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Case Report

Bioeconomic Analysis of In-Pond Raceway System Production of Foodsize and Stocker Hybrid Catfish (Channel Catfish *Ictalurus punctatus* ♀× Blue Catfish, *I. furcatus* ♂)

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Abstract: The U.S. catfish industry is seeking production systems that are efficient, intensive, and profitable. Growing foodsize and stocker-sized fish in the same pond is attractive as it is often difficult to obtain larger-sized stockers early each year. This case study evaluated the performance and economics of producing foodsize hybrid catfish and stocker-sized fingerlings in in-pond raceway systems (IPRS) placed into four 0.4 ha ponds. Growout raceways (RW1/RW2) in ponds 1 and 2 were 63 m^3, and 45 m^3 in ponds 3 and 4 (RW3/RW4). Each pond had one (14 m^3) stocker unit raceway and a 5 HP of aeration that maintained adequate dissolved oxygen levels. Average growout production was 12,050 kg/ha in 63 m^3 raceways and 12,078 kg/ha in 45 m^3 raceways (228 days of production) and achieved harvest weights ranging from 564 to 661 g. The raceway stocker unit had production yields ranging from 3537 to 4388 kg/ha (143 days of production) and achieved harvest weights ranging from 123 to 234 g. Stocker units in ponds 1 and 2 generated 8540 stocker–fingerlings (21,102 fingerlings/ha) and units in ponds 3 and 4 generated 7954 fingerlings (19,654 fingerlings/ha). An investment of USD 39,996 was needed for ponds 1 and 2 and USD 21,196 for ponds 3 and 4. When scenarios were analyzed financially, positive financial net returns occurred when farm level investment decreased, leading to reduced payback periods, increased net present values, and higher internal rates of return. IPRS used stocker units to culture fingerlings for future stocking of foodsize fish. IPRS provided good inventory control, and high production yields compared to traditional pond culture of catfish.

Keywords: channel catfish; enterprise budgeting; high density; performance; profitability; sensitivity analysis

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1. Introduction

Estimated freshwater and marine aquaculture production in the United States (U.S.) was 298,000 metric tons valued at USD 1.5 billion in 2020 [1]. In the same year, freshwater U.S. aquaculture production was primarily composed of catfish (164,000 metric tons, 56%), crawfish (101,000 metric tons, 34%), and trout 30,000 metric tons, 10%) [1]. Farm-raised catfish processed in the U.S. was 146,000 metric tons in 2022 [2]. The top four states, Mississippi, Alabama, Arkansas, and Texas produced 205,000 metric tons (97% of all catfish produced in the U.S. in 2022) [3]. Channel catfish (*Ictalurus punctatus*) and hybrid catfish (channel catfish *I. punctatus* ♀× blue catfish, *I. furcatus* ♂) production represents 53% and 47%, respectively, of the total U.S. catfish production [4].

The dynamics and drivers of the various periods of growth, contraction, and recovery of catfish production offer important lessons for other segments of U.S. and global aquaculture [5]. Numerous innovations in the aquaculture sector were credited to the U.S. catfish industry, including improved aeration technologies [6], production systems, and practices, genetic improvement, and nutritionally balanced feed formulations [7]. The U.S. catfish industry is one of the few industries that successfully navigated the treacherous and often painful causeway of a maturing industry. Regardless, fish farmers continue to face problems with high production costs relative to sales price (i.e., low profit margin). High costs occur because fish produced in traditional ponds experience predation by birds [8], expensive disease treatments [9,10], inefficient feed conversions [4,11], and difficulty in knowing and controlling fish inventories [12,13]. There is a continued need for the U.S. catfish industry to develop and adopt more efficient and profitable production technologies.

Economists engage with farmers to understand the on-farm realities and base economic research on data collected from farms, research verification trials, and pond production trials, rather than models based on hypothetical situations and assumptions. This is essential to provide adequate information for farmers to make good decisions on technologies and management that will work best on their farms [8,14–16].

The in-pond raceway systems (IPRS) consist of a rectangular raceway/cage placed into an existing pond with high aeration, which makes the water move throughout the pond and raceway. This system allows for more control of the production cycle by confining cultured fish into a smaller volume of water compared to a traditional pond and facilitates feeding, chemical treatment, and inventory control, but can also compound risks due to the high biomass densities involved [17]. Catfish farming must become more efficient to remain profitable and sustainable. The IPRS approach presented herein intensifies catfish production by growing larger fingerlings and market size fish in the same pond in two raceways in an effort to reduce production costs and increase profits. The aim of this descriptive case study was to evaluate the growth performance and economic efficiency of two sizes of IPRS units using two stocking density approaches raising stocker and foodsize hybrid catfish (channel catfish, *Ictalurus punctatus*, ♀× blue catfish, *I. furcatus*, ♂) in IPRS units.

2. Materials and Methods

2.1. Performance Analysis

For this bioeconomic evaluation of the IPRS, an experiment was conducted in four 0.4 ha ponds totaling a 1.6 ha water area at the E.W. Shell Fisheries Center, Auburn, Alabama, U.S. Hybrid catfish fingerlings were obtained from a commercial supplier in Mississippi (Jubilee Farms, Indianola, Mississippi). For the trials, four larger floating IPRS units were placed into each of four 0.4 ha ponds (designated RW1, RW2, RW3, and RW4), with each fingerling fish growing to foodsize. These raceways will be referred to as 'growout' raceways. The growout IPRS raceways in ponds 1 (RW1) and 2 (RW2) were 63 m^3 (4.9 m wide, 10.7 m long, and 1.2 m water depth), and in ponds 3 (RW3) and 4 (RW4) were 45 m^3 (3.1 m wide; 12.2 m long, and 1.2 m water depth). An additional "stocker unit", a smaller floating IPRS unit 14 m^3 (1.8 m × 5.8 m × 1.30 m) was placed into each of four 0.4 ha ponds next to the growout units, and will be referred to herein as 'stocker' units or raceways. Each pond was rectangular, with dimensions of 120.7 m long × 33.5 m wide × 1.2 to 2.0 m water deep. In total, the RW1/RW2 and RW3/RW4 plus stocker units represented 1.5% and 1.2% of the 0.4 ha pond surface area, respectively. Additionally, each pond was stocked with ten 8" grass carp (*Ctenopharyngodon idella*) to control excess grass growing into the pond and algal blooms within the pond.

Growout raceways RW1 and RW2 (63 m^3) were made of aluminum (frame and walkways) and high-density polyethylene (HDPE) materials for the liner manufactured by a private welding company with a cost of USD 25,000. Growout raceways RW3 and RW4 (45 m^3) and stocker units (14 m^3) in volume were constructed in-house with wood, wire, and HDPE materials with a cost of USD 6000 and USD 1867, respectively. In each pond, a fabric curtain, called a baffle "wall", extended from the IPRS outflow to at least 2/3 of the distance of the pond diagonal, reaching from the pond bottom to just above water level, and was suspended by floats. This barrier guided water circulation around the pond and toward a second and third white water unit device (WWU) before re-entering the IPRS unit's fish growth area (Figure 1).

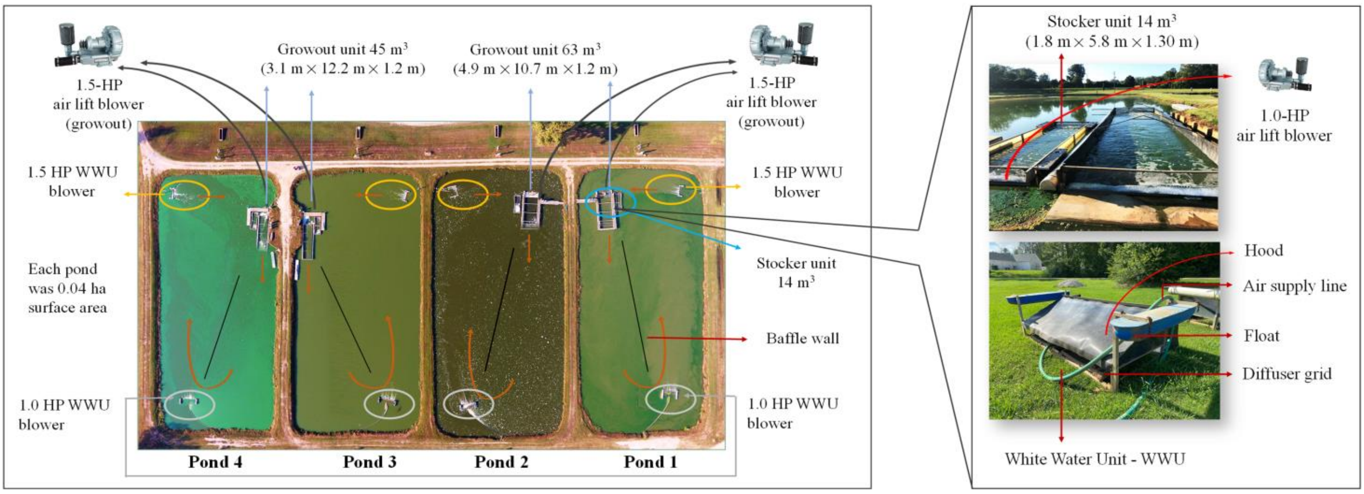

Figure 1. Aerial view of the four 0.4 ha ponds including the four growout and four stocker IPRS units per pond.

Each pond had a total of 5.0 HP for aeration, water flow, and mixing through white water units (WWU) (Figure 1). One 1.5-HP WWU blower propelled the airlift apparatus at the entrance of the larger growout RW. One additional 1.5 HP WWU blower unit was placed in each pond corner perpendicularly from the IPRS unit and diagonally from the growout IPRS unit to sustain water movement, destratify the water column, and increase the water oxygen level. Additionally, one 1.0 HP WWU blower propelled water in the pond and one 1.0 HP WWU blower propelled the airlift apparatus at the entrance of the smaller stocker unit RW. A 55 m-long and 1.5 m-high baffle fence or "curtain" made of woven plastic fiber was installed diagonally inside each pond to direct the water circulation around the entire pond (Figure 1).

Dissolved oxygen, temperature (YSI Pro 20i) and pH (YSI EcoSenseR pH 10A) were measured twice a day at 8 am and 4 pm. Other pond water parameters (total ammonia, chloride, CO_2, nitrite, secchi disk, alkalinity, and hardness were monitored twice a month using a Lamotte water quality test kit.

Hybrid catfish, mean weight 31 g, were stocked into growout IPRS units in April 2018 and in the "stocker unit", 29 g hybrid fingerlings were stocked in July 2018. Hybrid catfish (all ponds) were fed a 32% crude protein floating commercial catfish pellet (4 to 6 mm) for 228 days (growout) and 143 days (stocker). Fish were fed twice a day depending upon water temperature. Each feeding event lasted for 5 to 10 min, until near satiation of fish was reached.

We hypothesized that stocking similar numbers of fish in either larger or smaller growout raceway units would result in a similar production level on a per hectare basis. Thus, RW1 and RW2 (63 m^3) were each stocked with 8686 fish, a stocking density of 138 fish/m^3 or 4.29 kg/m^3. This is equivalent to 21,462 fish/ha. RW3 and RW4 (45 m^3) were each stocked with 8597 fish, a stocking density of 191 fish/m^3, or 6.03 kg/m^3. This is equivalent to 21,244 fish/ha.

Total biomass produced was recorded for each raceway unit (total weight harvested at the end of the production cycle) and used to calculate biomass gain by subtracting the total weight stocked from the total harvested weight. Net feed conversion ratio (Net FCR) for each raceway was calculated by dividing the amount of feed fed by biomass gained for each unit. Specific growth rate was calculated by dividing the individual weight gain in grams by the total number of production days. Gross yield, as kg/ha, was determined by the total biomass of catfish harvested per raceway divided by the pond area. Net yield, as kg/ha, was determined by dividing the total biomass gain of catfish in each raceway by the pond area. Survival percentage was determined by the number of fish harvested divided by the number of fish stocked x100.

2.2. Economic Analysis

Enterprise budgets were developed for each growout and stocker raceway unit in a pond using standard farm management procedures [18,19]. This included accounting for variable and fixed costs associated with production from 228 days of field data. Receipts, as well as variable and fixed costs were calculated separately for each raceway unit (growout and/or stocker IPRS units) using their respective data on production for each production cycle (228 days for growout and 143 days for stocker units). Quantities sold and variable inputs were multiplied by their respective prices (Table 1).

Table 1. Per-unit value or cost used in the development of the in-pond raceway system (IPRS) enterprise budgets for stocker and foodsize hybrid catfish (channel catfish *Ictalurus punctatus* ♀× blue catfish, *I. furcatus* ♂), 2018.

Description	Unit	Value per Unit
Catfish price		
Fingerlings		
- Used in growout raceways	USD/each	0.17
- Used in stocker raceways	USD/each	0.16
Harvest size sales price		
- Small < 0.454 kg	USD/kg	2.40
- Premium: 0.454–1.82 kg	USD/kg	2.46
Stocker inventory value price	USD/kg	
- Stocker < 0.454 kg	USD/kg	2.40
- Stocker > 0.454 kg	USD/kg	2.46
Feed		
32% crude protein	USD/metric ton	430
Management and labor		
Management	USD/ha/year	600
Hired labor	USD/hour	10.00
Chemicals		
Lime, agricultural	USD/metric ton	50.00
Lime, hydrated	USD/kg	0.62
Salt	USD/metric ton	135.00
Copper sulfate	USD/22.68-kg bag	65.00
	USD/kg	2.87
Rotenone	USD/L	13.00
Formalin	USD/208.19 L drum	440
	USD/L	2.11
Diquat	USD/L	3.00
Potassium permanganate	USD/kg	11.63
Fuel		
Gasoline off-road price for agriculture	USD/L	0.72
Diesel price off-road	USD/L	0.79
Electricity, per kWhr at off-peak rate	USD/kW-hour	0.07
Other		
Insurance	USD/ha	2.53
Miscellaneous expenses	USD/cycle	200.00
Bird netting for two raceways	USD/roll	163.00

Fish price was determined by calculating an average using prices from January 2016 to June 2021 for small (<0.454 kg) and premium (0.454–1.82 kg) sized catfish. Since stocker fingerlings exceeded the maximum size sold in hatcheries, the same sales price designated by the processing plant for small harvest size fish (USD 2.40/kg) was used for the stockers.

Profitability metrics calculated from developed enterprise budgets included net returns above variable and fixed costs. Net return is an economic measure of profitability, as it includes cash and non-cash costs, such as depreciation and any unpaid or in-kind payments.

It is a measure of long-term profitability. The income above variable cost measure was calculated by subtracting total variable costs from total receipts and is an indicator of whether the business can continue to operate in the short-run. If all cash (variable) costs can be paid, then the operation can continue to operate (produce fish). The breakeven selling price (USD/kg, or cost of production) is the minimum price one needs to receive to cover all variable and fixed costs. It was calculated by dividing the total cost (variable + fixed costs) by the quantity of fish harvested. The breakeven yield (kg) is the quantity of fish needed to be produced to break even, assuming the selling price remains constant. It was calculated by dividing the total costs by the selling price.

An accounting approach to profitability was also used to show only cash expenditures and excluded fixed costs. Cash flow analyses were conducted through development of a ten-year cash flow for each pond IPRS. They were developed from the enterprise budgets to evaluate each system's performance. This approach is similar to the earnings before interest, taxes, depreciation, and amortization (EBITDA) approach that only includes cash expenditures and excludes fixed costs [20]. The EBITDA metric is a way to adjust for factors that can differ from one company to the next. For instance, when existing farm businesses already own the land, have ponds, electrical lines, and much of the required machinery and equipment, then using an accounting profitability would be the correct method for comparing alternatives. Cash flows allowed calculation of net present value (NPV), internal rate of return (IRR), and payback period (years).

Net present value takes into account the time value of money and converts a stream of cash flows over the entire life of the investment back to a single present value using a discount rate [19,21,22]. Spreadsheet software, such as Excel, has functions to calculate NPV using a discount rate, an initial investment (Table 2), and the annual net return values for years 1 through 10, including replacement of equipment and machinery items as they wore out. We used a 5.0% discount rate based on our calculation of the quarterly average effective interest rates on non-real estate bank loans made to farmers from 2013 to 2017, representing the five-year average before the study case completion (Ag Finance Updates) [23]. A positive NPV means the system is a good investment opportunity, though care must be taken in only using this as the sole decision criterion, as other factors, such as the magnitude of the investment involved and potential risks, need to be included in the decision process. The IRR is similar to the NPV, but it equates NPV to zero and solves for the discount rate percentage [19,22]. Again, spreadsheet software has functions that calculate this by using the initial investment and the series of annual net returns from year 1 to year 10. IRR is often used when comparing alternative investment opportunities or for comparing other returns an investor might make in savings accounts or the rate of return for another investment. The payback period is calculated by dividing the initial investment by the average annual net return from the ten-year cash flow. This provides an idea of how long it might take to pay off the initial investment given steady annual returns [19,22].

2.3. Sensitivity Analyses

A series of sensitivity analyses were conducted based on required aquaculture investment levels for varying initial situations (scenarios) of an operation and varying fish/feed price changes on each scenario's net return. These were conducted to avoid overly optimistic enterprise budgets and misleading results [18]. Four scenarios were developed. Scenario 1 represented a new aquaculture operation, requiring land purchase, pond construction, electricity, water supply, and purchase of all necessary aquaculture farm machinery and equipment. This is the base scenario to which other scenarios will be compared. Scenario 2 represents the situation in Scenario 1, except the land is already owned. Scenario 3 represents the situation in Scenario 2 but 80% of the aquaculture farm machinery and equipment was already purchased and available. Scenario 4 represents the situation in Scenario 3, with only some very specific IPRS raceway components needing to be purchased. All scenarios included separate analyses for large raceways (RW1/RW2 + stocker units) and small raceways (RW3/RW4 + stocker units).

Table 2. Land, construction of 0.4 ha ponds and in-pond raceway system (IPRS) capital items, and machinery and equipment investment for raising stocker and foodsize hybrid catfish (Channel catfish *Ictalurus punctatus* ♀× Blue catfish, *I. furcatus* ♂) in the same pond, 2018.

Items	USD	Investment			
		Quantity	63 m^3 IPRS	Quantity	45 m^3 IPRS
Capital items					
Land, USD/ha	2031	0.49	986	0.49	986
Pond construction [a], USD/ha	3830	0.40	1550	0.40	1550
Growout RW1 and RW2, placed in ponds 1 and 2 (4.9 m × 10.7 m × 1.2 m = 63 m^3)	25,000	1	25,000	-	-
Growout RW3 and RW4, placed in ponds 3 and 4 (3.0 m × 12.2 m × 1.2 m = 45 m^3)	6000	-	-	1	6000
Stocker unit RWs, placed in ponds 1, 2, 3, and 4 (1.8 m × 5.8 m × 1.30 m = 14 m^3)	1867	1	1867	1	1867
Subtotal			29,403		10,403
Machinery and Equipment					
Equipment [b], USD/ha	3739	0.40	1513	0.40	1513
1.0 HP blower for white water unit	880	1	880	1	880
1.5 HP blower for raceway unit	1200	1	1200	1	1200
1.5 HP blower for white water unit	1200	1	1200	1	1200
1.0 HP blower for small RW unit	900	1	900	1	900
White water unit (large RWs)	2500	1	2500	1	2500
White water unit (small RWs)	1200	1	1200	1	1200
Baffle fencing and floats	200	1	200	1	200
Boardwalks—raceways 1 and 2	1000	1	1000	-	-
Boardwalks—raceways 3 and 4	1200	-	-	1	1200
Subtotal			10,593		10,793
TOTAL			39,996		21,196

[a] Includes construction of pond with water supply, drainage, and electrical service, but no wells because they are seldom used on western Alabama catfish farms. Their primary water source is from watershed runoff. [b] Equipment costs included a backup generator (20 kW plus transfer switch), propane tank for generator, electrical line for white water movers, tractors, trucks, mower, electrical aerators, power take-off aerator, feeder, feed bin, pump, office, shop, tools, utility trailer, storage container, dissolved oxygen meter, and computer.

Using the four investment scenarios, a three-way sensitivity analysis, combining changes in feed and fish prices for the four scenarios with net return as the profitability metric, was calculated. A base-weighted average fish selling price was calculated according to the differing prices received and quantities produced of small- and premium-sized fish. Both ponds with large raceways (RW1/RW2 + stocker unit) and with small raceways (RW3/RW4 + stocker units) had a weighted average selling price of USD 2.44/kg (base). The sensitivity analysis was performed by decreasing and increasing the base price by 10 and 20 percent. Resulting fish selling prices used in this sensitivity analysis were USD 1.95, USD 2.19, USD 2.44 (base), USD 2.85, and USD 2.92/kg. Feed prices used in this sensitivity analysis were USD 370, USD 400, USD 430, USD 460, and USD 490/MT.

A second sensitivity analysis used the same four scenarios described above, as well as their effect on net returns, initial investment cost, payback period, net present value, and internal rate of return. RW1/RW2 was constructed using aluminum, an expensive material, whereas RW3/RW4 were constructed of much less expensive materials of wood, HDPE vinyl plastic, and wire grates. Thus, this sensitivity analysis investigated the economic effect when the less expensive RW materials were used in constructing the larger-sized raceways. We substituted the less expensive RW materials used in RW3/RW4 (wood and wire) for the more expensive materials used in RW1/RW2 (aluminum) for the 63 m^3 raceway construction. Initially, the raceway units placed into ponds 1 and 2 had a construction cost of USD 25,000 per RW unit (or USD 396 per m^3) and the raceway units placed into ponds 3 and 4 had a construction cost of USD 6000 per unit (or USD 133 per m^3). When the less expensive materials were substituted in, the USD 133 per m^3 construction cost was substituted in for the larger 63 m^3 raceways at USD 396 per m^3 cost. The re-calculated construction cost for RW1/RW2 would now be USD 8400 per RW unit for the 63 m^3 raceway (USD 133 per m^3), a 66% reduction in RW construction costs due to the use of the less expensive materials.

3. Results

3.1. Water Quality

Water quality measurements during production cycles raising stocker and foodsize hybrid catfish in IPRS units were within acceptable ranges throughout the study (Table 3). The stocking density used in these trials required backup generators be in place and ready for use in case of electrical failure, though none occurred during this study. A total of 5 HP (horsepower) of aeration per pond (white water unit WWU) was enough to maintain dissolved oxygen (DO) levels in the ponds and inside of the raceways above minimum DO levels. The WWUs created dynamic water flows and mixed water columns that, combined with efficient, plentiful aeration, managed DO levels at the pond bottoms and surface waters well, and promoted efficient biological oxidation of fish and feed wastes.

Table 3. Water chemistry results from within foodsize raceways and surrounding pond water when raising hybrid catfish (channel catfish *Ictalurus punctatus* ♀× blue catfish, *I. furcatus* ♂) in four 0.4 ha in-pond raceway systems, 2018.

	Pond 1	RW 1	Pond 2	RW 2	Pond 3	RW 3	Pond 4	RW 4
DO range, mg/L	2.3–12.9	2.6–11.8	1.7–13.8	2.4–13.4	1.8–13.4	2.4–12.9	1.2–12.5	1.7–12.0
Temperature °C	12.0–33.3	12.0–33.1	12.0–33.6	12.0–33.6	12.0–33.5	12.0–33.4	12.0–33.2	12.0–32.4
Total alkalinity	–	80–110	–	60–95	–	60–100	–	70–80
Total hardness	–	70–90	–	45–70	–	50–70	–	60–80
Chloride	–	240–380	–	120–400	–	120–400	–	140–400
pH	–	7.2–8.3	–	7.2–9.5	–	7.1–9.5	–	6.9–9.1
TAN mg/L	–	0.2–2.0	–	0.0–3.0	–	0.0–3.0	–	0.2–1.0
NH_3 mg/L	–	0.0–0.8	–	0.0–2.1	–	0.0–1.2	–	0.0–0.2
NO_2- mg/L	–	0.1–0.3	–	0.0–0.6	–	0.0–0.3	–	0.0–0.8
Secchi disk (m)	0.18–0.35	–	0.23–0.33	–	0.18–0.32	–	0.18–0.28	–

DO = dissolved oxygen inside the raceway—minimum and maximum; temperature = minimum and maximum; total alkalinity range (as ppm $CaCO_3$); total hardness range (as ppm $CaCO_3$); chloride concentration as ppm = minimum and maximum; pH = inside the raceway, afternoon range; total ammonia nitrogen (TAN) = maximum afternoon range; NH_3 (ammonia) = maximum afternoon range; nitrite nitrogen (NO_2-) = maximum afternoon range; and Secchi disk depth level during summer and early fall.

Some spikes in afternoon pH (9.5) and toxic ammonia (2.1 mg/L) were observed infrequently. Likewise, some early morning low DO levels (below 3 mg/L) inside the raceways during the summer period were observed. Pond DO concentrations in the early morning hours were higher during the spring (April and May) and fall (October and November) months, but lower during summer (June to September) months (Figures 2 and 3). This is normal for fish production in traditional and IPRS stocked at high densities. Dissolved oxygen inside the raceways rarely fell below 3 mg/L in ponds 1, 2, and 3, with the exception of pond 4, which had an average of 2.76 mg/L in the pond and 3.03 mg/L inside of the raceway at one point in the summer months. Pond 4 also had the lowest Secchi disk transparency measurement (0.18–0.28 m), resulting from heavy phytoplankton blooms. Even though DO concentrations were low during summer in pond 4, no fish mortalities occurred.

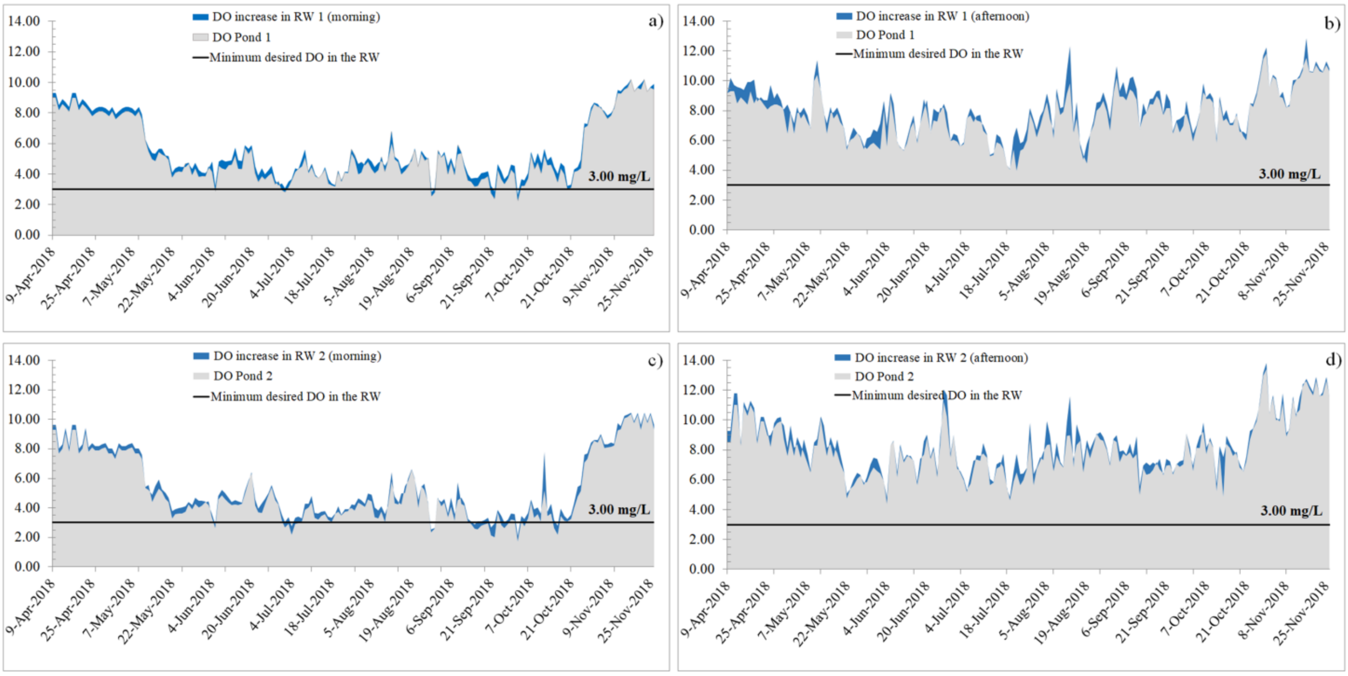

Figure 2. Illustration of the early morning (**left**) and afternoon (**right**) dissolved oxygen concentrations in the pond (light grey) and inside growout raceways (blue) RW1 (**a**,**c**) and RW2 (**b**,**d**). The blue area above the light grey area indicates how much more oxygen the IPRS aeration device added to the water at the entrance of the raceway, keeping dissolved oxygen levels inside the raceway at or above 3 mg/L (minimum desired level), seldom below 2 mg/L, and regularly above the outside pond water, 2018. DO = Dissolved oxygen mg/L.

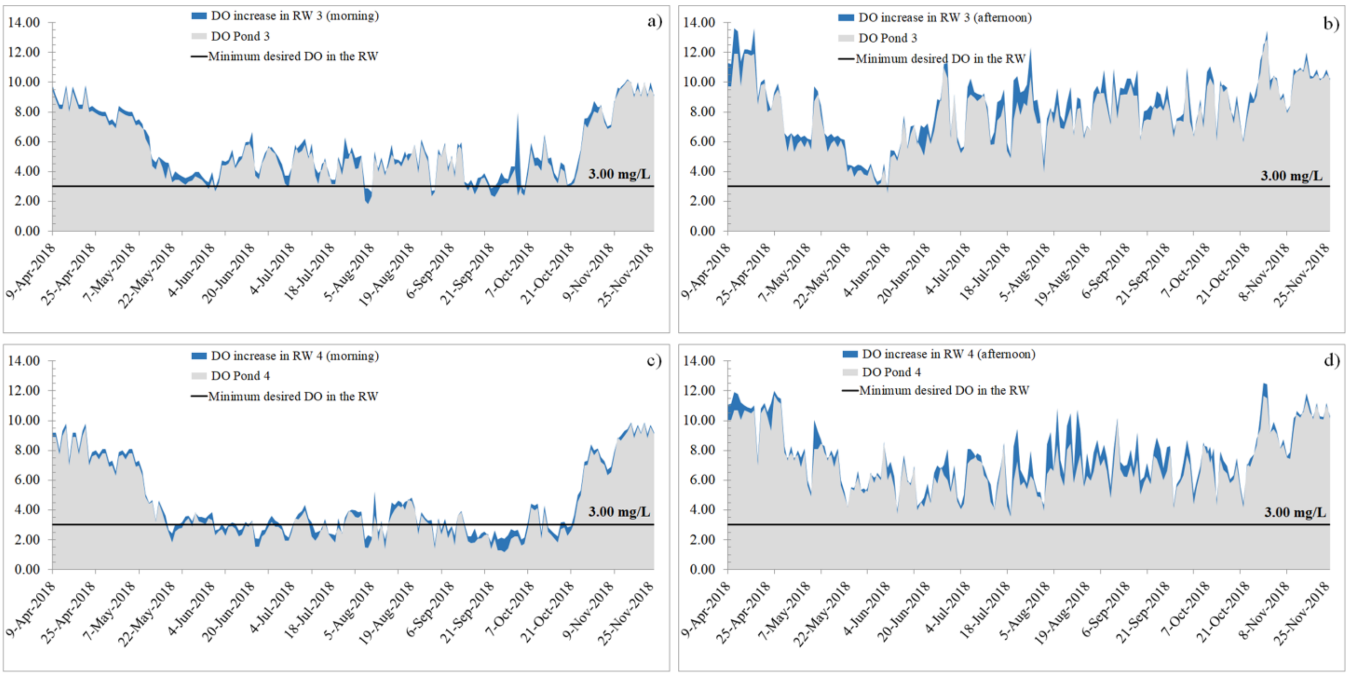

Figure 3. Illustration of the early morning (**left**) and afternoon (**right**) dissolved oxygen concentrations in the pond (light grey) and inside growout raceways (blue) RW3 (**a**,**c**) and RW4 (**b**,**d**). The blue area above the light grey area indicates how much oxygen the IPRS aeration device added to the water at the entrance of the raceway, keeping dissolved oxygen levels inside the raceway at or above 3 mg/L (minimum desired level), seldom below 2 mg/L, and regularly above the outside pond water, 2018. DO = Dissolved oxygen mg/L.

Water temperature changed markedly by season and varied from 23.8 to 27.0 °C during spring months, 29.8 to 30.1 °C during summer months, and 23.8 to 24.0 °C during fall months. These temperature ranges allow hybrid catfish to grow well during late spring, all summer, and into early fall. Total alkalinity in study ponds ranged from 60 to 110 ppm/$CaCO_3$ and hardness ranged from 45 to 90 mg/$CaCO_3$. Pond chloride concentrations ranged from 120 to 480 ppm followed by very lower levels of nitrite (maximum level of 0.8 NO_2-mg/L on pond 4).

3.2. Fish Performance

The fish stocking density for the growout foodsize system resulted in yields of 12,050 kg/ha and 12,078 kg/ha, respectively (Table 4). Average harvest weight for the growout raceways ranged from 564 to 661 g (228 days of production) with a specific growth rate of 2.55 g for both groups RW1/RW2 (76% of fish harvested were in the premium size range) and RW3/RW4 (80% of fish harvested were in the premium size range). Excellent feed conversion ratios (FCR) and high survival rates were registered for foodsize hybrid catfish, at 1.72 and 90.7% for RW1/RW2, and 1.67 and 91.6% for RW3/RW4, respectively.

Table 4. Growout growth performance of hybrid catfish (channel catfish *Ictalurus punctatus* ♀× Blue catfish, *I. furcatus* ♂) raised in in-pond raceway system (IPRS) raceways placed in 0.4 ha ponds, 2018.

	Raceway 1 63 m^3	**Raceway 2 63 m^3**	**Average Raceways 1 and 2 (Standard Error)**	**Raceway 3 45 m^3**	**Raceway 4 45 m^3**	**Average Raceways 3 and 4 (Standard Error)**
Production cycle (days)	228	228	228	228	228	228
Number of fish stocked	8714	8657	8686 (29)	8603	8592	8597 (6)
Stocking density (fish/m^3)	138	137	138 (0.5)	191	191	191 (0.1)
Stocking density (fish/ha)	21,533	21,391	21,462 (71)	21,258	21,230	21,244 (14)
Stocking density (kg/m^3)	4.4	4.2	4.3 (0.1)	5.9	6.2	6.0 (0.1)
Mean weight at stocking (g)	31.8	30.4	31.1 (0.7)	30.9	32.2	31.6 (0.7)
Stocking biomass (kg)	277	263	270 (6.8)	266	277	271 (5.7)
Mean weight at harvest (g)	625	602	613 (11.8)	661	564	613 (48.9)
Total harvested (kg)	4508	5132	4820 (311.8)	5277	4385	4831 (446.1)
Total harvest (number)	7218	8539	7878 (660)	7978	7779	7878 (99)
Feed fed (kg)	7321	8298	7809 (488.5)	7363	7722	7543 (179.9)
Net FCR [a]	1.73	1.70	1.72 (0.01)	1.47	1.88	1.67 (0.21)
Standing crop at harvest (kg/m^3)	71.6	81.5	76.5 (4.9)	117.3	97.4	107.4 (9.9)
Yield [b] (kg/ha)	11,271	12,830	12,050 (780)	13,193	10,963	12,078 (1115)
Net Yield [c] (kg/ha)	10,578	12,172	11,375 (797)	12,529	10,271	11,400 (1129)
Average feeding rate (kg/ha/day)	80.3	91.0	85.6 (5.4)	80.7	84.7	82.7 (2.0)
SGR [d] (g/fish/day)	2.60	2.50	2.55 (0.05)	2.77	2.33	2.55 (0.2)
Survival (%)	82.8	98.6	90.7 (8.3)	92.7	90.5	91.6 (0.01)

[a] Net feed conversion ratio (FCR) = feed fed, kg/(total harvested, kg—stocking biomass, kg); [b] Yield = total harvested, kg/pond size, 0.4 ha; [c] Net yield = (total harvested, kg—stocking biomass, kg)/pond size, 0.4 ha; and [d] SGR (specific growth rate) = (mean weight at harvest, g—mean weight at stocking, g)/production cycle, days.

Stocker unit raceway yields ranged from 3537 to 4388 kg/ha (143 days of production) and achieved harvest weights ranging from 123 to 234 g (Table 5). In the RW1/RW2 stocker unit, there was a survival rate of 84.6% and a FCR of 1.67 and in the RW3/RW4 stocker unit there was a survival rate of 76.5% and a FCR of 1.70. In each case, the stocker unit harvested enough stockers to start a new production cycle. Stocker units 1 and 2 generated 8540 stocker–fingerlings (21,102 fingerlings/ha) and units 3 and 4 generated 7954 fingerlings (19,654 fingerlings/ha), which is similar to our stocking density for the growout units at the beginning of these trials. In total, there were 32,988 stocker fish harvested, and when divided into four, there would be an average of 8247 fingerlings available per RW in the next production cycle. Combining foodsize fish plus stocker–fingerling biomass, the total harvest weight per pond ranged from 14,500 kg/ha to 17,581 kg/ha.

Table 5. Stocker growth performance of hybrid catfish (channel catfish *Ictalurus punctatus* ♀× blue catfish, *I. furcatus* ♂) raised in the in-pond raceway system (IPRS) "stocker unit" raceways placed in 0.4 ha ponds, 2018.

	Raceway 1 14 m³	**Raceway 2 14 m³**	**Average Raceway 1 and 2 (Standard Error)**	**Raceway 3 14 m³**	**Raceway 4 14 m³**	**Average Raceway 3 and 4 (Standard Error)**
Production cycle (days)	143	143	143	143	143	143
Number of fish stocked	10,000	10,159	10,079 (79)	10,147	10,735	10,441 (294)
Stocking density (fish/m³)	714	726	720 (5.7)	725	767	746 (21.0)
Stocking density (fish/ha)	24,710	25,102	24,906 (196)	25,073	26,527	25,800 (727)
Stocking density (kg/m³)	18.5	20.8	19.6 (1.1)	22.4	23.7	23.0 (0.6)
Mean weight at stocking (g)	25.9	28.6	27.2 (1.4)	30.9	30.9	30.9 (0.0)
Stocking biomass (kg)	259	291	275 (15.9)	313	331	322 (9.08)
Mean weight at harvest (g)	201	123	162 (39.3)	133	234	183 (50.4)
Total harvested (kg)	1415	1709	1562 (147.0)	1755	1603	1679 (76.3)
Total harvest (number)	7041	10,039	8540 (1499)	8919	6989	7954 (964)
Feed fed (kg)	2004	2296	2150 (146.0)	2335	2255	2295 (40.2)
Net FCR [a]	1.73	1.62	1.67 (0.06)	1.62	1.77	1.70 (0.08)
Standing crop at harvest (kg/m³)	101.1	122.0	111.6 (10.5)	125.4	114.5	119.9 (5.4)
Yield [b] (kg/ha)	3537	4272	3904 (367.4)	4388	4007	4197 (190.7)
Net Yield [c] (kg/ha)	2890	3545	3218 (327.7)	3605	3178	3391 (213.4)
Average feeding rate (kg/ha/day)	35.0	40.1	37.59 (2.6)	40.8	39.4	40.1 (0.7)
SGR [d] (g/fish/day)	1.23	0.66	0.94 (0.3)	0.71	1.42	1.07 (0.4)
Survival (%)	70.4	98.8	84.6 (14.2)	87.9	65.1	76.5 (11.4)

[a] Net feed conversion ratio (FCR) = feed fed, kg/(total harvested, kg—stocking biomass, kg); [b] Yield = total harvested, kg/pond size, 0.4 ha; [c] Net yield = (total harvested, kg—stocking biomass, kg)/pond size, 0.4 ha; and [d] SGR (specific growth rate) = (mean weight at harvest, g—mean weight at stocking, g)/production cycle, days.

3.3. Economic Analysis

Investment was computed for the raceway growout and stocker units in each 0.4 ha pond (Table 2). The investment necessary for each pond having a 63 m^3 growout raceway plus a 14 m^3 stocker unit raceway was USD 39,996. For ponds having a 45 m^3 growout raceway plus a 14 m^3 stocker raceway, the investment was USD 21,196. The investment difference was due to the raceway size difference, costlier raceway materials, and more robust, larger boardwalks. A single larger growout raceway unit (63 m^3) cost USD 25,000 (20 years of useful life, 20% salvage value, and 3% of initial cost for annual maintenance, variable repair and maintenance cost was USD 25/month) to manufacture by a private welding company and used aluminum for its frame and walkways, and high-density polyethylene (HDPE) materials for its liner. A smaller growout raceway unit (45 m^3) cost USD 6000 (10 years of useful life, 5% salvage value, and 5% of initial cost for annual maintenance. Variable repair and maintenance was USD 50/month) was constructed in-house with wood, wire, and HDPE materials. All stocker raceway units (14 m^3) cost USD 1867 and were constructed using wood, wire, and HDPE materials.

Capital items represented 74% (USD 29,403) of the total investment for ponds 1 and 2, but only 49% (10,403) for ponds 3 and 4 (Table 2). Ponds 1 and 2 housed larger growout raceways and were 25% higher than in ponds 3 and 4. Machinery and equipment comprised 26% (USD 10,593) of the cost for the larger growout stocker raceway set up and 51% (USD 10,793) of the smaller growout stockers raceway set up. Depreciation on capital, machinery, and equipment items was USD 1410 for the larger growout units and USD 1030 for the smaller growout units (Table 6), plus USD 612 for the stocker units in ponds 1 and 2 and USD 618 for those units in ponds 3 and 4 (Table 7). Average fixed costs were USD 3461 for large growout units (63 m^3) and USD 2249 for small growout units (45 m^3). Average fixed costs were USD 1477 for stocker units in ponds 1 and 2, and USD 1488 for stocker units in ponds 3 and 4. Differences were due to fixed interest and depreciation cost calculations on machinery and equipment (boardwalks size and prices were slightly different) and repairs and maintenance were based on each raceway production.

Table 6. Growout enterprise budgets for four in-pond raceway system (IPRS) producing foodsize hybrid catfish, channel catfish *Ictalurus punctatus* ♀× blue catfish, *I. furcatus* ♂, with each raceway placed in a 0.4 ha pond, USD, 2018.

	Raceway 1 63 m³		Raceway 2 63 m³		Average Raceway 1 and 2		Raceway 3 45 m³		Raceway 4 45 m³		Average Raceway 3 and 4	
	Value or Cost	**Value or Cost/kg**	**Value or Cost**	**Value or Cost/kg**	**Value or Cost**	**Value or Cost/kg**	**Value or Cost**	**Value or Cost/kg**	**Value or Cost**	**Value or Cost/kg**	**Value or Cost**	**Value or Cost/kg**
Catfish sales receipts												
Small, <0.454 kg	2782	2.40	2811	2.40	2797	2.40	1484	2.40	3000	2.40	2242	2.40
Primium:0.454–1.82 kg	8244	2.46	9749	2.46	8996	2.46	11,455	2.46	7708	2.46	9581	2.46
Total receipts	11,026	2.45	12,560	2.45	11,793	2.45	12,939	2.45	10,708	2.44	11,823	2.45
Variable costs												
Feed, 32% protein	3143	0.70	3562	0.69	3353	0.70	2760	0.52	3315	0.76	3038	0.64
Labor and management	1452	0.32	1432	0.28	1442	0.30	1432	0.27	1398	0.32	1415	0.30
Catfish fingerlings	1438	0.32	1428	0.28	1433	0.30	1419	0.27	1418	0.32	1419	0.30
Carp fingerlings	49	0.01	49	0.01	49	0.01	49	0.01	48	0.01	48	0.01
Harvest and transportation	497	0.11	566	0.11	531	0.11	581	0.11	483	0.11	532	0.11
Fuel (diesel and gas)	47	0.01	46	0.01	46	0.01	46	0.01	45	0.01	46	0.01
Repairs and maintenance	200	0.04	200	0.04	200	0.04	400	0.08	400	0.09	400	0.08
Electricity, aeration	1191	0.26	1180	0.23	1185	0.25	1180	0.22	1162	0.27	1171	0.24
Chemicals	1061	0.24	1045	0.20	1053	0.22	1144	0.22	1113	0.25	1129	0.24
Miscellaneous	100	0.02	90	0.02	95	0.02	99	0.02	96	0.02	97	0.02
Interest on operating capital	386	0.09	404	0.08	395	0.08	383	0.07	399	0.09	391	0.08
Total variable cost	9564	2.12	10,001	1.95	9782	2.03	9494	1.80	9876	2.25	9685	2.03
Income above variable costs	1462	0.32	2559	0.50	2010	0.42	3445	0.65	832	0.19	2138	0.44
Fixed costs												
Land charge	493	0.11	493	0.10	493	0.10	493	0.09	493	0.11	493	0.10
Depreciation on capital items	761	0.17	761	0.15	761	0.16	375	0.07	375	0.09	375	0.08
Depreciation on machinery and equipment items	649	0.14	649	0.13	649	0.14	655	0.12	655	0.15	655	0.14
Interest on capital loans	757	0.17	757	0.15	757	0.16	199	0.04	199	0.05	199	0.04
Interest on equipment loans	183	0.04	183	0.04	183	0.04	186	0.04	186	0.04	186	0.04
Repairs and maintenance	10	0.00	10	0.00	10	0.00	10	0.00	10	0.00	10	0.00
Taxes	606	0.13	606	0.12	606	0.13	326	0.06	326	0.07	326	0.07
Insurance	2	0.00	2	0.00	2	0.00	2	0.00	2	0.00	4	0.00
Total fixed costs	3461	0.77	3461	0.67	3461	0.72	2247	0.43	2247	0.51	2249	0.47
Total costs	13,025	2.89	13,461	2.62	13,243	2.76	11,741	2.23	12,124	2.77	11,934	2.50
Net return above all costs	−1999	−0.44	−902	−0.18	−1450	−0.31	1198	0.23	−1416	−0.32	−110	−0.05

Some columns of number may not add up as presented due to integer rounding.

Table 7. Stocker enterprise budgets for four in-pond raceway system (IPRS) producing stocker hybrid catfish, channel catfish *Ictalurus punctatus* ♀× blue catfish, *I. furcatus* ♂, with each raceway placed in a 0.4 ha pond, USD, 2018 *.

	Raceway 1 14 m^3		Raceway 2 14 m^3		Average Raceway 1 and 2		Raceway 3 14 m^3		Raceway 4 14 m^3		Average Raceway 3 and 4	
	Value or Cost	Value or Cost/kg	Value or Cost	Value or Cost/kg	Value or Cost	Value or Cost/kg	Value or Cost	Value or Cost/kg	Value or Cost	Value or Cost/kg	Value or Cost	Value or Cost/kg
Inventory/sale value												
Catfish stocker <0.454 kg	3232	2.40	4104	2.40	3668	2.40	4212	2.40	3402	2.40	3807	2.40
Catfish stocker > 0.454 kg	170	2.46	0	2.46	85	2.46	0	2.46	454	2.46	227	2.46
Total	3402	2.40	4104	2.40	3753	2.40	4212	2.40	3857	2.41	4034	2.41
Variable costs												
Feed, 32% protein	861	0.61	986	0.58	923	0.59	1002	0.57	968	0.60	985	0.59
Labor and management	456	0.32	477	0.28	466	0.30	476	0.27	511	0.32	494	0.30
Catfish fingerlings	1610	1.14	1636	0.96	1623	1.05	1634	0.93	1728	1.08	1681	1.01
Carp fingerlings	16	0.01	16	0.01	16	0.01	16	0.01	17	0.01	17	0.01
Fuel (diesel and gas)	15	0.01	16	0.01	15	0.01	15	0.01	16	0.01	16	0.01
Repairs and maintenance	50	0.04	50	0.03	50	0.03	50	0.03	50	0.03	50	0.03
Electricity, aeration	419	0.30	430	0.25	424	0.27	429	0.24	442	0.28	436	0.26
Chemicals	315	0.22	329	0.19	322	0.21	329	0.19	388	0.24	358	0.21
Miscellaneous	31	0.02	33	0.02	32	0.02	33	0.02	35	0.02	34	0.02
Interest on operating capital	159	0.11	167	0.10	163	0.10	168	0.10	175	0.11	171	0.10
Total variable cost	3930	2.78	4138	2.42	4034	2.60	4152	2.37	3315	0.76	4242	2.54
Income above variable cost	−528	−0.37	−35	−0.02	−197	−0.12	59	0.03	−474	−0.30	−207	−0.12
Fixed costs												
Land charge	493	0.35	493	0.29	493	0.32	493	0.28	493	0.31	493	0.29
Depreciation on capital items	197	0.14	197	0.12	197	0.13	197	0.11	197	0.12	197	0.12
Depreciation for machinery and equipment items	415	0.29	415	0.24	415	0.27	421	0.24	421	0.26	421	0.25
Interest on capital loans	78	0.05	78	0.05	78	0.05	78	0.04	78	0.05	78	0.05
Interest on equipment loans	137	0.10	137	0.08	137	0.09	140	0.08	140	0.09	140	0.08
Repairs and maintenance	10	0.01	10	0.01	10	0.01	10	0.01	10	0.01	10	0.01
Taxes	144	0.10	144	0.08	144	0.09	146	0.08	146	0.09	146	0.09
Insurance	2	0.00	2	0.00	2	0.00	2	0.00	2	0.00	2	0.00
Total fixed costs	1477	1.04	1477	0.86	1477	0.95	1488	0.85	1488	0.93	1488	0.89
Total costs	5407	3.82	5615	3.29	5511	3.55	5640	3.22	5819	3.63	5730	3.43
Net return above all costs	−2005	−0.48	−1511	−0.22	−1758	−0.35	−1428	0.17	−1962	−0.36	−1695	−0.09

Some columns of number may not add up as presented due to integer rounding.

Income above variable cost results are positive for all growout RW sizes, indicating the business should continue to produce foodsize fish as all cash (variable) costs were covered or paid (Table 6). On the other hand, income above variable costs for each stocker unit was negative for all stocker RWs, indicating that stocker production should cease, as money is being lost for every additional kg of stocker fish produced. This result is according to our stocker pricing and valuation method, which could be imperfect, as stockers are not normally sold because their size precludes shipping many fish at a time for long distances, as they can for fingerlings. Net returns above all costs were negative for all growout units, except for RW3, which had a positive net return of USD 1198. When enterprise budgets were combined (growout plus stocker units), all net returns above variable costs were positive, ranging from USD 933 to USD 3505 (Table 8), but negative when fixed costs were included (USD −4004 to USD −231).

The breakeven fish selling price range to cover all costs ranged from USD 2.23 to USD 2.89/kg for foodsize fish and from USD 3.22 to USD 3.82/kg for stocker fish (Tables 6 and 7, respectively, see total cost/kg cells). As the price paid to producers by processing plants ranged from USD 2.40 to 2.45/kg, economic losses occurred in all growout pond units, except in pond 3. The lowest total cost to produce foodsize catfish was USD 2.23/kg and for stocker fingerlings was USD 3.22/kg in pond 3, in which the raceways had the higher survival rates and lowest FCR of any other raceways. Accounting profits for growout, IPRS ranged from USD 2682 to USD 4920 per raceway (Table 9). With the exception of negative accounting profits in the pond 1 stocker unit (-USD 70), accounting results for the other three stocker raceway units had positive net returns, ranging from USD 53 to USD 545 (Table 10).

The breakeven yield for RW1/RW2 was 5405 kg and the actual harvest was 4820 kg, which was 585 kg less yield than needed to break even economically; and for RW3/RW4 the breakeven yield was 4871 kg and the actual harvest was 4831 kg, which was 40 kg less than the yield needed to break even economically. The breakeven yield for the RW1/RW2 stocker unit was 2296 kg and the actual harvest was 1562 kg, which was 734 kg less yield than needed to break even economically; and for the RW3/RW4 stocker unit, the breakeven yield was 2378 kg, and the actual harvest was 1679 kg, which was 699 kg less than the yield needed to break even economically. Foodsize and stocker production needs to be targeted to meet these breakeven yields.

3.4. Sensitivity Analyses

The first sensitivity analysis investigated different required IPRS investment levels according to existing farm situations, going from beginning an aquaculture farm to a fully functional aquaculture operation (Table 11). Raceway component purchases were required for all scenarios. Scenario 1 investment for ponds with 63 m^3 growout plus 14 m^3 stocker units was USD 39,996, and USD 21,196 for 45 m^3 growout plus 14 m^3 stocker units. Scenario 2 had an investment of USD 39,010 for large growout plus stocker units and USD 20,210 for the small growout plus stocker units. Scenario 3 had an investment of USD 36,839 for large growout plus stocker units, and USD 17,879 for small growout plus stocker units. The least expensive investment occurred in Scenario 4 in the case where only raceway components were purchased (USD 34,747 for large growout plus stocker units and USD 15,747 for smaller growout raceway plus stocker units). Itemized investment requirements for the four scenarios are shown in Table 11.

Table 8. Summary enterprise budgets for four in-pond raceway system (IPRS) producing foodsize and stocker hybrid catfish, channel catfish *Ictalurus punctatus* ♀× blue catfish, *I. furcatus* ♂, in a 0.4 ha pond, USD, 2018 *.

	Pond 1		Pond 2		Average Pond 1 and 2		Pond 3		Pond 4		Average Pond 3 and 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	Value or Cost	Cost per kg	Value or Cost	Cost per kg
Growout IPRS												
Catfish sales receipts												
Small, <0.454 kg	2782	2.40	2811	2.40	2797	2.40	1484	2.40	3000	2.40	2242	2.40
Primium: 0.454–1.82 kg	8244	2.46	9749	2.46	8996	2.46	11,455	2.46	7708	2.46	9581	2.46
Total receipts	11,026	2.45	12,560	2.45	11,793	2.45	12,939	2.45	10,708	2.44	11,823	2.45
Variable costs	9564	2.12	10,001	1.95	9782	2.04	9494	1.80	9876	2.25	9685	2.03
Income above variable costs	1462	0.32	2559	0.50	2010	0.42	3445	0.65	832	0.19	2138	0.44
Fixed costs	3461	0.77	3461	0.67	3461	0.72	2247	0.43	2247	0.51	2249	0.47
Total costs	13,025	2.89	13,461	2.62	13,243	2.76	11,741	2.23	12,124	2.77	11,934	2.50
Net return above all costs	−1999	−0.44	−902	−0.18	−1450	−0.31	1198	0.23	−1416	−0.32	−110	−0.05
Stocker inventory/sale value												
Catfish stocker <0.454 kg	3232	2.40	4104	2.40	3668	2.40	4212	2.40	3402	2.40	3807	2.40
Catfish stocker > 0.454 kg	170	2.46	0	2.46	85	2.46	0	2.46	454	2.46	227	2.46
Total sales value	3402	2.40	4104	2.40	3753	2.40	4212	2.40	3857	2.41	4034	2.41
Variable costs	3930	2.78	4138	2.42	4034	2.60	4152	2.37	3315	0.76	4242	2.54
Income above variable costs	−528	−0.37	−35	−0.02	−281	−0.18	59	0.03	−474	−0.30	−207	−0.12
Fixed costs	1477	1.04	1477	0.86	1477	0.95	1488	0.85	1488	0.93	1488	0.89
Total costs	5407	3.82	5615	3.29	5511	3.55	5640	3.22	5819	3.63	5730	3.43
Net return above all costs	−2005	−0.48	−1511	−0.22	−1758	−0.35	−1428	0.17	−1962	−0.36	−1695	−0.09
Combined growout and stocker												
Catfish sales receipts												
Total receipts	14,428	2.44	16,664	2.44	15,546	2.44	17,150	2.44	14,565	2.43	15,857	2.44
Variable costs	13,495	4.90	14,139	4.37	13,817	4.64	13,646	4.17	14,207	4.96	13,926	4.56
Income above variable costs	933	0.16	2525	0.37	1729	0.26	3505	0.50	357	0.06	1931	0.28
Fixed costs	4938	1.81	4938	1.54	4938	1.68	3735	1.27	3735	1.44	3735	1.36
Total costs	18,432	6.71	19,077	5.91	18,754	6.31	17,381	5.44	17,942	6.40	17,662	5.92
Net return above all costs	−4004	−4.28	−2413	−3.47	−3209	−3.87	−231	−3.00	−3378	−3.97	−1804	−3.48

* Some columns of number may not add up as presented due to integer rounding.

Table 9. Summarized economic and accounting profit results for four growout in-pond raceway systems (IPRS) producing foodsize hybrid catfish, channel catfish *Ictalurus punctatus* ♀× blue catfish, *I. furcatus* ♂, with each raceway placed in a 0.4 ha pond, USD, 2018.

	RW 1 63 m^3	RW 2 63 m^3	Average RW 1 and 2	RW 3 45 m^3	RW 4 45 m^3	Average RW 3 and 4
Economic Profit						
Net return above all costs, USD	−1999	−902	−1450	1198	−1416	−109
- NR USD/kg	−0.44	−0.18	−0.31	0.23	−0.32	−0.05
Total cost, USD/kg	2.89	2.62	2.76	2.23	2.77	2.50
Accounting Profit						
EBITDA [a], USD	2682	3776	3229	4920	2288	3604
- NR USD/kg	0.59	0.74	0.67	0.93	0.52	0.73
Total cost, USD/kg	1.85	1.71	1.78	1.52	1.92	1.72

[a] EBITDA—Earnings before interest, taxes, depreciation, and amortization; it is a measure of system performance. NR = Net return; RW = raceway.

Table 10. Summarized economic and accounting profit results for four in-pond raceway systems (IPRS) producing stocker hybrid catfish, channel catfish *Ictalurus punctatus* ♀× blue catfish, *I. furcatus* ♂, with each raceway placed in a 0.4 ha pond, USD, 2018.

	RW 1 14 m^3	RW 2 14 m^3	Average RW 1 and 2	RW 3 14 m^3	RW 4 14 m^3	Average RW 3 and 4
Economic Profit						
Net return above all costs, USD	−2005	−1511	−1758	−1428	−1962	−1695
- NR USD/kg	−0.48	−0.22	−0.35	0.17	−0.36	−0.09
Total cost, USD/kg	3.82	3.29	3.55	3.22	3.63	3.43
Accounting Profit						
EBITDA [a], USD	−70	452	191	545	53	299
- NR USD/kg	0.55	0.69	0.62	0.88	0.49	0.68
Total cost, USD/kg	2.45	2.14	2.30	2.09	2.38	2.23

[a] EBITDA—Earnings before interest, taxes, depreciation, and amortization; it is a measure of system performance. NR = Net return; RW = raceway.

The effect of the four investment scenarios and varying feed and fish prices produced a matrix of net returns with some positive and negative values (Table 12). The worse case scenario, that is, the lowest net returns, always occurred in Scenario 1, where the business needed a full initial investment to get the farm and IPRS up and running regardless of fish or feed price. The best-case scenarios, that is, the highest net returns, always occurred in Scenario 4 where the primary investments were lowest and only for growout and stocker IPRS units and their associated components (Table 12). Highlighted cells in Table 12 indicate positive net returns under different feed and fish prices and Scenarios 1 through 4. In RW1/RW2 raceways, feed prices would need to decrease by USD 30/MT to USD 400/MT (from the base feed price of USD 430/MT) and fish selling price would need to increase by USD 0.48/kg (+20%) to USD 2.92/kg (from the base fish selling price of USD 2.44/kg) for net returns to be positive for Scenarios 1 (USD 523), and even higher net returns for Scenarios 2, 3, and 4. However, in Scenario 1 for RW3/RW4 at average prices (feed price = USD 430/MT and fish selling price = USD 2.44/kg), a 20% increase in fish selling price (to USD 2.92/kg) is required to have a positive net return (USD 1351), and even higher net returns resulted for Scenarios 2, 3, and 4 at these prices. Alternatively, at the same +20% fish price, a decrease in feed price by USD 30/MT (to USD 400/MT) also led to a positive net return for Scenario 1 (USD 1644), and higher returns for Scenarios 2, 3, and 4.

Table 11. Different levels of investment required for growout (63 m^3 or 45 m^3) plus stocker unit (14 m^3) in-pond raceway system (IPRS) scenario sensitivity analyses for each raceway placed in a 0.4 ha pond, USD, 2018.

Items	Investment Required per Scenario [a]							
	1		2		3		4	
	63 m^3 IPRS	45 m^3 IPRS	63 m^3 IPRS	45 m^3 IPRS	63 m^3 IPRS	45 m^3 IPRS	63 m^3 IPRS	45 m^3 IPRS
Capital items								
Land, USD/ha [b]	986	986	0	0	0	0	0	0
Pond construction [c], USD	1550	1550	1550	1550	1550	1550	0	0
RW 1 and 2 (4.9 × 10.7 × 1.2 m = 63 m^3)	25,000	-	25,000	-	25,000	-	25,000	-
RW 3 and 4 (3.0 × 12.2 × 1.2 m = 45 m^3)	-	6000	-	6000	-	6000	-	6000
RW 1, 2, 3 and 4 (1.8 m × 5.8 m × 1.30 m = 14 m^3)	1867	1867	1867	1867	1867	1867	1867	1867
Subtotal	29,403	10,403	28,417	9417	28,417	9417	26,867	7867
Machinery and equipment								
Equipment [d], USD/ha	1513	1513	1513	1513	303	303	0	0
1.0 HP blowers for water movers	880	880	880	880	880	880	880	880
1.5 HP blower's raceway units	1200	1200	1200	1200	1200	1200	1200	1200
1.5 HP blowers for water movers	1200	1200	1200	1200	1200	1200	1200	1200
1.0 HP blowers for small RW units	900	900	900	900	900	900	900	900
Water mover units (large RWs)	2500	2500	2500	2500	2500	2500	2500	2500
Water mover units (small RWs)	1200	1200	1200	1200	1200	1200	1200	1200
Baffle fencing and floats	200	200	200	200	40	40	0	0
Boardwalks—raceways 1 and 2	1000	-	1000	-	200	-	0	-
Boardwalks—raceways 3 and 4	-	1200	-	1200	-	240	-	0
Subtotal	10,593	10,793	10,593	10,793	8423	8463	7880	7880
TOTAL 2018	39,996	21,196	39,010	20,210	36,839	17,879	34,747	15,747

[a] Scenario 1 represents a new aquaculture operation, requiring land purchase, pond construction, and purchase of all machinery and equipment; this is the base scenario to which other scenarios are compared. Scenario 2 represents the situation in Scenario 1, except the land is already owned. Scenario 3 represents the situation in Scenario 2, but 80% of the machinery and equipment are already on hand. Scenario 4 represents the situation in Scenario 3, with only some raceway component purchases. The [b] land charge was USD 2031/ha. [c] Pond construction (USD 3830/ha) includes construction of the pond with water supply, drainage, and electrical service, but no wells because they are seldom used on western Alabama catfish farms. [d] Equipment costs (USD 3739/ha) include a backup generator (20 kW plus transfer switch), propane tank for generator, electrical line for water movers, tractors, trucks, mower, electrical aerators, power take-off aerator, feeder, feed bin, pump, office, shop, tools, utility trailer, storage container, dissolved oxygen meter, and computer.

Profitability measurements stemming from the cash flow analysis showed the highest NPV (Table 13) was realized in the smaller raceway combinations (45 m^3 growout + stocker), where lower investment was required, that is, when land and most aquaculture farm equipment was already owned and appropriately configured ponds existed, as in Scenario 4. In the large raceway combinations (63 m^3 + stocker), the NPV remained negative, even in the best-case scenario, ranging from USD 26,939 in Scenario 1 to USD 21,649 in Scenario 4. In the small raceway combinations (45 m^3 + stocker), NPV values ranged from USD 34,797 (Scenario 1) to USD 53,424 (Scenario 4). Likewise, for the IRR with an increase from 28.6% to 45.0%. Longer PBPs were found for the large raceway combinations (RW1/RW2) compared to smaller raceway combinations (RW3/RW4), with a reduction from 28.1 years to 2.7 years for Scenario 1, respectively. This showed the large impact of higher initial investment for RW1/RW2 and their negative net returns to the lower initial investment and positive net returns for RW3/RW4. Lower initial investment and positive net returns are crucial for profitability. Comparison of PBP for RW1/RW2 in Scenario 1 (28.1 years) to RW1/RW2 in Scenario 4 (23.8 years) shows how high initial investment combined with negative net returns could do little to reduce the payback period. For small raceways, when shifting from the base investment level (Scenario 1) to Scenario 4, PBP was reduced from 2.7 years to 1.9 years.

Table 12. Effects of different feed price, fish price, and investment scenarios on net returns required for growout (63 m^3 or 45 m^3) plus stocker unit (14 m^3) in-pond raceway system (IPRS) from producing hybrid catfish (channel catfish *Ictalurus punctatus* ♀× blue catfish, *I. furcatus* ♂) in in-pond raceway systems (IPRS), with each raceway placed in a 0.4 ha pond, USD, 2018.

		RW1/RW2 (Growout +Stocker Unit)				RW3/RW4 (Growout +Stocker Unit)			
Feed Price	**Fish Price**	**Scenario** [a]				**Scenario** [a]			
		1	**2**	**3**	**4**	**1**	**2**	**3**	**4**
USD 370/MT	1.95	(5385)	(4691)	(4431)	(4253)	(4390)	(3386)	(3108)	(2890)
	2.19	(3830)	(3136)	(2876)	(2698)	(2805)	(1800)	(1522)	(1305)
	2.44	(2275)	(1582)	(1322)	(1144)	(1219)	(214)	63	281
	2.85	(721)	(27)	233	411	367	1372	1649	1867
	2.92	834	1528	1787	1966	1937	2941	3219	3437
USD 400/MT	1.95	(5696)	(4691)	(4742)	(4564)	(4683)	(3678)	(3401)	(3183)
	2.19	(4141)	(3136)	(3187)	(3009)	(3097)	(2092)	(1815)	(1597)
	2.44	(2586)	(1582)	(1633)	(1455)	(1512)	(507)	(229)	(12)
	2.85	(1032)	(27)	(78)	100	74	1079	1357	1574
	2.92	523	1528	1476	1654	1644	2649	2926	3144
USD 430/MT	1.95	(6318)	(5313)	(5053)	(4875)	(4976)	(3971)	(3693)	(3476)
	2.19	(4763)	(3758)	(3499)	(3320)	(3390)	(2385)	(2108)	(1890)
	2.44	(3209)	(2204)	(1944)	(1766)	(1804)	(799)	(522)	(304)
	2.85	(1654)	(649)	(389)	(211)	(219)	786	1064	1282
	2.92	(99)	905	1165	1343	1351	2356	2634	2851
USD 460/MT	1.95	(6836)	(5624)	(5364)	(5186)	(5268)	(4264)	(3986)	(3768)
	2.19	(5282)	(4069)	(3810)	(3631)	(3683)	(2678)	(2400)	(2183)
	2.44	(3727)	(2515)	(2255)	(2077)	(2097)	(1092)	(815)	(597)
	2.85	(2172)	(960)	(700)	(522)	(511)	494	771	989
	2.92	(618)	594	854	1032	1059	2063	2341	2559
USD 490/MT	1.95	(7355)	(5935)	(5675)	(5497)	(5561)	(4556)	(4279)	(4061)
	2.19	(5800)	(4380)	(4121)	(3943)	(3975)	(2971)	(2693)	(2475)
	2.44	(4246)	(2826)	(2566)	(2388)	(2390)	(1385)	(1107)	(890)
	2.85	(2691)	(1271)	(1012)	(833)	(804)	201	479	696
	2.92	(1136)	283	543	721	766	1771	2048	2266

[a] Scenario 1 represents a new aquaculture operation, requiring land purchase, pond construction, and purchase of all machinery and equipment; this is the base scenario to which other scenarios are compared. Scenario 2 represents the situation in Scenario 1, except the land is already owned. Scenario 3 represents the situation in Scenario 2, but 80% of the machinery and equipment are already on hand. Scenario 4 represents the situation in Scenario 3, with only some raceway component purchases. Highlighted cells indicate positive net returns under different feed and fish prices and Scenarios 1 through 4. MT = Metric ton.

The final sensitivity analysis investigated the effects of reducing IPRS growout raceway construction cost (note that the stocker unit IPRS unit cost in this analysis was not changed, as they were built from the lower cost materials in all four cases). After the per unit construction material cost for the smaller growout raceways, RW3/RW4 cost per m^3 was substituted in for the per unit costs of the larger growout raceway dimensions, and the reduction in investment costs ranged from −58% to −52% over Scenarios 1 to 4, respectively (Figure 4a) (note, in Figure 4a,b and Figure 5a,b, the dark blue legend is for RW3/RW4 which had the lower cost construction materials, and is included in Figures 4 and 5 as a reference for comparison to the original and reduced RW1/RW2 investment costs). Sensitivity results show payback periods were reduced from 28.1 years (original raceways cost in Scenario 1) to 4.0 years (reduced raceway cost for Scenario 1) and to 1.9 years (reduced raceway cost reduction for Scenario 4) (Figure 4b).

Table 13. Financial measures of profitability for the four investment scenarios producing foodsize and stocker hybrid catfish, channel catfish *Ictalurus punctatus* ♀× blue catfish, *I. furcatus* ♂, in in-pond raceway systems (IPRS), per raceway placed in a 0.4 ha pond, 2018.

Item	Investment Scenarios [a]							
	1		2		3		4	
	Average Pond 1 and 2	Average Pond 3 and 4	Average Pond 1 and 2	Average Pond 3 and 4	Average Pond 1 and 2	Average Pond 3 and 4	Average Pond 1 and 2	Average Pond 3 and 4
Financial net return, USD	1421	7732	1421	7732	1737	8794	1928	9700
Investment cost, USD	39,996	21,196	39,010	20,210	36,839	17,879	34,747	15,747
Payback period, year	28.1	2.7	27.4	2.6	21.2	2.0	18.0	1.6
Net present value, USD	−26,938	34,797	−25,998	35,737	−21,509	45,226	−18,028	53,424
Internal rate of return, %	−18.0%	28.6%	−17.7%	30.1%	−14.1%	37.5%	−11.6%	45.0%

Using a discount rate of 5%. [a] Scenario 1: pond construction, all machinery, all land (base scenario). Scenario 2: pond construction, all machinery, and no land. Scenario 3: pond construction, some machinery, and no land. Scenario 4: existing ponds, machinery, and land. Net return in Scenario 1 and 2 were the same because the depreciation for both scenarios was the same; the only difference is that the land was not purchased in Scenario 2, but it is not depreciable.

Net present value (Figure 5a) and IRR values (Figure 5b) increased accordingly at the new investment cost over the four scenarios. Net present value shifted from USD −26,938 when the original raceways cost for Scenario 1 was used to a NPV of USD 19,484 at the reduced raceway cost for Scenario 1. These results show the huge influence that material costs have on initial investments. Scenario 1 is the farm level where all land, pond construction, machinery, and equipment for running an IPRS need to be purchased and is the reason for the large difference in NPV values between the original and reduced investment costs. The best-case scenario (Scenario 4) had a NPV of USD 42,834 compared to the Scenario 1 NPV of USD −26,938, which is an increase of 259% (Figure 5a). Internal rate of return percentages also shifted from −18.0% (original raceways cost for Scenario 1) to +19.3% (reduced raceway cost for Scenario 1 and RW1/RW2) and to 39.7% for the reduced raceway cost for Scenario 4 and RW1/RW2 (Figure 5b).

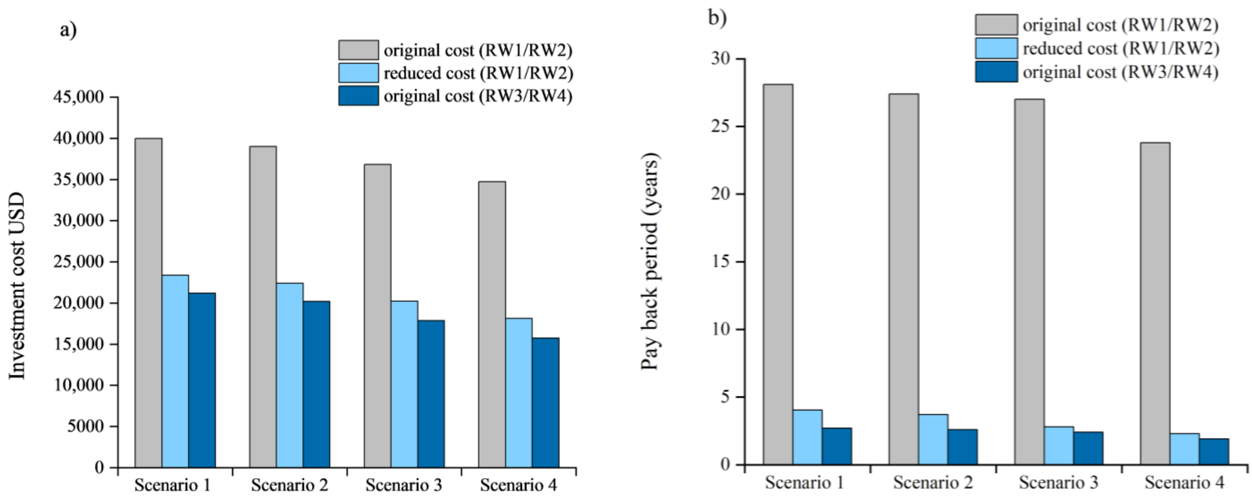

Figure 4. Effect of reducing the IPRS growout raceway construction investment cost by 66% on (**a**) investment cost (USD), (**b**) payback period (years). Scenario 1 includes pond construction, all machinery/equipment cost, and all land costs. Scenario 2 includes pond construction, all machinery/equipment cost, and no land cost. Scenario 3 includes pond construction, 80% less machinery/equipment cost, and no land cost. Scenario 4 represents an existing aquaculture operation that requires no pond construction, no machinery, and no land purchases, only some specialty IPRS items. Stocker units were built from the less expensive materials, only the price of growout units was reduced.

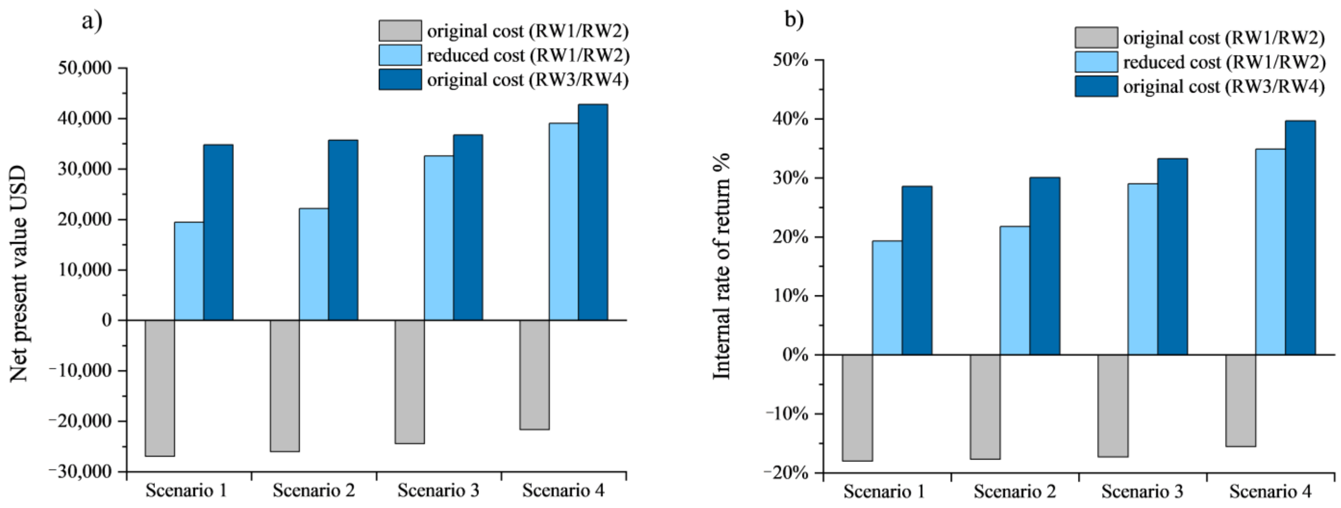

Figure 5. Effect of reducing the IPRS growout raceway construction investment cost by 66% on (**a**) net present value (USD) and (**b**) internal rate of return (%). A discount rate of 5% was used. Scenario 1 includes pond construction, all machinery/equipment cost, and all land costs. Scenario 2 includes pond construction, all machinery/equipment cost, and no land cost. Scenario 3 includes pond construction, 80% less machinery/equipment cost, and no land cost. Scenario 4 represents an existing aquaculture operation that requires no pond construction, no machinery, and no land purchases, only some specialty IPRS items. Stocker unit were built from the less expensive materials, only growout units had their price reduced.

4. Discussion

4.1. Water Quality

Water temperatures varied noticeably with season. Seasonal temperature variations occurred in this study and were similar to values reported by Boyd for the same location (Auburn, Alabama [24]. Higher temperatures occurred in the summer months (July to September). The combination of elevated total alkalinity, total hardness, and chloride concentrations was thought to be beneficial for fish production and equated to a more balanced and stress-free rearing environment, preventing nitrite toxicity or methaemoglobinaemia, commonly known as "brown blood disease" [25]. Note that in IPRS having high biomass densities, an emergency aeration system is required and must automatically turn on when electricity to WWUs goes off.

4.2. Fish Performance

Our study showed superior yields from IPRS (14,500 kg/ha to 17,581 kg/ha) compared to traditional earthen ponds' average yields of 4500 to 5500 kg/ha [25] and 9000 to 14,000 kg/ha [14,15,26]. Additionally, IPRS yields here were superior to the study conducted by Roy in their fixed concrete IPRS cells, which resulted in 7800 kg/ha of hybrid catfish harvested in their first cycle (10–12 months) and 6195 kg/ha harvested in their second cycle (12–19 months) [27]. In general, good results were found producing hybrid catfish in the IPRS, with very low observed mortalities, demonstrating that IPRS has the potential to double or triple traditional catfish farm production. Other intensive aerator and split pond systems have similar yields as found in this IPRS study [7].

When ponds were outside of the acceptable and desired water quality ranges, we saw the negative impacts on fish survival. Pond 4 had low dissolved oxygen ranges in early morning hours (also this pond had a visible phytoplankton bloom on the water surface throughout the cycle), which possibly resulted in a lower survival rate. Small fish consume more oxygen for a given total weight than larger fish, and oxygen uptake increases as water temperature increases [28]. An interesting fact was observed in this particular pond, where low survival was found (stocker unit in pond 4). Even after having low oxygen levels during the summer months, the fish caught up in terms of growth by the end of the cycle and had the highest final average weight (grams) than in other raceways. It is potentially true that the early fish losses actually promoted rapid weight gain [29].

We also observed that in late October and in early November, fish stopped eating and some low mortality occurred (fish floating on the surface were recorded), possibly a disease outbreak. However, no signs of bacterial infection were visibly noticed (unfortunately fish were not taken for a disease diagnosis, which would potentially give us more information on what happened in this period). The health of fish from pond 4 growout and stocker raceways were probably impacted by the many days of lower oxygen levels and consequently had lower survival rates. While pond 1 had lower survival rates, we did not observe floating dead fish. They remained on the bottom of the raceway and potentially disintegrated or were consumed by muskrats, raccoons, or other fish predators. As soon as fish stopped eating in the fall, they were placed into a prophylactic formalin bath at 125 ppm for 40 min per RW unit. This chemical bath is possible due to the small RW size volume, and also lowered chemical treatment cost when compared to treating whole ponds [30].

Harvest results show similar average production for hybrids in raceways RW1/RW2 plus stocker units (15,279 kg/ha) and RW3/RW4 plus stocker units (15,597 kg/ha), while Brown et al. (2014) harvested 26,057 kg/ha of hybrid catfish in their IPRS research [31]. This suggests that we could increase the number of fish produced or extend the production cycle to harvest heavier fish (grams) in the 0.4 ha ponds. In fact, we still do not know the carrying capacity of a system of this size in this pond size. A total biomass ranging from 72 to 117 kg/m^3 was produced in the growout units and 101 to 124 kg/m^3 for the stocker units in this study. Roy et al. (2019) produced a biomass that varied between 51 and 125 kg/m^3 for catfish hybrids [27] and Brown et al. (2011) produced 55 to 199 kg/m^3 for channel catfish and 159 to 215 kg/m^3 for hybrids [25]. Literature shows that different species were produced in IPRS in China [32,33]. For example, a 220 m^3 raceway with an associated waste collector was able to produce bluntnose black bream (83 kg/m^3 or 5288 kg/ha), channel catfish (67 kg/m^3 or 4322 kg/ha), yellow catfish (55 kg/m^3 or 3138 kg/ha), and largemouth bass (48 kg/m^3 or 2603 kg/ha) [34].

4.3. Economic Analysis

To survive the short run, i.e., the current operating year, farm businesses must be able to sell fish at a price that is greater than its breakeven price above variable costs [35]. Engle (2012) suggests calculating whether the farm can survive the short run by using the breakeven price above variable costs and comparing it to the price that the farmer actually receives or expects to receive. The difference would be the USD/kg profitability margin. In our study, the breakeven price above variable cost was less than the selling price, indicating that the short-term profitability was positive at the income minus variable cost point in the enterprise budget. Net income above variable cost determines if an operation should continue to produce. Here, the higher production led to greater receipts and improved the chance of being profitable [18], but greater production also means greater production costs. The breakeven price covering variable and fixed costs was greater than the price received, indicating that the long-term was not profitable under the current conditions. This was the case in all but one raceway, RW3, where the highest biomass (total harvest kg) and lowest FCR occurred.

Our research found production costs ranging from USD 2.23 to USD 2.89/kg, having profit margins ranging from USD +0.23 to USD −0.44/kg for the four foodsize catfish (Table 9); and production costs for the stocker units ranged from USD 3.22 to USD 3.82/kg, having profit margins ranging from USD +0.17 to USD −0.48/kg (Table 10). When the EBITDA approach was used, the breakeven price decreased and resulted in profit margins ranging from USD 0.52 to USD 0.93/kg for foodsize (Table 9) and USD 0.55 to USD 0.88/kg for stocker catfish (Table 10). As can be seen, production costs for stockers were higher than for foodsize fish in both approaches (economic and EBITDA). With a lack of information on stocker selling prices, we decided to use foodfish prices for stockers grown in the stocker unit raceways. Ninety percent of produced stockers were within the small fish size category (<0.454 kg), which received a selling price of USD 2.40/kg from processers for this size category. Usually, fingerlings are sold by length, up to a maximum of 23 cm (104 g), and not by weight. Our stockers from the fingerling to stocker unit had an average weight of 120 g (25 cm), and thus were valued by weight instead of length. These stockers are too large for hatcheries to transport easily and would require more technical skills and oxygen. On the other hand, it is easy to harvest them from our stocker unit and restock (transfer, split) them into the growout raceway located next to each other in the pond.

Breakeven yields for RW1/RW2 could be achieved only if we ran the trial for another 47 days (hypothetically) to achieve the breakeven yield required to be economically profitable. In this case, fish would conceivably gain more weight (2.55 g/day). Analyzing this result, it seems as though we should stock these larger raceways (RW1/RW2) more heavily compared with the growout small raceways. Breakeven yields in RW3/RW4 could easily surpass the actual yields by increasing survival by less than 1% or by increasing production days by four (hypothetically). To be able to achieve breakeven yields in the stocker units, we would also need to stock at a higher density or by extending the production cycle by 85 days for RW1/RW2 and 75 days for RW3/RW4 (hypothetically).

A recent multi-state survey of the U.S. catfish industry (Alabama, Arkansas, and Mississippi) was conducted to identify specific reasons influencing the decisions of producers to adopt or not adopt alternative catfish production technologies (intensive aeration, in-pond raceways, or split-pond systems) [36]. High yield and greater control over the production process were the major reasons for the adoption of alternative catfish production technologies. Early adopters had significantly larger farms, greater numbers of ponds, and significantly greater percentages of hybrid catfish use. The primary reason for the adoption of alternative production technologies was "to achieve higher yields". Our research shows IPRS can achieve higher yields in pilot scale IPRS. The most-cited reason for non-adopters having no plans to adopt alternative production technologies in the future was "high investment cost" [36]. Thus, it is important to investigate using less expensive IPRS building materials.

During the research period, fish prices (USD/kg) were not very attractive, making the IPRS unprofitable. Our sensitivity analyses changing fish and feed prices showed interesting results and could address uncertainties that farmers have about IPRS being unprofitable and hinder their future adoption of this system. The sensitivity analysis (Table 12) demonstrated that there were price combinations that made the IPRS profitable and by how much. Additionally, the sensitivity analysis included different farmer situations, from absolute beginner to advanced aquaculture operations (Table 12). Such analyses were conducted to avoid overly optimistic net returns and potentially misleading results to those investigating this new technology [18]. The farmer can view prices they face currently and their farm investment level when considering this new technology to see if it would be profitable or not for their situation. In fact, fish selling prices increased to USD 2.88/kg in August 2021, an increase of USD 0.44 per kg, from the prices used when this study occurred in 2018. Unfortunately, feed prices increased as well, from USD 430/MT used in the study to USD 490/MT currently. Prices are dynamic and can change due to fish demand, supply of feed ingredients, and other supply chain issues, such as COVID-19 [37]. The alert farmer stays abreast of price changes and reacts to these risks by changing harvest schedules, calculating when to use advanced feed booking, and timing other purchases when 'bargain' prices occur.

In Scenario 1 for RW1/RW2, the return to the IPRS was not profitable (USD −3209) at our study's base prices (fish = USD 2.44/kg and feed = USD 430/MT). However, at current prices (fish = USD 2.85/kg and feed = USD 490/MT), we see that Scenarios 2, 3, and 4 were positive (profitable) for RW3/RW4, including the stocker units in all cases (Table 12). When feed price was USD 370/MT and fish prices ranged from USD 2.44/kg to USD 2.92/kg, 83% of the net returns were positive (highlighted in Table 12). For current price levels (August 2021), the fish price increased by 10% over our initial sensitivity analysis fish price

(USD 2.85/kg), and the current feed price increased by 14% to USD 490/MT from the base feed price, and we see three of the four RW3/RW4 scenarios had positive net returns (highlighted in Table 12) at these prices (none were positive for the RW1/RW2 scenarios).

Financial measures of profitability were positive at different stages of farm development, i.e., different required levels of investment for IPRS implementation (Table 13). Scenarios 1 and 2 had the same net return, USD 1421, because the only difference between them was the land purchase. Since land is not depreciated and all other items in the cash flow were constant, net returns did not change. If a farm implemented five IPRS, then the financial net return would be USD 7105 (USD 1421 × 5) at the end of one RW1/RW2 production cycle, and for five ponds of RW3/RW4 raceway size, the financial net return would be USD 38,660 (USD 7732 × 5). If an aquaculture farm already exists (Scenario 4), the financial net return would be USD 9640 (USD 1928 × 5) using RW1/RW2 raceway size, and USD 48,500 (USD 9700 × 5) for RW3/RW4 raceway size. These results confirm that initial raceway investment costs strongly impact the long-term feasibility of the IPRS operation.

The average size of a catfish farm in Alabama is 99 ha [38] and our IPRS was placed into 0.4 ha ponds, and we had four ponds (1.6 ha total water area), which would be 1.6% of the average farm pond area. Continuing with the five IPRS pond example above, multiplying 0.4 ha pond size by five ponds, we would use 2.0 ha or 2.0% of the total farm surface area only and harvest 24,130 kg of foodsize hybrid catfish and 8100 kg of stocker-sized catfish.

When NPV is positive, the investment is profitable because the flow of returns, after accounting for the time value of money at the specified discount rate (5% used herein), is greater than zero. When NPV is negative, then the investment earns less than its opportunity cost, i.e., potential interest earned if the IPRS investment capital was put into another investment, and is not profitable [18]. This suggests that the key factors needing careful evaluation during the IPRS planning stage should include the initial investment, fish species selection, achievable production, and fish selling price, as well as the largest input costs for feed and labor.

This study shows the advantage of producing stockers from the "stocker unit" to supply fish for the start of the next growout raceway production cycle, but by itself, it was not profitable. Its advantage lies in the availability of large fingerlings or even stocker-sized fish to put into the next cycle's growout raceways. It is not practical to transport these larger stocker-sized fish for long distances, and their availability is limited. It is okay for the stocker unit to produce different size large fingerlings or small stockers, as staggering the stocking of growout cells with different-sized fish can allow different harvest times and supply that is available to sell year-round.

Roy et al. (2019) used different fish sizes in each raceway cell to stagger production. This allowed harvests to be marketed throughout the year. When they stocked larger fingerlings (175 g) the net yield was higher in four of the five cells, suggesting that larger fingerlings result in higher production [27]. This indicates the need for further research on stocking larger fish (stockers) in IPRS units. Recent trends in processor demand for a live catfish product indicates a 0.68 to 0.90 kg catfish would require additional growout time and a corresponding rise in operational expenses [39]. These authors suggested that a fingerling-to-stocker pond phase would be beneficial, and in one treatment, they stocked fingerlings approximately 10.2 to 15.2 cm (23 to 27 g) and grew them to a stocker size (92 g) during a 6–7-month period. Our study stocked fingerlings measuring 15 cm weighing 29.1 g and achieved a final weight of 120 g in 4.7 months (143 days). Research conducted by [15] in traditional ponds showed that catfish hybrids required at least 10 months (0.83 years) to grow from 0.031 kg fingerling to 0.86 kg premium-sized foodfish, while we grew a 0.031 kg fingerling to a 0.61 kg foodfish in 7.4 months. The premium-sized catfish range is currently 0.45 to 1.81 kg per fish, though this can change as the processor needs change.

5. Conclusions

Hybrid catfish yields from the IPRS stocker and foodsize raceway units surpassed those from traditional catfish production systems. Feed conversion ratios ranged between

1.6 and 1.8 for stockers and foodsize hybrid catfish produced in IPRS and were within ranges for other intensive catfish production systems and technologies. Initial raceway cost had a large impact on the long-term feasibility of the IPRS, and raceways made with less expensive materials had a higher profit potential. However, the less expensive raceway materials may result in a shorter life span and require more repairs, maintenance, and replacement costs. Lowering initial farm level investment reduced the payback period, increased net present values and internal rates of return. IPRS shows promise at intensifying production and profitability, suggesting that further research could improve these metrics. Survival, stocking density, and prophylactic disease treatments would be key to increasing yields and profitability. Based on our observations of the growout raceways and ponds during these studies, we feel that the carrying capacity of each raceway pond was not surpassed. We would recommend to new users of IPRS that growout stocking should be increased above the levels used herein. Secondly, we recommend very careful monitoring of fish behavior and water quality for early intervention to correct these threats.

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Data Availability Statement: The data that support the findings of this study are available from the corresponding author, upon reasonable request.

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References

1. NMFS F of the US. *2020 Fisheries of the United States. National Marine Fisheries Service Office of Science and Technology Fisheries Statistics Division*; NOAA National Marine Fisheries Service: Silver Spring, MD, USA, 2022; p. 28. Available online: https://media.fisheries.noaa.gov/2022-05/Fisheries-of-the-United-States-2020-Report-FINAL.pdf (accessed on 1 January 2023).
2. Hanson, T. *Catfish Processing—December 2022. January through December 2022 Processing Up 5 Percent from Same Period in 2021*; Released 17 January 2022; The Catfish Institute: Jackson, MS, USA, 2022; p. 9.
3. USDA, United States Department of Agriculture. *Catfish Production. Catfish Value of Sales Up 12 Percent from 2020 [Internet]*; National Agricultural Statistics Service (NASS): Washington, DC, USA, 2022. Available online: https://downloads.usda.library.cornell.edu/usda-esmis/files/bg257f046/8c97ms16p/n296z193k/cfpd0222.pdf (accessed on 1 January 2023).
4. Hegde, S.; Kumar, G.; Engle, C.; Hanson, T.; Roy, L.A.; Cheatham, M.; Avery, J.; Aarattuthodiyil, S.; Senten, J.; Johnson, J.; et al. Technological progress in the US catfish industry. *J. World Aquac. Soc.* **2022**, *53*, 367–383. [CrossRef]
5. Engle, C.R.; Hanson, T.; Kumar, G. Economic history of U.S. catfish farming: Lessons for growth and development of aquaculture. *Aquac. Econ. Manag.* **2021**, *26*, 1–35. [CrossRef]
6. Boyd, C.E.; Torrans, E.L.; Tucker, C.S. Dissolved Oxygen and Aeration in Ictalurid Catfish Aquaculture: Dissolved oxygen and aeration. *J. World Aquac. Soc.* **2017**, *49*, 7–70. [CrossRef]
7. Kumar, G.; Engle, C.R.; Hanson, T.R.; Tucker, C.S.; Brown, T.W.; Bott, L.B.; Roy, L.A.; Boyd, C.E.; Recsetar, M.S.; Park, J.; et al. Economics of alternative catfish production technologies. *J. World Aquac. Soc.* **2018**, *49*, 1039–1057. [CrossRef]
8. Engle, C.R.; Christie, T.W.; Dorr, B.S.; Kumar, G.; Davis, B.; Roy, L.A.; Kelly, A.M. Principal economic effects of cormorant predation on catfish farms. *J. World Aquac. Soc.* **2020**, *52*, 41–56. [CrossRef]
9. Kumar, G.; Gaunt, P. Medicated-Feed Intervention in Catfish Farming: An Economic Perspective. *N. Am. J. Aquac.* **2020**, *82*, 190–199. [CrossRef]

10. Peterman, M.A.; Posadas, B.C. Direct Economic Impact of Fish Diseases on the East Mississippi Catfish Industry. *N. Am. J. Aquac.* **2019**, *81*, 222–229. [CrossRef]
11. Wu, G.; Saoud, I.P.; Miller, C.; Davis, D.A. The Effect of Feeding Regimen on Mixed-Size Pond-Grown Channel Catfish, *Ictalurus punctatus*. *J. Appl. Aquac.* **2004**, *15*, 115–125. [CrossRef]
12. Engle, C.R.; Valderrama, D. An Economic Analysis of the Performance of Three Sizes of Catfish *Ictalurus punctatus* Fingerlings Understocked in Multiple-Batch Production. *J. World Aquac. Soc.* **2001**, *32*, 393–401. [CrossRef]
13. Kumar, G.; Wise, D.; Li, M.; Aarattuthodiyil, S.; Hegde, S.; Rutland, B.; Pruitt, S.; Griffin, M.; Khoo, L. Effect of understocking density of channel catfish fingerlings in intensively aerated multiple-batch production. *J. World Aquac. Soc.* **2020**, *52*, 30–40. [CrossRef]
14. Hanson, T.R.; Bott, L.B.; Chappell, J.A.; Whitis, G.N.; Kelly, A.M.; Roy, L.A. Research Verification of Single- and Multiple-Batch Production Practices at Two Channel Catfish Farms in Western Alabama. *N. Am. J. Aquac.* **2020**, *82*, 1–10. [CrossRef]
15. Bott, L.B.; Roy, L.A.; Hanson, T.R.; Chappell, J.; Whitis, G.N. Research Verification of Production Practices Using Intensive Aeration at a Hybrid Catfish Operation. *N. Am. J. Aquac.* **2015**, *77*, 460–470. [CrossRef]
16. Kaliba, A.R.; Engle, C.R. Economic Impact of the Catfish Yield Verification Trials. *J. Appl. Aquac.* **2005**, *17*, 25–45. [CrossRef]
17. Roy, L.A.; Brown, T.W. In-pond raceway systems: Are they a good alternative for U.S. catfish farmers? *Ark. Aquafarm.* **2016**, *33*, 6–7.
18. Engle, C.R. *Aquaculture Economics and Financing: Management and Analysis*; Wiley-Blackwell: Hoboken, NJ, USA, 2010; p. 260.
19. Kay, R.D.; Edwards, W.M.; Duffy, P.A. *Farm Management*, 9th ed.; McGraw Hill Education: New York, NY, USA, 2020; p. 480.
20. Hall, J. What Is EBITDA and Why Does It Matter? *The Motley Fool*. 2021. Available online: https://www.fool.com/investing/how-to-invest/stocks/ebitda/ (accessed on 30 November 2021).
21. Gallo, A.; A Refresher on Net Present Value. Harvard Business Review—Finance and Investing. 2014. Available online: https://hbr.org/2014/11/a-refresher-on-net-present-value (accessed on 30 November 2021).
22. Shaner, W.W. *Project Planning for Developing Economies*; Praeger: New York, NY, USA, 1979; p. 235.
23. Federal Reserve Bank of Kansas City. Average Effective Interest Rate on Non-Real Estate Bank Loans Made to Farmers. [Internet]. Available online: https://www.kansascityfed.org/agriculture/agfinance-updates/ (accessed on 1 January 2023).
24. Boyd, C.E. *Water Quality: An Introduction*, 2nd ed.; Springer: Boston, MA, USA, 2015; 357p.
25. Brown, T.W.; Chappell, J.A.; Boyd, C.E. A commercial-scale, in-pond raceway system for Ictalurid catfish production. *Aquac. Eng.* **2011**, *44*, 72–79. [CrossRef]
26. Kumar, G.; Li, M.H.; Wise, D.J.; Mischke, C.C.; Rutland, B.; Tiwari, A.; Aarattuthodiyil, S.; Griffin, M.J.; Khoo, L.H.; Ott, B.; et al. Performance of Channel Catfish and Hybrid Catfish in Single-Batch, Intensively Aerated Ponds. *N. Am. J. Aquac.* **2019**, *81*, 406–416. [CrossRef]
27. Roy, L.A.; Hanson, T.R.; Bott, L.B.; Chappell, J.A. 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. *JSAFWA* **2019**, *6*, 58–66.
28. Tucker, C.S.; Robinson, E.H. *Channel Catfish Farming Handbook*; Kluwer Academic Publishers: Boston, MA, USA; Dordrecht, The Netherlands; London, UK, 2002; 454p.
29. Torrans, L.; Ott, B. Effects of Density on Production of Hybrid Catfish in Intensively Aerated Earthen Ponds where Dissolved Oxygen is Not a Limiting Factor. *N. Am. J. Aquac.* **2019**, *81*, 417–423. [CrossRef]
30. Bott, L.B.; Roy, L.A.; Hanson, T. Chemical treatment costs reduced with in- pond raceway systems. *Glob. Seaf. Alliance* **2014**, *17*, 62–64.
31. Brown, T.W.; Hanson, T.R.; Chappell, J.A.; Boyd, C.E.; Wilson, D.S. Economic Feasibility of an In-Pond Raceway System for Commercial Catfish Production in West Alabama. *N. Am. J. Aquac.* **2013**, *76*, 79–89. [CrossRef]
32. Yuan, J.; Ni, M.; Liu, M.; Wang, H.; Zhang, C.; Mi, G.; Gu, Z. Analysis of the growth performances, muscle quality, blood biochemistry and antioxidant status of Micropterus salmoides farmed in in-pond raceway systems versus usual-pond systems. *Aquaculture* **2019**, *511*, 734241. [CrossRef]
33. Wang, Y.; Xu, P.; Nie, Z.; Li, Q.; Shao, N.; Xu, G. Growth, digestive enzymes activities, serum biochemical parameters and antioxidant status of juvenile genetically improved farmed tilapia (*Oreochromis niloticus*) reared at different stocking densities in in-pond raceway recirculating culture system. *Aquac. Res.* **2019**, *50*, 1338–1347. [CrossRef]
34. Wang, Y.; Xu, G.; Nie, Z.; Shao, N.; Li, Q.; Xu, P. Growth Performance of Bluntnose Black Bream, Channel Catfish, Yellow Catfish, and Largemouth Bass Reared in the In-Pond Raceway Recirculating Culture System. *N. Am. J. Aquac.* **2019**, *81*, 153–159. [CrossRef]
35. Engle, C.R. *Determining the Profitability of an Aquaculture Business: Using Income Statements and Enterprise Budgets*; Southern Regional Aquaculture Center, SRAC: Stoneville, MS, USA, 2012; p. 6.
36. Kumar, G.; Engle, C.; Avery, J.; Dorman, L.; Whitis, G.; Roy, L.A.; Xie, L. Characteristics of early adoption and non-adoption of alternative catfish production technologies in the U.S. *Aquac. Econ. Manag.* **2020**, *25*, 70–88. [CrossRef]
37. Hanson, T. *January through June 2021 Processing down 8 Percent from Same Period in 2020*; Catfish Processing Report; Released 16 July 2021; The Catfish Institute: Jackson, MS, USA, 2021; p. 9.

38. Hanson, T.; Roy, L.A.; Kelly, A.M. 2020 Alabama Farm-Raised Catfish Industry Highlights. Alabama Cooperative Station [Internet]. 2021, p. 2. Available online: https://www.aces.edu/blog/topics/aquaculture/alabama-farm-raised-catfish-industry-highlights/?cn-reloaded=1 (accessed on 30 November 2022).
39. D'Abramo, L.R.; Steeby, J.A.; Hanson, T.R.; Gerard, P.D. Evaluation of a Fingerling-to-Stocker Phase as Part of a New Production Strategy for the Commercial Farming of Channel Catfish. *N. Am. J. Aquac.* **2007**, *69*, 22–35. [CrossRef]