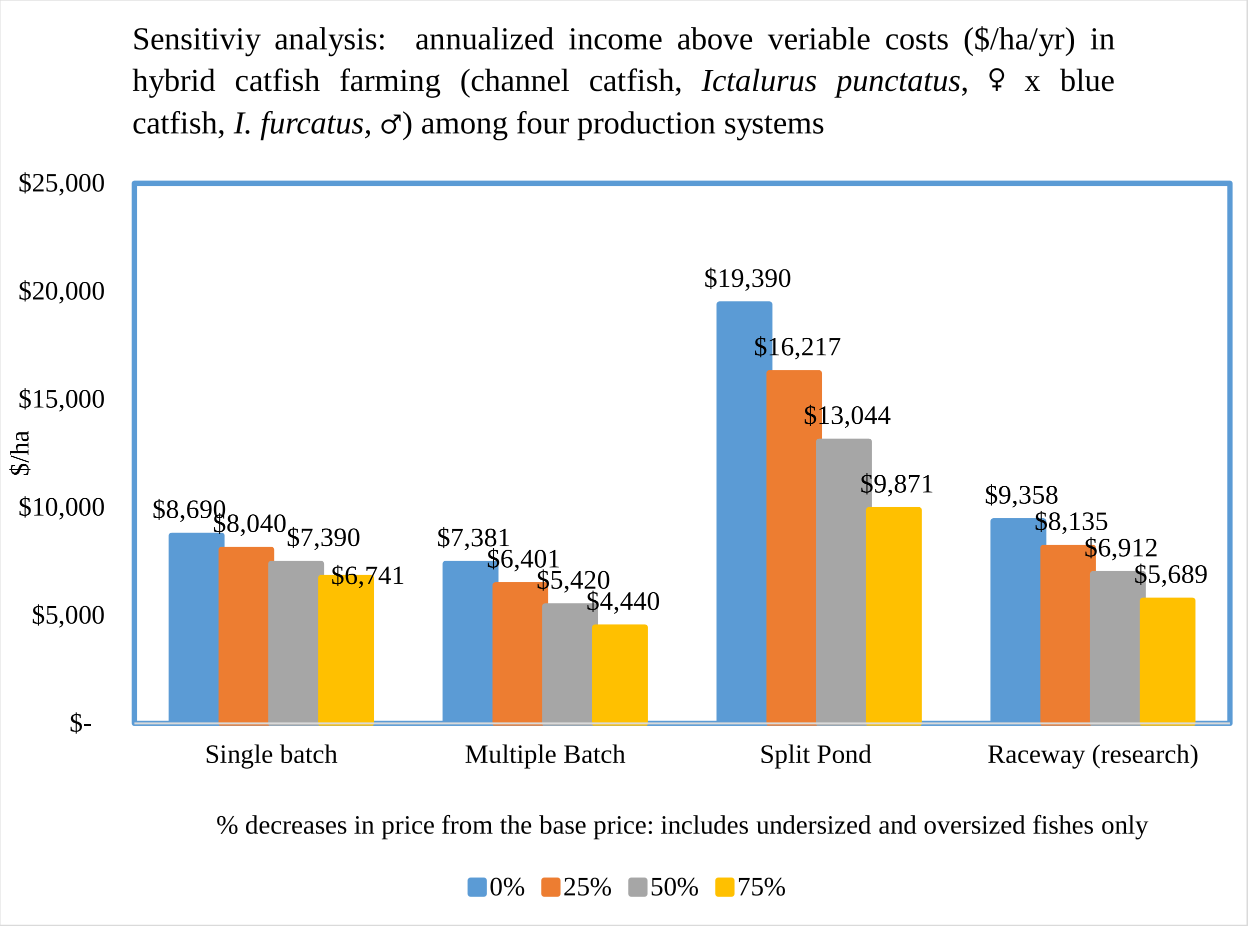


Figure 3.10: Sensitivity analysis by decreasing the prices for undersized and oversized categories of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) by 25%, 50%, and 75% from the base sales prices and the potential effects on the annualized, $/ha/yr, income above variable costs.

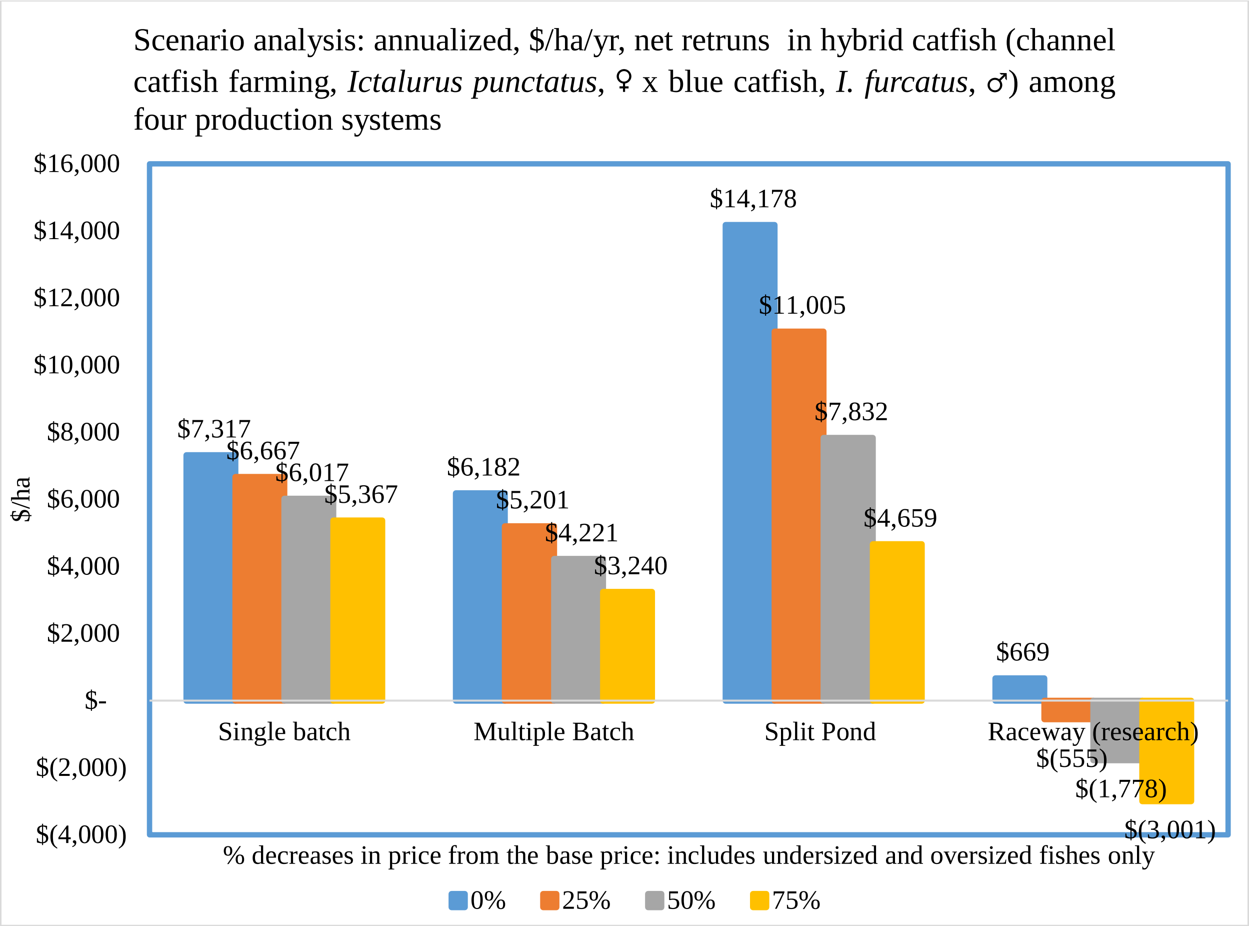


Figure 3.11: Sensitivity analysis by decreasing the prices of undersized and oversized categories of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) by 25%, 50%, and 75% from the base sales prices and the potential effects on the annualized, $/ha/yr, net returns to operator's labor and management.

Partial budget

The single batch production system had potential additional benefits from selling additional premium and undersized fish with saving money from feed input if a farmer would stock 20 cm size instead of 18 cm size fingerlings (Table 3.11). However, this additional benefit was lesser than the total additional costs, which included the additional fingerling cost and other input usage costs. Moreover, reduced revenue was also evident from the oversized fish categories that forced an increase in the total additional cost. A negative net benefit was evident for the practice of stocking 20 cm size in comparison to 18 cm size fingerlings in single batch production system (Table 3.11; Appendix Tables 3.1 and 3.2).

Table 3.11. A partial budget analysis of growing hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in a single batch production system changing the fingerling size from 18 cm to 20 cm in annualized units ($/ha/yr)

Category	**Items**	**Description**	**Unit**	**Value or cost**
Benefits	Additional revenue			
		Premium size fish	$/ha/yr	1,700
		Undersized fish ($/ha)	$/ha/yr	246
	Reduced cost			
		Feed cost	$/ha/yr	927
Total additional benefits		Other fixed costs	$/ha/yr	64
				2,938
Cost	Additional cost			
		Fingerlings	$/ha/yr	-2263
		Interest on operating capital	$/ha/yr	-108
		Other variable costs	$/ha/yr	-6
	Reduced revenue			
		Oversized fish ($/ha)	$/ha/yr	-625
Total additional costs			$/ha/yr	-3003
Net benefit				-65

A similar trend was found for the multiple batch production system, where the total additional costs were higher after stocking 20 cm size fingerlings (Table 3.12; Appendix Tables 3.3 and 3.4). Additional costs along with a reduced revenue led to a higher additional cost. Additional benefits were obtained from the feed costs with savings in the other variable/fixed costs. This additional benefit was small; thus, a negative net benefit was found for using 20 cm size rather than 18 cm size fingerlings in hybrid catfish production.

Table 3.12. A partial budget analysis of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) production in multiple batch production system changing the fingerling size from 18 cm to 20 cm in annualized units ($/ha/yr)

Category	Items	Description	Unit	Value or cost
Benefits				
	Additional revenue			
	Reduced cost			
		Feed	$/ha/yr	5,485
		Fingerlings	$/ha/yr	762
		Other variable costs	$/ha/yr	2,182
Total additional benefits				8429
Cost	Additional cost			
		Interest on operating capital	$/ha/yr	-606
		Other fixed costs	$/ha/yr	-167
	Reduced revenue			
		Premium size fish	$/ha/yr	-8,999
		Undersized fish ($/ha)	$/ha/yr	-423
		Oversized fish ($/ha)	$/ha/yr	-2,205
		Inventory of Sub-marketable fish	$/ha/yr	-394
			$/ha/yr	-12,400
Total additional costs				
Net benefit			$/ha/yr	-3,971

Partial budget analysis for the split pond system also showed a negative net benefit if a farmer adopted the practice of stocking large sized fingerlings (20 cm) instead of medium size fingerlings (18 cm) (Table 3.13, Appendix Tables 3.5 and 3.6). Total additional costs for stocking large sized fingerlings (20 cm) increased, and gross receipts reduced from the premium/under/oversized fish categories. Hence, a negative net benefit was found in this partial budget analysis of changing from the current 18 cm fingerling to stock 20 cm fingerling at the end of the production (Table 3.13).

Table 3.13. A partial budget analysis of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) production in split pond production system changing the fingerling size from 18 cm to 20 cm in annualized units ($/ha/yr)

Category	**Items**	Description	Unit	**Value or cost**
Benefits	Additional revenue			-
	Reduced cost	Feed cost	$/ha/yr	5,342
		Interest on operating capital	$/ha/yr	476
		Other variable costs	$/ha/yr	851
		Other fixed costs	$/ha/yr	456
Total additional benefits				7,124
Cost	Additional cost			
		Fingerlings	$/ha/yr	-487
	Reduced revenue			
		Premium size fish	$/ha/yr	-4,961
		Undersized fish ($/ha)	$/ha/yr	-1,756
		Oversized fish ($/ha)	$/ha/yr	-189
Total additional costs			$/ha/yr	-7,393
Net benefit			$/ha/yr	-269

Similarly, IPRS (research) also had a negative net benefit due to the increasing additional fingering cost and interest on operating capital after adopting the larger size fingerling (20 cm) (Table 3.14; Appendix Table 3.7). Individual enterprise budget analysis for all four production systems yielded similar results. The net return to operator’s labor and management was higher for medium size fingerlings (18 cm) compared to the 20 cm size fingerlings in all four systems (Appendices 3.1-3.7).

Table 3.14. A partial budget analysis of hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) in IPRS (research) system changing the fingerling size from 18 cm to 20 cm in annualized units ($/ha/yr)

Category	**Items**	**Description**	**Unit**	**Value or cost**
Benefits				
	Additional revenue			$ -
	Reduced cost			$ -
Total additional benefits				$ -
Cost				
	Additional cost			$ -
	Reduced revenue			
		Fingerling cost	$/ha/yr	$ 1,507
Total additional costs		Interest on operating capital	$/ha/yr	$ 126
				$ 1,633
Net benefit			$/ha/yr	$ 1,633

Discussion

The comparative analysis of traditional (single batch and multiple batch), split pond and IPRS (research) systems under a common set of assumptions revealed many important economic trade-offs among these hybrid catfish production systems and hybrid growth variation. The study showed that the split pond production system had the highest income above variable cost (\$11,731/ha) and net returns to operator's labor and management (\$8,578/ha) in comparison to other production systems (un-annualized). This is due to the higher gross receipts resulting from greater gross yields. The split pond system grossly received \$46,408/ha (un-annualized per ha), predominantly from premium size fish followed by undersized and oversized fish. In general, greater stocking densities used in split ponds contributed to the greater yields, especially given that there were significant differences found for survival rates and mean weight of fish harvested. Kumar et al. (2016) also found a similar result for hybrid catfish farming for the commercial screw-pump scenario of the split pond system. In the single batch, multiple batch and IPRS (research) systems, total gross receipts (\$/ha) for hybrid catfish production systems were \$33,698 and \$35,928 and \$36,144 /ha (un-annualized per ha), respectively. These gross receipts (\$/ha) surpassed those findings found by Ligeon et al. (2004), \$12,039/ha, and Rees (2013), \$6,253/ha, for the single batch of hybrid catfish production system. However, Bott et al. (2015) found higher gross receipts of 33,893/ha for multiple batch production systems. For the IPRS system, Fullerton (2016) found gross receipts of \$27,415/ha for commercial settings in West Alabama. The dockage rate was not considered for undersized and oversized fish in their analyses. Gross receipts can vary substantially due to the dockage rate, as indicated in the current analysis. The average revenue loss was 12 cents/kg for undersized fish and 38 cents/kg for oversized fish or in total, \$1,712/ha, regardless of the production system. Wiese et al. (2006) reported an average revenue loss was 7 cents/kg. Dockage rate pricing has a substantial economic impact on the gross receipts and net returns in catfish production systems (Wiese et al. 2006).

In terms of total cost, the split pond system was the highest due to greater input and investment costs compared to other systems. Among the input variables, feed cost accounted for approximately 62%, the highest percentage, to the total variable cost (TVC) in the multiple batch system. Similarly, this cost accounted for approximately 56%, 54%, and 35% of TVC in single batch, split pond and IPRS (research) systems, respectively. Ligeon et al. (2004) and Rees et al. (2014) also found similar results for single batch production systems. Moreover, Rees et al. (2014) reported that feed costs accounted for approximately 53%, 48% and 51% of TVC in hybrid catfish single batch production systems after stocking 13 cm, l9 cm and mixed size (13 and 19 cm) fingerlings for food fish production, respectively. For the multiple batch production system, Bott et al. (2015) suggested that feed cost accounted for approximately 58% of TVC. For the split pond system, feed cost was responsible for approximately 61% of TVC (commercial screw-pump scenario) (Kumar et al. 2016). Kumar and Engle (2010) also stated that fluctuations in feed prices could negatively affect the net returns in hybrid catfish production. In the in-pond raceway system (research), feed cost accounted for only 36% of TVC (Davis et al. 2017). Feed cost was responsible for the highest portion of TVC in hybrid catfish production regardless of the production system.

Fingerling cost formed the second largest cost of the TVC in all three production systems except IPRS. This was most likely due to the higher fingerling price of hybrid catfish in the current market. Moreover, this price varied based on size. Researchers found that the price of 19 cm fingerlings was approximately 46% higher than smaller sized fingerlings (13 cm) (Kumar and Engle 2010). Adoption of 13 cm, 18 cm and mixed size fingerlings constituted approximately 12%, 20% and 21% of the total variable cost of single batch hybrid catfish production, respectively (Rees 2013). Currently, the price of hybrid catfish fingerlings (15 to 18 cm or 6-7 inch in size or 26.72 kg/1,000 fingerling) is 1.0236 cents/cm (2.6 cents/inch) in Mississippi (Wilson Holland, personal communication). The cost of stockers (18 to 20 cm or 7-8 inch, or 58.32 kg/1000 fingerling) is considerably higher, 1.0826 cents/cm (2.75 cents/inch) (Wilson Holland, personal communication). The cost of larger stockers (> 20 cm or >8 inch or 85kg/1000 fingerling) is considerably higher at 1.1220 cents/cm (2.85 cents/inch) (Wilson Holland, personal communication). This larger stocker is difficult to obtain consistently (Wilson Holland, personal communication). Most of the fingerling producers are selling ungraded fingerlings, as the cost of graded fingerling is higher due to additional labor (for grading), and handling losses (Nagaraj Chatakondi, personal communication).

Overall, the net returns to operator's labor and management in the single batch system was $7,450 /ha (un-annualized) in contrast to $15,020 and $ 3,710 per ha found by Ligeon et al. (2004) and Rees et al. (2014), respectively. Bott et al. (2015) found a higher net return ($40,390/ha/year) for the multiple batch system, which was greater than current results ($6,495/ha) (un-annualized). The difference is likely due to the increased the price for input items in our analysis period or adoption of dockage policy and associated prices in the current analysis. In general, the catfish price received by the producer from the processor often varies as it is determined by market demand and supply. A review study showed that a shortage of catfish during

2014 resulted in a high price ($2.62/kg for premium size fish) paid by the fish processors to the producers (Fig. 3.1) (Hanson and Sites 2015). This value along with the price of 2016 ($2.63/kg) were the highest prices ever, which perhaps reflected the shortage of fish available during those years (Hanson and Sites 2015; Terry Hanson, personal communication). The prices for undersized and oversized fish also varies, and averaged $2.05 to $2.54/kg in the 2014-2016 period (Terry Hanson, personal communication). The lowest price ($1.23/kg) for oversized fish was seen in 2017, which was most likely due to low market demand and oversupply of very large fish in the market. Until recently, the oversized to undersized fish prices did not vary much from the premium size fish but in 2015 and 2017, the oversized fish price diverged drastically from the premium price, as did the undersized fish to a lesser degree.

Moreover, the farmers using the multiple batch system had the highest percentage of oversized fish (12%) compared to single batch (4%), split pond (4%) and IPRS (research) (1%). Intensive systems, such as the split pond system had the highest net return, which is related to greater stocking densitites, like the results of Kumar et al. (2016). In contrast, IPRS (research) system showed the lowest net retrun ($491/ha) (un-annualized), similar to the findings of Fullerton (2016) and Holland (2016). Higher investment cost during the initial period of IPRS installation could be the main reason for such an outcome. Fern (2014) also observed lower net returns from a newly developed IPRS system that had two or three years of operational and marketing experience. The author found that these newer systems could take a few years after initiation to become viable commercial enterprises and reach their optimal levels of production and efficiency. In terms of net return in IPRS (research), Fullerton (2016) and Holland (2016) also found a positive net retrun from their projected scenarios for IPRS system. However, they ommitted certain investment costs associated with land, pond construction and cost of additioanl labor involved in IPRS, hence, additional work is needed to determine whether the IPRS system is profitable or not after launching it in commercial settings.

Breakeven prices above variable and total costs ($1.98/kg and $2.41/kg) (including premium/under/oversized fish) were the highest for the IPRS (reasearch), which was due to the greater input usages and initial investment costs. In contrast, farmers who had adopted the split pond system had the highest breakeven yield above variable and total costs (23,615 and 25,762 kg/ha) (inlcuding premium/under/oversized fish), as indicated in the current analysis. This BEP and BEY was lower for single batch ($1.90/kg; 10,572 kg/ha) and multiple batch ($1.87/kg and 12,293 kg/ha) systems. Johnson et al. (2014) also reported that the BEP ($/kg) and BEY (kg/ha) above total cost were in the range of $1.96 to $2.84 and 10,285 to 18,944 kg/ha for hybrid catfish in the traditional production system, respectively.

Rees et al. (2014) also found comparatively higher BEP (above total cost) ($1.72/kg) for 19 cm fingerlings compared to 13 cm ($ 1.57/kg) or mixed size fingerings ($ 1.59 /kg) in single batch, hybrid catfish production. The BEY above total cost for small, large and mixed size fingerling treatments was 11,301, 12,223 and 17,023 kg/ha, respectively (Rees et al. 2014). Engle et al. (2017) also found a similar BEP (above total cost) for single size (13 cm) ($1.84/kg) and mixed size treatment ($1.48/kg) of hybrid catfish in single batch system. Courtwright (2013) found a higher BEP (above total cost) ($2.44/kg) for hybrid catfish in the traditional multi batch production system in Alabama. This was closer to the BEP (above total costs) of hybrid catfish farming at cage culture, split pond system and IPRS systems, which ranged from $1.72 to $1.96/

kg (Masser and Lazur 1997) and \$1.72 to \$2.05/kg (Kumar et al. 2016) and \$2.08/kg for hybrid catfish production in IPRS (Davis et al. 2017), respectively.

Sensitivity analyses showed that the income above variable costs and net returns to operator's labor and management were extremely sensitive to the farm price. Ligeon et al. (2004) also found that net returns were extremely sensitive to the farm price for hybrid catfish culture, which decreased after reducing the farm price by 10-30%. Bouras and Engle (2007) also found that net returns were sensitive after changing certain key parameters such as interest rates, feed conversion ratios, survival rates, catfish prices, harvesting costs, and the availability of operating capital. Usually, farmers could improve the net returns to operator's labor and management by 10-15% by producing a greater yield or by attaining a lower FCR, (Masser and Dunham 1998). Given that point, split pond production systems could be the most profitable enterprise for the farmers to pursue as it could provide highest net returns to operator's labor and management (maximum \$14,178), in all dockage price scenarios of undersized and oversized fish being decreased by 25%, 50%, and 75% % from the base sales price.

The partial budget analysis showed that adopting either 18 or 20 cm sized fingerlings would be an economically feasible enterprise; even though the individual net return to operator’s labor and management showed a higher outcome for the medium (18 cm) compared to large sized fingerlings (20 cm) in all three environments except for IPRS (research). In IPRS (research), the net return exhibited a positive return for 18 cm fingering, but it was slightly negative (-1,633) for 20 cm size fingerling. This net benefit differentiation in partial budget analysis was due to increasing fingerling cost in addition to the reduced revenue from the premium/under/oversized fish mixture. Additional revenue from feed cost reduction played a leading role in determining the net benefit in the partial budget analysis. This associated revenue could save a significant amount of money after adopting large (20 cm) compared to medium sized fingerling (18 cm) in all three environments except IPRS (research). Kumar and Engle (2010) also stated that hybrid catfish farmers could save $172/ha from the feed cost savings ($0.30/kg) resulting from the improved FCR, but the net benefit might not change due to the higher fingerling cost.

Overall, the split pond production system in this study had more economical benefits than the traditional single batch, multiple batch and IPRS (research) systems. The net returns to operator's labor and management were often higher for intensive split pond systems as a result of its higher yields. Higher stocking densities could be the explanation for such an outcome. The split pond production system was the most profitable enterprise resulting in the highest net return to operator's labor and management for all potential scenarios in the sensitivity analysis. Moreover, this system could spread out the total cost by producing a large output from a limited space. Johnson et al. (2014) also stated that the key to least-cost production in hybrid catfish farming was to balance the use of inputs, their associated costs, and the yield produced to achieve economic efficiency within the farm’s overall business and management model.

The other intensive system, IPRS (research), could also be a feasible enterprise as it reduced feed costs by lower FCR. Disease treatment cost could also be minimized by treating the fish in the targeted IPRS cell rather than treating the entire pond (Courtwright 2013). Moreover, this system could enhance growth uniformity by reducing the feed competition among different year-classes of fish by placing different year classes in individual cells (Courtwright 2013). Hybrid catfish can be produced at the rate of 14,978 kg/ha in the raceway compared to conventional pond production of 7,800 kg/ha in Alabama (Davis et al. 2017).

Traditional systems multiple batch or single batch were also profitable enterprise (Engle and Pounds 1993). Wiese et al. (2006) stated that dockage losses could be reduced by shifting either to longer-term single batch production or a more fingerling intensive grading system. Additionally, the longer-term production system should result in fewer small fish that would incur dockage losses. In the U.S., single batch and multiple batch systems were the two most commonly practiced systems for catfish production (Tucker and Robinson 2013); with the most frequently used system being the continuous, multiple-batch production system (Engle and Valderrama, 2001; Engle, 2003; Bastola and Engle 2012). The multiple batch production system allowed catfish farmers to generate cash flow in the presence of off-flavor induced market constraints (Engle et al. 1995).

In summary, dockage rate policy for price reduction had an inverse relationship with net returns to operator's labor, and management in all production systems. The revenue loss due to dockage rates and policies for undersized and oversized fish was, in total, $1,712/ha, regardless of the production system. Specifically, the average revenue loss was 12 cents/kg for undersized fish and 38 cents/kg for oversized fish. Adoption of large size fingerlings (20 cm) could be a good option to erase such revenue loss, but it would provide less net return to operator's labor, and management compared to medium size fingerlings (18 cm). Split pond production systems were the most profitable enterprise among the four production systems compared in this research.

Conclusion

In conclusion, dockage rates for oversized and undersized fish had a significant economic impact on the net returns to operator's labor, and management in all four production systems analyzed in this study. Increasing the yield by adopting intensive production systems could be a good option to minimize undersized and oversized fish quantities. Alternatively, using medium size fingerling (18 cm) could give comparatively higher revenues compared to stocking large 20 cm size fingerlings in all four production systems. Even though the gross receipt is less after using medium size fingerlings, resulting from the higher percentage of undersized and oversized fish, this is more than compensated by lower feed and fingerling costs. Future research should focus on determining the effect of grading hybrid catfish fingerlings on all four production systems and to update surveys of current processing plant dockage rates and how they impact net returns for the catfish producer.

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Appendix

Appendix 3.1

Enterprise budget for the hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) of SINGLE BATCH system (used for partial budget analysis) (N=16) (area 3.47 ha; stocking density 21,530 /ha; fingerling size 18 cm, feed 31 [a]MT/ha, yield 13,256 kg/ha)

Item	**Description**	**Unit**	**Quantity**	**Price/Cost ($)**	**Total ($)**	**Total ($/ha)**	**Annualized total ($/yr)**	**Annualized ($/ha/yr)**
1. Gross receipts	Premium size	Kg	41,664	2.46	102,449	29,509	101,523	29,242
	Undersized fish	Kg	2,056	2.34	4,813	1,386	4,770	1,374
	Oversized fish	Kg	2,303	2.08	4,786	1,379	4,743	1,366
Total Gross receipts		Kg	46,023	2.43	112,048	32,274	111,035	31,982
2. Operating costs								
Feed	28% protein floating	MT	107	442	47,410	13,656	46,982	13,532
Fingerlings	Size: 18 cm	Each	74,747	0.18	13,454	3,875	13,333	3,840
Labor	Owner supplied labor	$/ha	3.47	772	2,681	772	2,657	765
	Seasonal labor	$/ha	3.47	386	1,340	386	1,328	383
Chemicals	Empirical average	Ha	3.47	322	1,118	322	1,108	319
Gas and diesel	Empirical average	Ha	3.47	365	1,269	365	1,257	362
Electricity	Empirical average	Ha	3.47	486	1,689	486	1,673	482
Repairs and maint.	Empirical average	Ha	3.47	308	1,070	308	1,060	305
Bird depredation supplies	Empirical average	Ha	3.47	15	54	15	53	15
Seining & hauling	Empirical average	kg	46,023	0.13	5,983	1,723	5,929	1,708
Telephone	Empirical average	Ha	3.47	42	146	42	145	42
Office supplies	Empirical average	Ha	3.47	27	94	27	94	27
Interest on operating capital		$	63,590	0	6,359	1,832	6,302	1,815
Total operating costs	Per pond				82,668	23,811	81,920	23,596
3. Income Above operating costs					29,381	8,463	29,115	8,386
							-	-
4. Fixed costs							-	-

Farm insurance	Empirical average	Ha	3.47	108	374	108	371	107
Legal/accounting	Empirical average	Ha	3.47	46	161	46	160	46
Interest on Investment							-	-
Land	Empirical average	$	7,048	0.10	705	203	698	201
Wells	Empirical average	$	2,016	0.10	202	58	200	58
Pond construction	Empirical average	$	2,141	0.10	214	62	212	61
Equipment	Empirical average	$	8,918	0.10	892	257	884	255
Annual depreciation							-	-
Equipment	Empirical average	Ha	3.47	665	2,308	665	2,287	659
Total Fixed costs	Per pond				4,855	1,399	4,811	1,386
5. Total costs	Per pond				87,523	25,210	86,732	24,982
6. Net returns to operator's labor, and management	Per pond				24,525		24,304	
	Per Ha				7,064	7,064	7,000	7,000
Breakeven Price	Above variable costs	$/kg			1.80		1.78	
	Above total costs	$/kg			1.90		1.88	
Breakeven Yield	Above variable costs	Kg			33,955		33,648	9,692
		kg/ha			9,780		9,692	
	Above total costs	kg			35,949		35,624	10,261
		kg/ha			10,355		10,261	

[a]MT= metric ton

Appendix 3.2

Enterprise budget for the hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) of SINGLE BATCH system (N=8) (used for partial budget analysis) (area 3.72 ha; stocking density 28,689 /ha; fingerling size 20 cm, feed 30 aMT/ha, yield 14,304 kg/ha)

Item	Description	Unit	Quantity	Price/Cost ($)	Total ($)	Total ($/ha)	Annualized total ($/yr)	Annualized ($/ha/yr)
1. Gross receipts	Premium size	kg	49,184	2.46	120,940	32,469	115,256	30,943
	Undersized fish	kg	2,704	2.34	6,330	1,699	6,032	1,620
	Oversized fish	kg	1,393	2.08	2,895	777	2,759	741
Total Gross receipts		kg	53,281	2.44	130,165	34,945	124,048	33,303
2. Operating costs								
Feed	28% protein floating	MT	111	442	49,267	13,227	46,952	12,605
Fingerlings	Size: 20 cm	Each	106,863	0.22	23,856	6,405	22,735	6,104
Labor	Owner supplied labor	$/ha	3.72	772	2,876	772	2,741	736
	Seasonal labor	$/ha	3.72	386	1,438	386	1,371	368
Chemicals	Empirical average	ha	3.72	322	1,200	322	1,144	307
Gas and diesel	Empirical average	ha	3.72	365	1,361	365	1,297	348
Electricity	Empirical average	ha	3.72	486	1,812	486	1,727	464
Repairs and maint.	Empirical average	ha	3.72	308	1,148	308	1,094	294
Bird depredation supplies	Empirical average	ha	3.72	15	58	15	55	15
Seining & hauling	Empirical average	kg	53,281	0.13	6,927	1,860	6,601	1,772
Telephone	Empirical average	ha	3.72	42	156	42	149	40
Office supplies	Empirical average	ha	3.72	27	101	27	96	26
Interest on operating capital		$	75,167	0	7,517	2,018	7,163	1,923
Total operating costs	Per pond				97,716	26,234	93,124	25,001
3. Income Above operating costs					32,449	8,711	30,924	8,302
							-	-
4. Fixed costs							-	-
Farm insurance	Empirical average	ha	3.72	108	401		382	103
Legal/accounting	Empirical average	ha	3.72	46	173		165	44
Interest on Investment							-	-
Land	Empirical average	$	7,561	0.10	756		721	193
Wells	Empirical average	$	1,879	0.10	188		179	48

Pond construction	Empirical average	$	2,141	0.10	214		204	55
Equipment	Empirical average	$	9,568	0.10	957	2,569	912	245
Annual depreciation							-	-
Equipment	Empirical average	ha	3.72	665	2,476		2,360	633
Total Fixed costs	Per pond				5,165	1,387	4,922	1,322
5. Total costs	Per pond				102,882	27,621	98,047	26,323
6. Net returns to operator's labor, and management	Per pond				27,283		26,001	
	Per Ha				7,325	7,325	6,981	6,981
Breakeven Price	Above variable costs	$/kg			1.83		1.75	0.47
	Above total costs	$/kg			1.93		1.84	0.49
Breakeven Yield	Above variable costs	kg			39,999		38,119	10,234
		kg/ha			10,738		10,234	2,747
	Above total costs	kg			42,113		40,134	10,775
		kg/ha			11,306		10,775	2,893

[a]MT= metric ton

Appendix 3.3

Enterprise budget for the hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) of MULTIPLE BATCH SYSTEM (N=14) (used for partial budget analysis) (area 3.74 ha; stocking density 25,049 /ha; fingerling size 18 cm, Feed 40 [a]MT/ha, yield 16,236 kg/ha, inventory of sub-marketable fish 3,795 kg/ha)

Item	**Description**	**Unit**	**Quantity**	**Price/Cost ($)**	**Total ($)**	**Total ($/ha)**	**Annualized total ($/yr)**	**Annualized ($/ha/yr)**
1.Gross receipts	Premium size	kg	38,692	2.46	95,142	25,468	92,518	24,766
	Undersized fish	kg	1,993	2.34	4,665	1,249	4,537	1,214
	Oversized fish	kg	5,789	2.08	12,032	3,221	11,700	3,132
	Inventory of Sub-marketable fish	kg	14,177	1.85	26,218	7,018	25,495	6,825
Total Gross receipts		kg	60,652	2.28	138,058	36,956	134,250	35,937
2. Operating costs								
Feed	28% protein floating	MT	151	442	66,615	17,832	64,777	17,340
Fingerlings	Size: 18 cm	Each	93,574	0.18	16,480	4,412	16,026	4,290
Labor	Owner supplied	$/ha	3.74	772	2,885	772	2,805	751
	Seasonal labor	$/ha	3.74	386	1,442	386	1,403	375
Chemcials	Empirical average	ha	3.74	322	1,203	322	1,170	313
Gas and diesel	Empirical average	ha	3.74	365	1,365	365	1,328	355
Electricity	Empirical average	ha	3.74	486	1,817	486	1,767	473
Repairs and maint.	Empirical average	ha	3.74	308	1,151	308	1,120	300
Bird depredation supplies	Empirical average	ha	3.74	15	58	15	56	15
Seining & hauling	Empirical average		46,475	0	6,042	1,617	5,875	1,573
Telephone	Empirical average	ha	3.74	42	157	42	153	41
Office supplies	Empirical average	ha	3.74	27	102	27	99	26
Interest on operating capital		$	82,764	0.10	8,276	2,215	8,048	2,154
Total operating costs	Per pond				107,593	28,801	104,625	28,007
3. Income Above operating costs	Per pond				30,465	8,155	29,625	7,930
4. Fixed costs								
Farm insurance	Empirical average	ha	3.74	108	402	108	391	105
Legal/accounting	Empirical average	ha	3.74	46	174	46	169	45
Interest on Investment							-	-
Land	Empirical average	$	2,030	0	203	54	197	53
Wells	Empirical average	$	2,015	0	202	54	196	52
Pond construction	Empirical average	$	2,141	0	214	57	208	56

Equipment	Empirical average	$	8,923	0	892	239	868	232
Annual depreciation								
Equipment	Empirical average	ha	3.74	665	2,483	665	2,415	646
Total Fixed costs	Per pond				4,570	1,223	4,444	1,190
5. Total costs	Per pond				112,163	30,025	109,069	29,196
6. Net returns to operator's labor, and management	Per pond				25,895		25,181	
	Per ha				6,932	6,932	6,741	6,741
Breakeven Price	Above variable costs		$/kg		1.77		1.73	0
	Above total costs		$/kg		1.85		1.80	0
Breakeven Yield	Above variable costs	total	kg		47,268		45,964	12,304
		per ha	kg/ha		12,653		12,304	3,294
	Above total costs	total	kg/ha		49,275		47,916	12,827
		per ha	kg/ha		13,190		12,827	3,434

[a]MT= metric ton

Appendix 3.4

Enterprise budget for the hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) of MULTIPLE BATCH SYSTEM (N=2) (used for partial budget analysis) (area 3.64 ha; stocking density 19,073/ha; fingerling size 20 cm, feed 32 [a]MT/ha, yield 12,480 kg/ha, inventory of sub-marketable fish 3,795 kg/ha)

Item	**Description**	**Unit**	**Quantity**	**Price/Cost ($)**	**Total ($)**	**Total ($/ha)**	**Annualized total ($/yr)**	**Annualized ($/ha/yr)**
1. Gross receipts	Premium size	kg	28,185	2.46	69,306	19,028	57,427	15,767
	Undersized fish	kg	1,487	2.34	3,481	956	2,884	792
	Oversized fish	kg	1,961	2.08	4,075	1,119	3,377	927
	Inventory of Sub-marketable fish	kg	13,822	2.04	28,266	7,761	23,421	6,430
Total Gross receipts		kg	45,455	2.31	105,128	28,863	87,109	23,916
2. Operating costs								
Feed	28% protein floating	MT	118	442	52,109	14,307	43,178	11,855
Fingerlings	Size: 20 cm	Each	69,470	0.22	15,508	4,258	12,850	3,528
Labor	Owner supplied	$/ha	3.64	772	2,813	772	2,330	640
	Seasonal labor	$/ha	3.64	386	1,406	386	1,165	320
Chemcials	Empirical average	ha	3.64	322	1,173	322	972	267
Gas and diesel	Empirical average	ha	3.64	365	1,331	365	1,103	303
Electricity	Empirical average	ha	3.64	486	1,772	486	1,468	403
Repairs and maint.	Empirical average	ha	3.64	308	1,123	308	930	255
Bird depredation supplies	Empirical average	ha	3.64	15	56	15	47	13
Seining & hauling	Empirical average		31,633	0	4,112	1,129	3,407	936
Telephone	Empirical average	ha	3.64	42	153	42	127	35
Office supplies	Empirical average	ha	3.64	27	99	27	82	23
Interest on operating capital		$	68,046	0.10	6,805	1,868	5,638	1,548
Total operating costs	Per pond				88,460	24,287	73,298	20,124
3. Income Above operating costs	Per pond				16,668	4,576	13,811	3,792
							-	-
4. Fixed costs							-	-
Farm insurance	Empirical average	ha	3.64	108	392	108	325	89
Legal/accounting	Empirical average	ha	3.64	46	169	46	140	38
Interest on Investment								
Land	Empirical average	$	2,030	0	203	56	168	46
Wells	Empirical average	$	2,015	0	202	55	167	46
Pond construction	Empirical average	$	2,141	0	214	59	177	49

Equipment	Empirical average	$	8,923	0	892	245	739	203
Annual depreciation								
Equipment	Empirical average	ha	3.64	665	2,421	665	2,006	551
Total Fixed costs	Per pond				4,494	1,234	3,723	1,022
5. Total costs	Per pond				92,953	25,521	77,022	21,147
Net returns to operator's labor, and management	Per pond				12,174		10,088	
	Per ha				3,343	3,343	2,770	2,770
Breakeven Price	Above variable costs		$/kg		1.95		1.61	
	Above total costs		$/kg		2.04		1.69	
Breakeven Yield	Above variable costs	total	kg		38,249		31,693	
		per ha	kg/ha		10,501	10,501	8,701	8,701
						-	-	-
	Above total costs	total	kg/ha		40,191	11,035	33,303	9,143
		per ha	kg/ha		11,035		9,143	

[a]MT= metric ton

Appendix 3.5

Enterprise budget for the hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) of SPLIT POND system (N=38) (used for partial budget); (area 3.23 ha; stocking density 33,552 /ha; fingerling size 18 cm, feed 45 [a]MT/ha, yield 19,081 kg/ha)

Item	**Description**	**Unit**	**Quantity**	**Price/Cost ($)**	**Total ($)**	**Total ($/ha)**	**Annualized total ($/yr)**	**Annualized ($/ha/yr)**
1. Gross receipts	Premium size	kg	50,430	2.46	124,005	38,397	210,624	65,217
	Undersized fish	kg	8,532	2.34	19,968	6,183	33,916	10,502
	Oversized fish	kg	2,662	2.08	5,532	1,713	9,397	2,910
Total Gross receipts		kg	61,623	2.43	149,506	46,293	253,937	78,629
2. Operating costs							0	0
Feed	28% protein floating	MT	146	442	64,644	20,016	109,797	33,998
Fingerlings	Size: 18 cm	Each	108,359	0.18	19,504	6,039	33,128	10,258
Labor	Owner supplied	$/ha	3.23	772	2,494	772	4,236	1,312
	Extra Feeding labor	hr./ha	3.23	83	3,217	996	5,463	1,692
Chemicals	Empirical average	ha	3	38	123	38	208	65
Gas and diesel	Empirical average	ha	3	228	736	228	1,251	387
Electricity	Empirical average	ha	3	1445	4,667	1,445	7,926	2,454
Repairs and maintenance	Empirical average	ha	3	268	866	268	1,470	455
Bird depredation supplies	Empirical average	ha	3	15	50	15	85	26
Seining & hauling	Empirical average	kg	61,623	0.11	6,779	2,099	11,513	3,565
Telephone	Empirical average	ha	3	26	84	26	143	44
Office supplies	Empirical average	ha	3	28	90	28	154	48
Interest on operating capital		$	86,044	0.10	8,604	2,664	14,615	4,525
Total operating costs					111,857	34,635	189,990	58,828
3. Income Above operating costs					37,649	11,658	63,947	19,800
4. Fixed costs								
Farm insurance	Empirical average	ha	3.23	63	204	63	347	107
Legal/accounting	Empirical average	ha	3.23	15	49	15	84	26
Interest on Investment								
Land	Empirical average	$	6,637	0.10	664	206	1,127	349
Wells	Empirical average	$	1,880	0.10	188	58	319	99
Pond construction	Empirical average	$	11,287	0.10	1,129	350	1,917	594
Equipment	Empirical average	$	39,159	0.10	3,916	1,213	6,651	2,059
Annual depreciation						0	0	0
Equipment	Empirical average	ha	3.23	1,255	4,053	1,255	6,884	2,132

Total Fixed costs			10,203	3,159	17,330	5,366
5. Total costs			122,060	37,794	207,319	64,194
6. Net returns to operator's labor, and management		Per pond	27,446		46,617	
		Per Ha	8,498	8,498	14,434	14,434
Breakeven Price	Above variable costs	$/kg	1.82		1.82	
	Above total costs	$/kg	1.98		1.98	
Breakeven Yield	Above variable costs	kg	46,105	14,276	78,310	24,248
		kg/ha	14,276		24,248	
	Above total costs	kg	50,311	15,578	85,453	26,460
		kg/ha	15,578		26,460	

[a]MT= metric ton

Appendix 3.6

Enterprise budget for the hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) of SPLIT POND system (N=42) (used for partial budget); (area 3.71 ha; stocking density 30,893 /ha; fingerling size 20 cm, feed 42 [a]MT/ha, yield 18,968 kg/ha)

Item	Description	Unit	Quantity	Price/Cost ($)	Total ($)	Total ($/ha)	Annualized total ($/yr)	Annualized ($/ha/yr)
1. Gross receipts	Premium size	kg	58,313	2.46	143,387	38,677	223,387	60,256
	Undersized fish	kg	8,892	2.34	20,812	5,614	32,423	8,746
	Oversized fish	kg	3,115	2.08	6,474	1,746	10,086	2,721
Total Gross receipts		kg	70,319	2.43	170,673	46,037	265,896	71,722
2. Operating costs								
Feed	28% protein floating	MT	154	442	68,190	18,393	106,235	28,656
Fingerlings	Size: 20 cm	Each	114,531	0.22	25,568	6,897	39,833	10,744
Labor	Owner supplied	$/ha	3.71	772	2,863	772	4,460	1,203
	Extra Feeding labor	hr./ha	3.71	83	3,692	996	5,753	1,552
Chemicals	Empirical average	ha	4	38	141	38	219	59
Gas and diesel	Empirical average	ha	4	228	845	228	1,317	355
Electricity	Empirical average	ha	4	1445	5,357	1,445	8,346	2,251
Repairs and maintenance	Empirical average	ha	4	268	994	268	1,548	418
Bird depredation supplies	Empirical average	ha	4	15	57	15	89	24
Seining & hauling	Empirical average	kg	70,319	0.11	7,735	2,086	12,051	3,251
Telephone	Empirical average	ha	4	26	96	26	150	41
Office supplies	Empirical average	ha	4	28	104	28	162	44
Interest on operating capital		$	96,369	0.10	9,637	2,599	15,014	4,050
Total operating costs					125,279	33,793	195,176	52,646
3. Income Above operating costs					45,394	12,244	70,720	19,076
4. Fixed costs								
Farm insurance	Empirical average	ha	3.71	63	234	63	365	99
Legal/accounting	Empirical average	ha	3.71	15	57	15	88	24
Interest on Investment						0	0	0
Land	Empirical average	$	7,619	0.10	762	206	1,187	320
Wells	Empirical average	$	1,880	0.10	188	51	293	79
Pond construction	Empirical average	$	12,957	0.10	1,296	350	2,019	544
Equipment	Empirical average	$	44,951	0.10	4,495	1,213	7,003	1,889
Annual depreciation								
Equipment	Empirical average	ha	3.71	1,255	4,653	1,255	7,249	1,955
Total Fixed costs					11,684	3,152	18,203	4,910

5. Total costs			136,963	36,944	213,379	57,556
6. Net returns to operator's labor, and management		Per pond	33,709		52,517	
		Per ha	9,093	9,093	14,166	14,166
Breakeven Price	Above variable costs	$/kg	1.78		1.78	
	Above total costs	$/kg	1.95		1.95	
Breakeven Yield	Above variable costs	kg	51,616	13,923	80,415	21,691
		kg/ha	13,923		21,691	
	Above total costs	kg	56,430	15,221	87,914	23,714
		kg/ha	15,221		23,714	

[a]MT= metric ton

Appendix 3.7

Enterprise budget for the hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) of IN-POND RACEWAY SYSTEM (N=4) (used for partial budget) (area 0.40 ha; stocking density 9505 /0.40 ha; fingerling size 20 cm, feed 9 [a]MT/0.40 ha, yield 5,985 kg/0.40 ha)

Item	**Description**	**Unit**	**Quantity**	**Price/Cost ($)**	**Total ($)**	**Total ($/ha)**	**Annualized total ($/yr)**	**Annualized ($/ha/yr)**
1. Gross receipts	Premium size	kg	5,357	2.46	13,173	32,551	17,941	44,333
	Undersized fish	kg	570	2.34	1,335	3,299	1,818	4,493
	Oversized fish	kg	57	2.08	119	294	162	400
Total Gross receipts		kg	5,985	2.44	14,627	36,144	19,921	49,226
2. Operating costs								
Feed	32% protein floating	MT	9	473	4,189	10,350	5,705	14,096
Fingerlings	Size: 20 cm	Each	9,505	0.22	2,122	5,243	2,890	7,141
Labor	Owner supplied labor	$/ha	0.40	6,818	2,759	6,818	3,758	9,286
Chemicals	Empirical average	ha	0.40	665	269	665	367	906
Gas and diesel	Empirical average	ha	0.40	333	135	333	184	454
Electricity	Empirical average	ha	0.40	1524	617	1,524	840	2,075
Repairs and maintenance	Empirical average	ha	0.40	1498	606	1,498	826	2,040
Bird depredation supplies	Empirical average	ha	0.40	16	6	16	9	22
Seining & hauling	Empirical average	kg	5985	0.11	658	1,627	897	2,216
Telephone	Empirical average	ha	0.4	26	11	26	14	35
Office supplies	Empirical average	ha	0.40	28	11	28	15	38
2Interest on operating capital	Empirical average	$	9486	0.1	949	2,344	1,292	3,192
Total operating costs					12,332	30,472	16,795	41,501
3. Income Above operating costs					2,296	5,672	3,126	7,726
4. Fixed costs								
Farm insurance	Empirical average	ha	0.40	63.3	26	63	35	86
Legal/accounting	Empirical average	ha	0.40	15.0	6	15	8	20
Interest on Investment							0	0
Land	Empirical average	$	1,174	0.10	117	290	160	395
Wells	Empirical average	$	2,015	0.10	202	498	274	678
Pond construction	Empirical average	$	372	0.10	37	92	51	125
Equipment	Empirical average	$	15,583	0.10	1,558	3,850	2,122	5,244
Annual depreciation							0	0
Equipment	Empirical average	$	0.40	1,571.85	636	1,572	866	2,141
Total Fixed costs					2,582	6,380	3,517	8,690
5. Total costs					14,914	36,852	20,312	50,190

6. Net returns to operator's labor, management, and risk		Per raceway	-287		-390	
		Per ha	-708	-708	-964	-964
Breakeven Price	Above variable costs	$/kg	2.06		2.06	
	Above total costs	$/kg	2.49		2.49	
Breakeven Yield	Above variable costs	kg	5,046		6,872	16,980
		kg/ha	12,468		16,980	
	Above total costs	kg	6,102		8,311	20,536
		kg/ha	15,078		20,536	

[a] MT= metric ton

Appendix 3.8

Live hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) sampling with Mr. Carl Jeffers from USDA, contact farmer, and the author at MS

Appendix 3.9

Live hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀ x blue catfish, *I. furcatus*, ♂) seining before sampling with the author at the surveyed farm in MS