Production and Economic Comparison of Single Versus Multiple Harvests of Hybrid Catfish in a Commercial In-pond Raceway System in West Alabama Targeting Two Market Outlets

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Abstract: This study evaluates the production and economic feasibility of a fixed-floor, in-pond raceway system (IPRS) to supply processor and niche live catfish markets while also highlighting production issues that arose by targeting these two markets. A west Alabama catfish producer grew hybrid catfish (♀ *Ictalurus punctatus x* ♂ *Ictalurus furcatus*) to market size in two production cycles (2012–2013 and 2013–2015). Management and harvest of IPRS-raised catfish changed from production cycle 1 to production cycle 2 due to higher market prices received from niche-live fish market buyers. The high density of fish in the IPRS and the small size of the raceway cells made it easier to frequently harvest small quantities of catfish for niche markets. Small quantities of catfish cannot be harvested efficiently from the large ponds traditionally used in the U.S. farm-raised catfish industry. Catfish processors, being the second market outlet, preferred a single harvest of fish from the raceway cells because they could take large quantities of fish at a time; but they also paid a lower unit price. While the farmer viewed the niche market opportunity as a success, several production issues occurred, including incidences of disease, that reduced survival, growth, and profitability of hybrid catfish raised in the IPRS. Production and net returns varied by year, and even when the producer was receiving a higher fish price from the niche-live fish market buyer than from the processor, overall net returns were greater from the higher survival, lower priced, single harvest catfish production system (processor market) than for the lower survival, higher priced, multiple harvest catfish production system (niche market).

Key words: intensive aquaculture, enterprise budget, net returns, in-pond raceway system

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Most commercial catfish farmers in the southeastern United States sell their fish directly to a processing plant versus smaller niche markets, as it is difficult to harvest small quantities from large traditional levee or watershed ponds. Commercial catfish ponds typically range in size from 3.6 to 10.1 ha, with the average size being approximately 4.1 ha (Steeby et al. 2004). In 2006, 93% of farm-raised catfish in the United States were sold through processing companies (Neira and Quagrainie 2007), and even though U.S. catfish industry production declined sharply between 2003 and 2011, the percent of sales to processors was still 96% in 2017 (USDA-NASS 2018). Processing companies can set the terms of trade (Neira and Quagrainie 2007), but their ability to purchase large quantities of fish at a time and close proximity to local farms make it convenient for farmers to sell their product. A limitation of pursuing niche marketing is that these markets require more effort and time to develop (Wiese and Quagrainie 2006) as well as it is more difficult to sustain production systems in which small quantities of fish can be frequently and easily harvested.

Due to fluctuations in the supply and demand for catfish, farm-gate prices do not always keep up with changes in production costs and often fluctuate widely (Hanson and Sites 2015). Competition from foreign imports has compounded the problem by keeping the wholesale price of fresh/frozen catfish low at the processor level, leading to lower prices paid to U.S. producers for their live fish. While the processor is by far the largest market outlet available for the U.S. catfish producer, there are also alternative niche markets. These include recreational pond owners, fee-fishing establishments, retail fish outlets, direct sales to consumers, live hauling companies, and other catfish producers. Fish buyers selling to niche markets often pay fish producers a higher price than processors will pay (Swann and Reipe 1994, Young et al. 1999, Quagrainie 2006, Neira and Quagrainie 2007, Dasgupta and Durborow 2009, Quagrainie et al. 2011).

In recent years, in order to increase efficiency and maximize production, the U.S. catfish industry has been testing a number of alternative pond-based production systems including in-pond

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raceway systems, split ponds, and intensively-aerated ponds (Brown et al. 2011, Bott et al. 2015, Kumar et al. 2016, Kumar and Engle 2017, Kumar et al. 2018). In-pond raceway systems (IPRS) are alternative intensive pond-based production systems that are effectively a culture system housed within a pond. Each IPRS consists of individual raceway cells and commercial varieties typically vary from systems containing from one to six raceways cells. Fish are stocked into the IPRS raceway cells and typically the rest of the pond serves as a waste treatment unit (Brown et al. 2011). The use of the IPRS allows for more control of the production cycle by confining cultured fish in a smaller volume of water compared to a traditional pond that facilitates feeding, chemical treatment, and inventory control, but also compounds risk due to high biomass densities involved (Roy and Brown 2016). Commercial farmers have tested both "fixed-floor" and "floating" prototypes of IPRS. Fixed-floor IPRS typically have poured concrete bottoms, whereas floating raceways are simply attached to large floats in the pond with thick plastic liners on the bottom and sides. Although fixed-floor IPRS are more expensive to construct, they typically are more robust in design than floating varieties.

The IPRS is considered intensive production, allowing for both large- and small-scale marketing of catfish (Mattei 1994, Brown et al. 2011, Brown et al. 2014). Since the development of the first commercial-scale IPRS in Alabama (Brown et al. 2011, Brown et al. 2014), there has been little adoption of these systems by the U.S. catfish industry (Roy and Brown 2016). The design of the IPRS makes harvest of small amounts of fish feasible from the standpoint of labor, time, and cost. Because fish are confined to raceway cells that are easily crowded and harvested, labor costs are substantially reduced compared to harvesting larger traditional levee or watershed ponds. This reduction in labor cost has made it feasible to harvest smaller amounts of catfish on a weekly basis to supply niche market demand for smaller quantities of live fish. The IPRS farm used in this study previously had originally developed niche markets for Nile tilapia (*Oreochromis niloticus*) raised in an indoor recirculating facility; subsequently, the farm began supplying those same markets with live catfish grown in an outdoor IPRS. Wholesale meat and fish companies indicated that "one stop shopping" for a variety of fish products from a single producer was desirable (Brown et al. 2011, 2014); IPRS farmers noted this strategy was a factor that created conditions for profit (Brown et al. 2011, 2014).

In order to obtain a higher price for its product, one farm in west Alabama developed an alternative niche live market for catfish within the Asian grocery store community in the southeastern United States, supplying it exclusively with hybrid catfish (♀ *Ictalurus punctatus x* ♂ *Ictalurus furcatus*) produced in an IPRS. Asian niche markets typically do not require an off-flavor check, required by most large catfish processors, making Asian niche markets desirable to some producers. For two production seasons at the participating farm, catfish produced in the IPRS were sold weekly to Asian markets and other niche markets located in multiple states. In 2012–2013, more than half of the fish produced in the IPRS were sold to niche markets and the rest were sold to a large-scale processor. In 2013–2015, this same farm expanded its niche market sales to local recreational lake owners and pond stocking companies; all harvested raceway cells were sold to these markets.

Despite the expansion of the U.S. catfish niche market, few studies have evaluated the economic feasibility of this approach compared to selling to traditional processor markets. The objectives of this study were to 1) monitor sales of IPRS catfish production to niche markets (frequent small harvests) and a processor market (single harvest per year), and 2) to evaluate the production and economic feasibility of these two different approaches.

Methods

Hybrid catfish fingerlings were stocked in an IPRS in western Alabama for two production cycles. The IPRS was housed in a 2.43-ha earthen pond with a mean depth of 1.7 m and supplied by well water and watershed runoff. A complete description of the IPRS system is provided in Brown et al. (2011). Briefly, the IPRS consisted of six individual raceway cells that shared common cement block walls that were attached to a permanent concrete foundation and represented only 0.9% of the total pond area (Figure 1). Fish were confined in raceway cells (45.9 m^3) by end partition screen barriers that spanned the width of each raceway cell. Water flow into the raceway cells was supplied by a rotating paddlewheel and was exchanged in each raceway cell approximately every 5 min. Water flowed from raceway cells into the north side of the pond, moved counterclockwise to the south side of the pond, and returned to the inflow side of the raceways. A central baffle wall extended from the raceway system into the pond to assure water circulated in a long pathway to allow more time for organic matter oxidation and breakdown (Figure 1). Further, a 1.2-kW regenerative blower (Sweetwater, Pentair Aquatic Ecosystems, Inc., Apopka, Florida) equipped with a diffuser grid was placed in each raceway cell to aerate water and mix dissolved oxygen (DO) throughout the water column to maintain DO levels in a desirable range (>5.0 mg L^{-1}) in the raceway cells. An additional 7.5-kW paddlewheel aerator (Stillwater Machine, Newbern, Alabama) was deployed over the deepest portion of the pond to destratify, aerate, and mix water throughout the water column and help maintain flow around the pond.

Temperature and DO were monitored four times per day in each raceway cell throughout the trial using an automated system

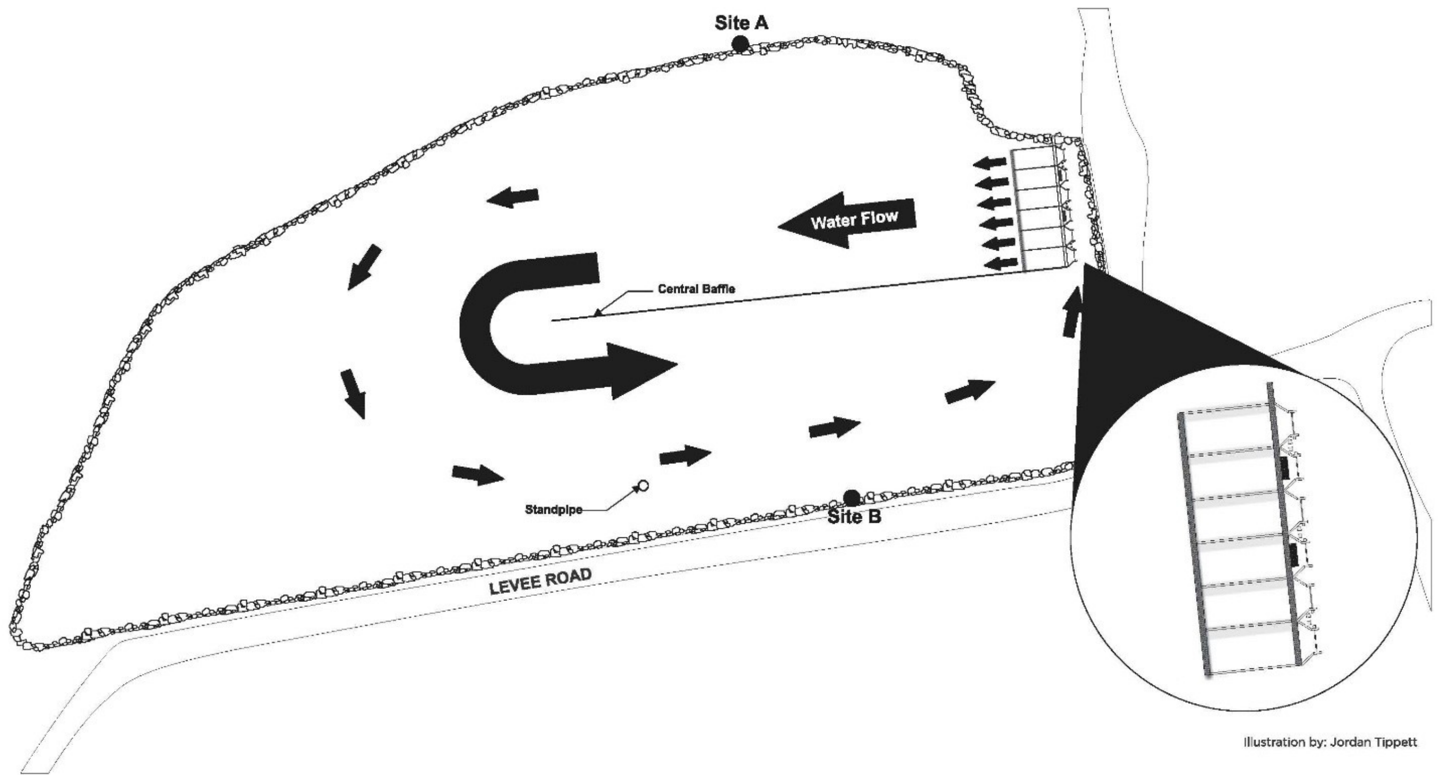

Figure 1. View of the west Alabama in-pond raceway system and its scale relative to the entire pond. The raceway cell production area was 0.02 ha of the 2.43-ha pond area. Site A and Site B denote the locations where water quality was taken in the pond throughout the trial.

(In-Situ, Fort Collins, Colorado). Total ammonia nitrogen and nitrite nitrogen were assessed biweekly according to Nessler's method (APHA et al. 1989) and Parsons et al. (1985), respectively, and pH was also monitored biweekly (Pinpoint pH Monitor, Pentair Aquatic Ecosystems, Lake Apopka, Florida). Chloride, total alkalinity, and total hardness were monitored monthly throughout the trial in each raceway cell according to APHA methods (APHA et al. 1989). In addition, water quality in the pond was also monitored at two different locations.

In this study, disease and parasite treatments were administered on an as-needed basis, which was dependent on temperature. Potassium permanganate applications (2.5–5.0 mg L^{-1}) lasting 0.5–1.0 h were used to treat for parasites (*Trichodina* sp.) following Brown et al. (2011). Application of these treatments required reducing the water flow through the individual raceway cell by turning off the paddlewheel and hanging a barrier at each end to keep the chemical within the raceway cell (Bott 2015). A large tarp with a weighted piece of 2.5 cm rebar was temporarily lowered in front of the back barrier of each raceway cell to block water from exiting during the administration of the chemical treatment. Farm personnel were present during treatments to monitor fish and quickly remove the barriers and restart the paddlewheel water flow if fish became stressed and/or DO levels dropped below 4 mg L^{-1}. Copper sulfate (1 ppm) and diuron (10 ppb) treatment concentrations were administered for algal bloom control according to label instructions based on water alkalinity levels for the entire volume of the IPRS and the pond in which it was housed. Copper sulfate and diuron are pond-level treatments, hence the entire pond was treated taking into account the volume of water within the IPRS.

Production Cycles

Hybrid catfish fingerlings were obtained from a commercial supplier in Mississippi (Jubilee Farms, Indianola, Mississippi, see Table 1 for catfish size/weight definitions, USDA-NASS 2018). Varying hybrid catfish fingerling and stocker catfish sizes were stocked separately into raceways in 2012 (production cycle 1) and 2013 (production cycle 2) (Table 2). Initial stocking densities ranged 9,727–12,778 fish per raceway cell, but one raceway cell during production cycle 2 was stocked with 30,194 fish (Table 2). The high stocking density of this particular raceway cell was used to accommodate extra fish that the cooperating farmer had available. During production cycle 1, four raceway cells produced fish for the trial. Two of the raceways cells were utilized to supply niche markets (raceway cell 1 and 3), and catfish from raceway cells 2 and 4 were sold directly

Table 1. Enterprise budgeting and catfish production terms.

Enterprise budget—a projection of all the costs and returns for a single enterprise
Output—items produced from a production cycle, such as catfish pounds produced in a year
Input—items required to produce a product, such as feed, fingerlings, fuel, chemicals, labor, etc.
Outlet type—buyers of a product; in this case, either a processor or niche buyer
Gross receipts—the value or sales of production during a specified production period; it is calculated using kilograms produced multiplied by the selling price
Production or variable or cash costs—inputs with associated unit cost multiplied by the quantity of that input provided during the production cycle
Interest on operating costs—the charge for borrowed money to cover purchasing inputs during a production cycle; it is calculated by summing the variable costs and multiplying by the interest rate
Income above variable costs—an indicator of short-term profitability; it is calculated by subtracting variable costs from gross receipts. When the result is positive, all cash costs are covered, and when negative, the enterprise should be shut down immediately to avoid further financial losses
Fixed costs—costs incurred whether production takes place or not. These include depreciation, interest on medium- and long-term loans, farm repairs and maintenance, taxes, and insurance. Calculation of these items take into account time in the form of "economic life" of the machinery and equipment so the entire cost is not put into one single year but spread over many years.
Total costs—variable and fixed costs added together
Net returns to land, management, and capital—an indicator of long term profitability; calculated by subtracting total costs from gross revenue. It is a return to the land, labor, and capital factors of production that were not expensed within the variable and fixed costs sections of the enterprise budget
Cost per kg—the value or cost total divided by the kilograms of catfish produced in the individual raceway cell provides a breakdown of expenditures on a line item basis, which, when added up, provides a cost to produce a kilogram of fish. This is useful in comparing to the received price ($/kg) to quickly know if costs exceed receipts or not
Terms and definitions used for catfish production estimates (USDA-NASS 2018)
Net yield—total yield minus weight stocked
Feed conversion ratio (FCR)—the ratio of feed fed to weight gained
Fingerling—catfish weighing 0.9 to 27 g or 5 to 15 cm in length fingerlings
Foodsize (large)—fish weighing over 1.36 kg
Foodsize (medium)—fish weighing over 0.68 kg to 1.36 kg
Foodsize (small)—fish weighing over 0.34 kg to 0.68 kg
Fry—fish weighing less than 0.907 g or less than 5.08 cm in length
Stockers (large)—fish weighing over 81.6 g to 340.2 g
Stockers (small)—catfish weighing between 27.2 –81.6 g

to the processor. Three of the four raceways cells were stocked with large stocker sized fish (Raceway cells 1, 2, and 4) and the remaining raceway cell (3) was stocked with smaller fingerlings (Table 2). Following positive results from production cycle 1 and expansion of the farmer's niche market buyers, production cycle 2 utilized five raceway cells to produce fish exclusively for niche markets.

The grow-out phase was conducted for 10–19 months depending on initial fish size, stocking density, and whether fish were going to a processor or to niche markets. Fish destined for niche markets were grown and held in raceway cells for longer periods than fish going to the processor to provide smaller quantities of fish over a longer period. Fish were fed a commercial, floating feed (32% protein, Alabama Feed Mill, Uniontown, Alabama) two to four times per day based on biomass and water temperature. Due to the ease of harvest, a range of sizes was sold based on buyer demand and fish destined for the niche market were harvested throughout the study (Table 2). Research and extension personnel tracked production inputs and outputs, water quality, disease incidents, fish losses, and associated costs. The farmer carried out management of the IPRS and coordinated stocking and harvest events as well as daily feeding and other routine husbandry activities. At the end of each production cycle and complete harvest of each raceway cell, gross yield, net yield, food conversion ratio (FCR), and average weight were determined (Table 1).

Economic Analysis

Production data and variable inputs were used to calculate associated operating (variable) costs directly from farmer records compiled for both production cycles (see Table 1 for a list of enterprise budgeting terms). This was done for nine completed IPRS

Table 2. Production data for each raceway cell of an in-pond raceway system managed for niche and processor (Proc) markets over two production cycles.

	Production cycle 1				Production cycle 2				
Raceway cell	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**5**
Market outlet type	Niche	Proc	Niche	Proc	Niche	Niche	Niche	Niche	Niche
Production period (months)	12	10	11	10	19	19	12	19	16
Weight stocked (kg)	2,200	2,236	653	2,041	769	613	689	1,902	755
Number stocked	12,570	12,778	12,424	11,664	12,209	9,727	10,937	30,194	11,977
Mean weight at stocking (g)	175	175	49	175	63	63	63	63	63
Number of harvests	24	1	3	1	9	17	11	14	17
Total harvested (kg)	5,750	7,493	5,027	7,771	3,100	3,284	3,161	7,551	2,685
Mean weight at harvest (kg)	0.6	0.7	0.4	0.7	0.6	0.6	0.5	0.5	0.7
Net yield (kg)	3,550	5,257	4,418	5,730	2,331	2,671	2,472	5,649	1,930
Survival (%)	75	86	95	92	44	57	57	48	31
Total feed used (kg)	8,832	9,397	5,482	9,028	5,874	5,972	6,311	11,032	7,511
FCR[a]	2.49	1.79	1.25	1.58	2.52	2.23	2.55	1.95	3.88

a. FCR = Food Conversion Ratio

catfish raceway cells from 2012–2015 (final harvest for three cells was in January 2015). Standard farm management techniques were used to develop enterprise budgets for comparative analyses between raceway cells (Engle 2010, Kay et al. 2016). Because IPRS are relatively new, the budget analysis was conducted on a raceway cell-by-cell basis to show detailed results and variability of these systems. In this manner, results can be used as a guide to what other producers might expect to achieve from this type of IPRS system geared toward single or multiple harvests. There are scant detailed budget analyses available in the literature for a fixed floor IPRS system being used commercially (but see, for example, Brown et al. 2011, Brown et al. 2014, Kumar et al. 2018). Data were tracked for specific expenditures as they occurred. Farm records (feed, chemical treatments, PTO tractor usage) were collected monthly, and weekly visitation by research personnel allowed record keeping questions or obstacles to be addressed quickly.

Specific parameters measured for calculating total production costs included quantity and price of fish sold and quantity and price of purchased inputs, specifically feed, fingerlings, chemicals, electricity, fuel, harvest/transport, management/labor, and interest on operating costs (Engle 2010, Kay et al. 2016). Fixed costs included depreciation on the pond and machinery, land taxes, and interest on pond construction loans (as originally presented by Brown et al. 2014). In our raceway cell-by-cell analysis, the fixed costs of Brown et al. (2014), were divided by six (the number of raceway cells in this IPRS unit) to provide the fixed cost for an individual raceway cell and for use in individual raceway cell budget development. Fish sale prices from the processor and niche buyers varied, with a higher price received from the niche buyers. Sale prices from the processor was set at the time of the harvest. Niche buyers paid varying amounts at each purchase, but we used a weighted average price to combine all partial harvests for each raceway cell's analysis. Feed costs were calculated based on the bulk feed price for the year and quantity of feed fed for each raceway cell using producer records. After variable and fixed expenses were subtracted from the gross receipts, a net return to land, management and capital was calculated for each raceway cell to compare among each production cycle and outlet type, i.e., to either the processor or niche market buyers (Engle 2010, Kay et al. 2016).

All receipt and expenditure data from each production cycle were condensed into line-item categories and summarized into raceway cell-by-cell enterprise budgets that calculated sales, itemized variable costs, income above variable cost (an indicator of short term profitability), fixed costs, total costs, and net return above all costs (an indicator of long-term profitability). See Table 1 for an explanation of enterprise budgeting terms.

Results

Cycle 1—Production and Economics

Water quality remained acceptable throughout the production cycle in the raceway cells (Table 3). The two cells managed for the single harvest sold to processors (raceway cell 2 and 4) had fish survival of 86% and 92%, respectively, during the first production cycle (Table 2). All fish were harvested after 10 months following stocking. Net yields were 5,257 and 5,730 kg raceway cell^{-1} and FCRs were 1.79 and 1.58, respectively (Table 2). Catfish harvested from raceway cells 2 and 4 were sold to the processing plant at US\$1.87 and \$1.90 kg^{-1}, respectively (Table 4). The two raceway cells managed for multiple harvests sold to niche markets (raceway cell 1 and 3) had fish survival of 75% and 95%, respectively. All fish were harvested after 11–12 months following stocking; net yields were 3,550 and 4,418 kg raceway cell^{-1}, respectively, and FCRs were 2.49 and 1.25, respectively (Table 2). Fish from both raceway cells were sold for 2.54 kg^{-1} (Table 4).

Production cycle 1 enterprise budgets indicated positive net returns for the two raceway cells (2 and 4) that were managed for a single harvest and sold to a single processing company (Table 4). Greater gross receipts were obtained from these two raceway cells than for the two raceway cells sold to niche buyers due to greater harvest total yield, better survival rates, and better FCR levels (Tables 2 and 4). The variable cost of production of raceway cells 2 and 4 were \$1.32 kg^{-1} and \$1.21 kg^{-1}, respectively; these costs included a charge for harvesting and processing services provided by the processor-hired crew. Fixed costs per kg of fish produced were rela-

Table 3. Water quality variables measured during two production cycles of an in-pond raceway system used to supply catfish to niche and processor markets.

	Total ammonia nitrogen (mg L^{-1})	Total nitrite nitrogen (mg L^{-1})	pH	Chlorides (mg L^{-1})	Total alkalinity (mg L^{-1})	Total hardness (mg L^{-1})
Production cycle 1						
Raceway cells	1.45 ± 1.04	0.11 ± 0.09	8.28 ± 0.36	270.0 ± 81.3	148.6 ± 15.7	80.2 ± 18.2
Pond	1.68 ± 1.41	0.11 ± 0.09	8.30 ± 0.37	266.2 ± 83.9	147.9 ± 15.0	81.7 ± 18.4
Production cycle 2						
Raceway cells	1.02 ± 0.59	0.09 ± 0.10	8.41 ± 0.44	176.2 ± 82.9	116 ± 25.01	83.7 ± 23.7
Pond	1.1 ± 0.80	0.09 ± 0.08	8.59 ± 0.54	176.8 ± 71.1	113.2 ± 23.2	87.9 ± 30.2

Table 4. Summary enterprise budget for the IPRS production cycle 1, 2012–2013. Niche market sales came from raceway cells 1 and 3, while processor sales came from raceway cells 2 and 4. All values are in $US.

	Raceway cell 1		Raceway cell 2		Raceway cell 3		Raceway cell 4	
	Value or cost	Cost per kg	Value or cost	Cost per kg	Value or cost	Cost per kg	Value or cost	Cost per kg
Gross receipts								
Catfish sales	13,126	2.54	14,042	1.87	11,696	2.54	14,747	1.90
Variable costs								
Feed	4,160	0.80	4,427	0.59	2,582	0.56	4,253	0.55
Labor and management	1,450	0.28	1,208	0.16	1,329	0.29	1,208	0.16
Fingerlings	3,042	0.59	3,092	0.41	1,743	0.38	2,823	0.36
Harvest and transport	421	0.08	421	0.06	421	0.09	421	0.05
Aeration, electrical	91	0.02	91	0.01	91	0.02	91	0.01
Chemicals	152	0.03	182	0.02	150	0.03	182	0.02
Interest on operating capital	483	0.09	436	0.06	332	0.07	418	0.05
Total variable costs	9,799	1.89	9,857	1.32	6,648	1.44	9,396	1.21
Income above variable costs	3,327	0.64	4,185	0.56	5,048	1.09	5,351	0.69
Fixed costs								
Depreciation on capital items	840	0.16	840	0.11	840	0.18	840	0.11
Depreciation on equipment	1,120	0.22	1,120	0.15	1,120	0.24	1,120	0.14
Interest on capital loans	606	0.12	606	0.08	606	0.13	606	0.08
Interest on equipment loans	393	0.08	393	0.05	393	0.09	393	0.05
Repairs and maintenance	429	0.08	429	0.06	429	0.09	429	0.06
Total fixed costs	3,388	0.65	3,388	0.45	3,388	0.73	3,388	0.44
Total of all costs	13,187	2.55	13,246	1.77	10,037	2.18	12,785	1.65
Net return above all costs	–61	–0.01	796	0.11	1,659	0.36	1,962	0.25

tively low at $0.45 and $0.44 for raceway cells 2 and 4, respectively.

The raceway cells used for the niche market outlets were partially harvested 27 times, but still resulted in lower overall yield of fish harvested than the raceway cells managed for a single harvest and sold to the processor (Table 4). Even at higher selling prices than those received from the processor, the reduced quantity produced and sold to niche market buyers led to lower overall net returns. Net returns were negative for raceway cell 1 due to lower survival and higher FCR but raceway cell 3 had the highest net return due to an extremely good FCR and high survival (Table 4). Net returns for the two raceway cells sold to processors were intermediate to the two extremes observed for the niche-market raceway cells.

Cycle 2—Production and Economics

Water quality remained acceptable throughout the second production cycle in the raceway cells (Table 3). All five raceway cells in the second production cycle were managed for multiple harvests and sales to niche market buyers. During the second production cycle, several incidences of disease occurred in the raceway cells, including virulent *Aeromonas hydrophila*, enteric septicemia of catfish (*Edwardsiella ictaluri*), and columnaris (*Flavobacterium columnare*). Disease mortalities ranged from 31%–57% and drastically reduced net yields (range: 1,930–5,649 kg raceway cell^{-1}), FCR (range: 1.95–3.88), and subsequent profitability of production cycle 2 (Tables 2 and 5). In addition, the cycle 2 production period was longer compared to cycle 1. This extension was to accommodate niche market sales that required small quantities weekly and thus prolonged the overall production and holding period.

All sales in production cycle 2 were to niche live markets, including sales of stockers to recreational pond owners and larger food-size fish to fee fishing operations and Asian markets, resulting in a sales price ranging from $2.20 kg^{-1} to $3.85 kg^{-1} (average $2.87 kg^{-1}). This range depended on whether or not the fish were picked up on site by the customer or delivered by the farm. In year 1 when catfish from two of the raceway cells were sold to processors, the processors brought their own seining/harvesting crew and a per unit weight cost was charged; however, in year 2 when sold to direct buyers, the farm crew provided the labor and no additional charge was required as the farm crew were covered under the "Labor" heading. Thus, we accounted for harvest and transport charges for year 1

Table 5. Summary enterprise budget for the IPRS production cycle 2, Alabama 2013–2015. Niche markets sales came from all raceway cells in production cycle 2.

	Raceway cell 1		Raceway cell 2		Raceway cell 3		Raceway cell 4		Raceway cell 5	
	Value or cost	Cost per kg	Value or cost	Cost per kg	Value or cost	Cost per kg	Value or cost	Cost per kg	Value or cost	Cost per kg
Gross receipts										
Catfish sales	8,884	2.87	9,411	2.87	9,058	2.87	21,641	2.87	7,695	2.87
Variable costs										
Feed	2,833	0.91	2,880	0.88	3,044	0.96	5,320	0.70	3,623	0.61
Labor and management	2,296	0.74	2,296	0.70	1,450	0.46	2,296	0.30	1,933	0.33
Fingerlings	2,720	0.88	2,055	0.63	2,436	0.77	6,726	0.89	2,668	0.45
Harvest and transport	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Aeration, electrical	144	0.05	144	0.04	144	0.05	144	0.02	144	0.02
Chemicals	214	0.07	259	0.08	258	0.08	258	0.03	229	0.04
Interest on operating capital	574	0.19	534	0.16	513	0.16	1,032	0.14	602	0.10
Total variable costs	8,781	2.83	8,169	2.49	7,846	2.48	15,776	2.09	9,199	1.55
Income above variable costs	103	0.03	1,242	0.38	1,213	0.38	5,865	0.78	–1,504	–0.25
Fixed costs										
Depreciation on capital items	840	0.27	840	0.26	840	0.27	840	0.11	840	0.31
Depreciation on equipment	1,120	0.36	1,120	0.34	1,120	0.35	1,120	0.15	1,120	0.42
Interest on capital loans	606	0.20	606	0.18	606	0.19	606	0.08	606	0.23
Interest on equipment loans	393	0.13	393	0.12	393	0.12	393	0.05	393	0.15
Repairs and maintenance	429	0.14	429	0.13	429	0.14	429	0.06	429	0.16
Total fixed costs	3,388	1.09	3,388	1.03	3,388	1.07	3,388	0.45	3,388	1.26
Total of all costs	12,169	3.93	11,557	3.52	11,234	3.55	19,164	2.54	12,588	4.69
Net return above all costs	–3,285	–1.06	–2,146	–0.65	–2,176	–0.69	2,477	0.33	–4,893	–1.82

processor sales but not for year 2 niche buyer sales (Table 5). Costs of production varied among raceway cells and were influenced by low survival and high FCR. Four of the five raceway cells in cycle 2 had positive incomes above variable costs, but after including fixed costs they had negative net returns (Table 5). These four raceway cells had FCRs above 2.0 and had negative net returns ranging from \$–0.65 kg^{-1} to \$–1.82 kg^{-1}; the raceway cell with the best FCR (1.95) had a positive net return above all costs (\$0.33 kg^{-1}).

The combined total for the five raceway cells had an average variable cost of \$2.52 kg^{-1}, an average total cost of \$3.37 kg^{-1}, and an average net return of \$–0.51 kg^{-1} (Table 5). In order to supply niche markets catfish were graded and hand selected by the farmer routinely, and this caused a great amount of stress to the fish remaining in the cell. The five raceway cells were partially harvested a total of 68 times during the production cycle.

Discussion

Early research on IPRS in the 1990s encountered some issues with disease outbreaks (Masser 2004), some of which resulted in hybrid catfish survival as low as 54% (Hawcroft 1994, Bernardez 1995, Martin 1997). A more recent trial (2008) using the same IPRS as in our study showed higher survival rates (83%) and yields (20,540 kg ha^{-1}) than those we observed (Brown et al. 2011). Holland (2016) reported survival rates ranging from 75% for channel catfish to 91.5% for hybrid catfish; Fullerton (2016) reported survival rates ranging from 47%–69%. These research projects were conducted in a floating IPRS and experienced issues with disease during the production cycle (*Flavobacterium columnare* and *Aeromonas hydrophila*). For perspective, traditional pond production of catfish produces between 6,843–7,527 kg ha^{-1} (Courtwright 2013), and in more intensive, highly-aerated pond systems catfish production is between 6,862–14,748 kg ha^{-1} with survival ranging between 51%–91% (Bott et al. 2015).

There were a number of disease outbreaks in the second production cycle of our study that contributed to suboptimal production and net returns, resulting in poor production and profitability. Incidences of disease in the smaller confined fish culture cells of the IPRS was problematic and in some cells catastrophic. While densities utilized in this study were similar to those reported in other IPRS studies (Brown et al. 2011, Fullerton 2016, Holland 2016), when catfish were partially harvested on a weekly basis, crowding of fish in the raceway cells during harvest likely increased scrapes, cuts, and punctures of remaining catfish, thus increasing the ease of bacterial disease entry (Brown et al. 2011, Fullerton 2016, Holland 2016). Although the farmer often drew fish from different raceways on each occasion, individual cells were harvested up to a dozen times or more in a year to meet the demands of the particular niche market buyer (68 total harvests in the 5 raceway cells in production cycle 2). In order to satisfy recreational markets, catfish were often hand selected following grading, which imposed additional stress on remaining catfish. Thus, using an IPRS to serve this niche market subjected catfish to more frequent handling stress compared to a multiple-batch production cycle, which has typically one to three partial harvests per year. Hence, even though the producer was receiving a higher fish price from the niche market buyer (lower survival-higher priced fish), the overall net return was greater when selling to a processor (higher survival-lower priced fish).

Diseases can spread quickly in confined IPRS systems and need to be treated immediately. A survey of farmers utilizing IPRS from 2008 to 2013 in Alabama revealed that 79 diagnostic cases were reported from five different IPRS units on three farms, with the majority of disease cases being *Flavobacterium columnare* and *Edwardsiella ictaluri* (Roy et al. 2013). Disease protocols and treatment regimens need to be developed and further refined by researchers and extension personnel if IPRS systems are to be adopted by the U.S. catfish industry. Commercial catfish farmers are unaccustomed to managing diseases in these systems. The disease issues encountered by catfish farmers using IPRS are perhaps the primary reason these systems have not been widely adopted by the U.S. catfish industry (Roy and Brown 2016). While research studies at Auburn University, Alabama, have demonstrated some success in managing diseases in IPRS, this success has not yet translated to the commercial industry. This is in contrast to other alternative production systems such as split-pond systems and intensively aerated pond systems, where the management paradigm for treating diseases is similar to what farmers are accustomed to when raising fish in traditional earthen ponds.

The IPRS systems typically perform best when fish are fed multiple times per day. Production with an IPRS used to culture catfish was best achieved when feeding 2–4 times per day using an automated bin-auger-hopper feeding system that allowed for a more controlled feed application (Brown et al. 2011). In contrast, using alternative intensive production systems, such as split ponds and intensively aerated systems, farmers can achieve adequate production by feeding fish once daily, similar to traditional pond production systems. In our study, fish were not always fed at rates typical of a food-fish producer because the goal of the farmer was to provide a steady supply of fish that were routinely graded to meet the market size requirements of the customers. Furthermore, not all of the fish were harvested at the same time, thus the production cycles were longer. This is in contrast to the goal of most farmers using traditional earthen pond production systems or other alternative intensive production systems that feed at higher rates to shorten the production cycle (Bott et al. 2015).

In summary, IPRS can be effective culture systems for supplying processors and niche markets with live fish in the U.S. but farmers utilizing these systems must learn how to manage adverse issues affecting catfish production in these systems. The large size of most traditional catfish ponds in the U.S. (>3 ha) makes partial harvest for small quantities of fish impractical, time consuming, labor intensive, and costly. Weekly harvest of small amounts of fish from an IPRS can allow catfish producers to obtain higher prices for their product by targeting niche markets. Despite the production problems with the IPRS noted in this paper, the study farm was satisfied with the ability of the IPRS to facilitate a steady supply of catfish for an alternative niche market, and complement existing sales of Nile tilapia (*Oreochromis niloticus*). However, since this study the farm is exclusively utilizing the IPRS to supply niche markets with tilapia and is not having the same disease issues observed when raising catfish in this system.

The IPRS system appeared to perform best when production cycles were short, such as when larger stocked fingerlings or stockers were used and grown with few harvest events. The IPRS system performed less well when the production cycle was prolonged to provide smaller quantities of catfish frequently harvested to meet the needs of niche market buyers over a longer period, because the longer cycle resulted in greater mortalities and higher FCRs. Profitability, as measured by developed raceway cell-by-cell enterprise budgets, followed the pattern of survival and affected FCR; i.e., positive net returns occurred when higher survival rates and lower FCR levels occurred.

While there is potential for IPRS to supply food fish to niche markets, further research is needed on the IPRS system, particularly in the area of disease prevention and management. Specifically, improved protocols for managing fish health in intensive IPRS with numerous partial harvests need to be investigated and management procedures refined to take advantage of live fish niche marketing opportunities. Until these production issues are addressed through research and demonstration, it is unlikely U.S. catfish farmers will adopt the IPRS using a niche buyer approach. However, fish raised for the traditional processor market did result in a positive net return situation.

The supply of live niche markets using traditional earthen pond production schemes for catfish is problematic due to costs associated with labor and the small amounts of product being purchased by niche market buyers compared to fish processors. While the use of IPRS to supply small niche markets is an approach being investigated by a limited number of producers, further work is needed to validate this approach with catfish. The current price structure facing the U.S. catfish industry and the low prices being received do not appear to offset the production costs associated with using this particular system to supply live niche market outlets. A small number of farmers are exploring the use of IPRS to raise alternative species with a more attractive price point, such as tilapia, for niche markets as a forage fish for recreational pond owners or as a food fish for live Asian markets.

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