Evaluation of Split-Pond Systems for Production of Channel Catfish Fingerlings

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Abstract: Assessing alternative pond production systems that may reduce avian predation of channel catfish (*Ictalurus punctatus*) is of extreme interest to state/federal and private hatcheries. This study evaluated the culture of channel catfish fingerlings in a pilot-scale split-pond system (SPS) and compared it to traditional earthen ponds (TP). Six 0.04-ha ponds were covered by netting and stocked with channel catfish fingerlings at a rate of 200,000 fish ha^{-1}; ponds were evenly split between TP and SPS. Fingerlings were cultured for 99 days and fed a commercial diet twice daily. Fish were fed 4.0% to 6.5% of their total body weight during the first 73 days, then *ad libitum* until the end of the study due to reduced water temperatures. Production parameters were similar between treatments except for condition factor, which was higher for fish raised in the TP. Channel catfish fingerlings raised in SPS had a more uniform size distribution than in TP. Exclusion of avian predators in an aquaculture facility is expensive, and for that reason the use of the SPS may be considered as an integrated management approach to alleviate this problem.

Key words: intensive rearing, growth performance, survival

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Avian predation on fingerling channel catfish (*Ictalurus punctatus*) stocked into ponds on aquaculture facilities has and continues to be a significant problem in the southeastern United States (Dorr and Taylor 2003, Dorr and Fielder 2017, Engle et al. in press). Most commercial catfish operations are in Mississippi, Alabama, and Arkansas, and occur along the Mississippi Flyway, thus are highly available to a wide variety of migratory avian predators. Most production operations use intensively stocked ponds that provide a highly attractive food source for several migratory bird species.

The primary avian predators are all protected by the Migratory Bird Treaty Act, and they cause considerable losses on catfish farms. These include double-crested cormorants (*Phalacrocorax auratus*), great blue heron (*Ardea herodias*), the great egret (*A. alba*), and the American white pelican (*Pelecanus erythrorhynchos*) (King 1995, Stickley et al. 1995, Glahn et al. 1999, Glahn et al. 2000, King and Werner 2001, Dorr and Taylor 2003, Glahn and King 2004, Wise et al. 2008, King et al. 2010, Dorr et al. 2012). Due to federal protections, lethal control measures on aquaculture facilities are limited (Engle 2003, Engle and Stone 2013). Threats posed by avian predation on cultured catfish has been further exacerbated by a decrease in water ha of channel catfish production (Hanson 2019) and higher stocking densities (Tucker et al. 2014; Kumar and Engle 2017a, b; Kumar et al. 2018).

Economic losses to commercial catfish operations due to bird depredation are estimated in the millions of dollars annually (Wywialowski 1999, Glahn and Dorr 2002, Glahn and King 2004, Christie 2019, Engle et al. in press). Although all fish are vulnerable to bird depredation, the problem is especially severe for fingerlings due to their smaller size (Burr et al. 2020, p. 4). Piscivorous avian species also transfer many diseases to captive fish. Most notably, the American white pelican is an intermediate host of the catfish trematode (*Bolbophorus damnificus*). A study conducted by Wise et al. (2008) demonstrated that the impact of the catfish trematode was economically more significant than losses due to fish predation. Due to trematode outbreaks and predation losses, several catfish farm closures occurred in Louisiana and Mississippi (King and Werner 2001). Therefore, there has been great interest in finding new methods to mitigate fish losses due to birds.

Recently, the use of intensive pond-based production systems for culturing food-size catfish has been implemented by the U.S. catfish industry with great success (Bott et al. 2015, Kumar 2016, Kumar et al. 2016, Kumar and Engle 2017a, Kumar et al. 2018). The two most widely adopted intensive pond based systems include the split-pond system (SPS) and intensively aerated ponds; both systems, as of 2018, had over 1200 water ha in production in Mississippi, Arkansas, and Alabama (Kumar et al. 2018).

SPS ponds are divided into two sections, one being a fish culture unit that typically comprises 15%–20% of the pond area and the other being a waste-treatment section (Brown and Tucker 2014). The waste treatment section of the split pond serves to assimilate nitrogenous wastes and allows for more stable water quality throughout the production cycle (Tucker et al. 2014). In addition to being evaluated for use in the catfish industry, SPS ponds have been evaluated for baitfish and largemouth bass culture (*Micropterus salmoides*; Quintero et al. 2017, Smith and Stone 2017, Quintero et al. 2019). Using a SPS, commercial catfish farmers have been able to more than double traditional earthen pond production yields of marketable size fish within the industry (Kumar 2016, Kumar et al. 2016, Kumar and Engle 2017b, Kumar et al. 2018).

The success of the SPS for food-fish culture has sparked interest in using it to produce catfish fingerlings. However, no study has evaluated use of these systems to raise fingerling channel catfish. The original design of the SPS was to raise fish from 20 cm to food-fish market size (45 cm). The fish culture unit and the waste unit are separated by barriers constructed of mesh sized to restrict fish movement between units while minimizing reductions in water flow and biofouling (Brown and Tucker 2013). However, the mesh size required to raise channel catfish fingerlings in split ponds would need to be substantially reduced compared to what is currently used in systems for raising larger fish and would therefore possibly cause commensurate issues with flow and biofouling.

State agencies and sportfish producers have also indicated a need to evaluate smaller scale SPS to help solve avian predation issues at hatcheries, particularly for fish ranging in size from 5.0 to 30.5 cm TL. Small SPS can easily be fitted with streamers or permanent covers to deter bird depredation. Additional advantages to using an SPS include better inventory control, ease of harvest, reduced cost to aerate, and reduced cost associated with chemical treatments (Brown and Tucker 2014, Tucker et al. 2014). Hence, the objective of this study was to determine the feasibility of using a SPS to produce channel catfish fingerlings, primarily as a model alternative production system for state/federal and private sportfish hatcheries struggling with bird depredation issues.

Methods

Experimental Design and Culture Management

Channel catfish fingerlings were produced at the Aquaculture Experimental Research Station at the University of Arkansas at Pine Bluff during the 2017 spawning season. The experiment was conducted using a completely randomized design. Traditional ponds (TP) and SPS ponds were evaluated to raise channel catfish fingerlings. The TP treatment represented the control, as this is traditionally how fingerlings are produced. The SPS used in this study was developed by Smith and Stone (2017) and was divided so that 20% served as the fish culture unit and 80% as the waste treatment side. All TP and SPS ponds were 0.04 ha in size and averaged 1.5 m deep; ponds were evenly split between the two production systems. Two weeks before filling the ponds with well water, 1100 kg ha^{-1} calcium carbonate was applied to the pond bottom of each pond to enhance productivity and stabilize pH; after filling, 1100 kg ha^{-1} of salt was added to each pond to prevent nitrite toxicity. Channel catfish were stocked in each pond at a rate of 200,000 fish ha^{-1}; fish averaged 1.6 ± 1.2 g (mean ± SD). Aeration in each pond was set at 9.3 kW ha^{-1} using surface aerators (Kasco, New Hope, Minnesota, USA) in both production systems. The SPS had a slow-rotating (5.4 rpm), 0.25-hp, gear motor-driven paddlewheel to circulate water from the culture unit to the waste treatment side and back. The paddlewheel pushed approximately 3.7 m^3 min^{-1} of water, resulting in a complete water exchange in the fish culture unit every 27 min (Smith and Stone 2017). Fish were fed a formulated diet that was 50% protein and 17% lipid (Purina AquaMax Fry starter 200, Purina Animal Nutrition, Arden Hills, Minnesota, USA) twice daily throughout the study. Fish were fed 4.0%–6.5% of their total body weight daily during the first 70 days, and then *ad libitum* throughout the rest of the study due to decreased water temperatures that affected feeding behavior. Each pond was checked for fish mortalities twice daily.

Measurements and Calculations

Water temperature, dissolved oxygen (DO), and pH were measured in one location (in the fish culture unit of SPS) at each pond twice a day (0800 and 1600 hours) with a YSI 55 oxygen meter (Yellow Springs Instruments Inc., Ohio, USA) and Oakton pH 700 benchtop meter (Vernon Hills, Illinois, USA). Water samples for analyzing total ammonia nitrogen (TAN), nitrite nitrogen (NO_2-N), and chlorides were obtained from each pond twice per week, in one location for the TP ponds and two locations for the SPS ponds (fish culture and water treatment sides). The TAN and NO_2-N were analyzed with a HACH DR 3900 multi-parameter colorimeter (HACH, Co., Loveland, Colorado, USA) using the salicylate method for TAN and the diazotization method for NO_2-N. Chloride levels were analyzed using HACH test strips. Alkalinity and hardness were measured four times during the production cycle using the drop count titration method (HACH kit models AL-AP, and HA-71A, respectively). Since water parameters did not differ between the fish culture side and the waste treatment side, values measured in the fish-culture unit were used.

We took biweekly measurements of weight and TL for 30 fish in each pond; this was increased to 100 fish per pond at harvest to determine Fulton's condition factor (K; Heincke 1908). After 99 days, channel catfish fingerlings were harvested, and production parameters recorded for each pond including K, individual average final weight (g), final biomass (kg), total feed, feed conversion ratio (FCR), specific growth rate (SGR; Ricker 1975), weight gain rate (WGR), and survival rate (%).

Statistical Analysis

Water-quality data (DO, temperature, and pH) were analyzed using a two-sample *t*-test to determine significant differences among production systems. Ammonia, nitrite, chloride, alkalinity, and hardness were analyzed using repeated measures one-way ANOVA. Ammonia and nitrite data did not meet the assumption of normality of the one-way ANOVA model due to outliers; therefore, a Welch's *t*-test was performed. Production parameters were analyzed using a two-sample *t*-test of means to determine significant differences among treatments. Percentage data were arcsine square-root transformed before analysis. A chi-square test was performed to determine the association between the production system and the distribution in fish size. All statistical analyses were conducted using the SAS system for Windows (SAS Institute 2017) and significance was determined using $P \leq 0.05$.

Results

Water quality was suitable and considered safe throughout the trial for the culture of channel catfish fingerlings (Tables 1 and 2). Water-quality parameters were similar between treatments except for DO and pH in the afternoon and for TAN, all of which were higher in TP; however, these were small and likely not biologically significant. Overall, mean TAN was higher for the TP compared to the SPS (Table 2), but mean TAN was essentially similar between treatments through the first 60 days of culture before TAN increased drastically in TP (Figure 1). The estimated unionized ammonia levels ranged from 0.02 ppm for both systems to a maximum of 0.65 ppm in TP and 0.32 ppm in SPS treatments. Mean nitrite levels were similar between production systems (Table 2). However, mean nitrite peak values reached 0.5 ppm on day 60 in TP and 0.223 ppm on days 63 and 77 in SPS (Figure 2). Although the nitrite levels observed in this study were high, the chloride ion concentration was sufficient to prevent nitrite toxicity, as the chloride:nitrite ratio was close to 100:1 (Wise and Tomasso 1989).

Channel catfish fingerlings were fed consistently during the first 10 weeks of culture, reaching a maximum rate of 156 kg ha^{-1} day^{-1} on day 73; mean water temperatures averaged 25.9° and 29.3° C in the morning and afternoon, respectively. During the last 26 days, the weather turned colder, and average water temperature dropped to 16.4° and 18.7° C in the morning and afternoon, respectively, which reduced feeding (Figure 3). Occurrence of high ammonia and nitrite in ponds displayed an oscillatory behavior, with mean concentrations starting to increase after 56 days of culture, coinciding with the feeding rate of 110 kg ha^{-1} day^{-1} (Figure 3). The highest ammonia peak for all systems was on day 77, which corresponded to the higher feeding rate of 156 kg ha^{-1} day^{-1} of feed on day 73. After day 73, feeding dropped dramatically due to lower water temperatures, and this was also reflected in the ammonia and nitrite levels measured in the production systems.

During the first five weeks of production, aerators were turned on based on DO concentrations in ponds. The aerators were used regularly at night beginning in week seven of the study. The average number of aeration hours during the production cycle was 730 h pond^{-1} in the TP and 723 h pond^{-1} in the SPS.

Ponds were stocked with fish that varied considerably in average individual fish weight (Table 3). However, the gap in the individual fish weight within and between treatments was considerably reduced following the first two weeks of culture. At the end of the study, final biomass, final individual weight, specific growth rate, weight gain ratio, survival rate, feed conversion rate, and yield of channel catfish fingerlings were all similar between treatments (Table 4). However, K was lower for fish raised in SPS than in TP. The average individual final weight (mean ± standard error) at harvest was 41.08 ± 1.28 g in SPS and 44.18 ± 2.7 g in TP, which were similar between production systems. Likewise, survival and FCR were similar between production systems (Table 4). In the present study, total yield (kg ha^{-1}) ranged from 4569 to 6736 kg ha^{-1}, which produced an average of 138,319 fish in SPS and 125,433 in TP.

Table 1. Morning (AM) and afternoon (PM) dissolved oxygen (DO), temperature (°C), and pH in pond water used to raise channel catfish fingerlings in traditional ponds (TP) and split-pond systems (SPS) (Mean values ± SE).

Parameter	Time	TP	SPS	*t*	*P*
DO	AM	7.78 ± 0.12	7.60 ± 0.12	−1.13	0.2598
	PM	13.83 ± 0.22	12.37 ± 0.23	−4.58	<0.0001
°C	AM	23.60 ± 0.29	23.74 ± 0.29	0.36	0.7154
	PM	26.96 ± 0.32	26.22 ± 0.31	−1.66	0.0980
pH	AM	8.27 ± 0.03	8.22 ± 0.02	−1.44	0.1503
	PM	8.98 ± 0.03	8.78 ± 0.03	−4.87	<0.0001

Table 2. Chloride (Cl), alkalinity, hardness, total ammonia nitrogen (TAN), and nitrite nitrogen (NO_2-N) in pond water used to raise channel catfish fingerlings in traditional ponds (TP) and split-pond systems (SPS).

Water quality parameter	TP	SPS	*F*	*P*	*t*	*P*
Cl^- (mg/L)	47.81 ± 1.40	46.81 ± 1.068	0.21	0.8076		
Alkalinity (mg/L)	92.91 ± 9.78	101.34 ± 6.25	0.43	0.6563		
Hardness (mg/L)	104.67 ± 8.19	109.92 ± 6.58	0.75	0.4808		
TAN (mg/L)	0.554 ± 0.074	0.312 ± 0.030			−3.02	0.0032
NO_2-N (mg/L)	0.139 ± 0.023	0.109 ± 0.009			−1.20	0.2337

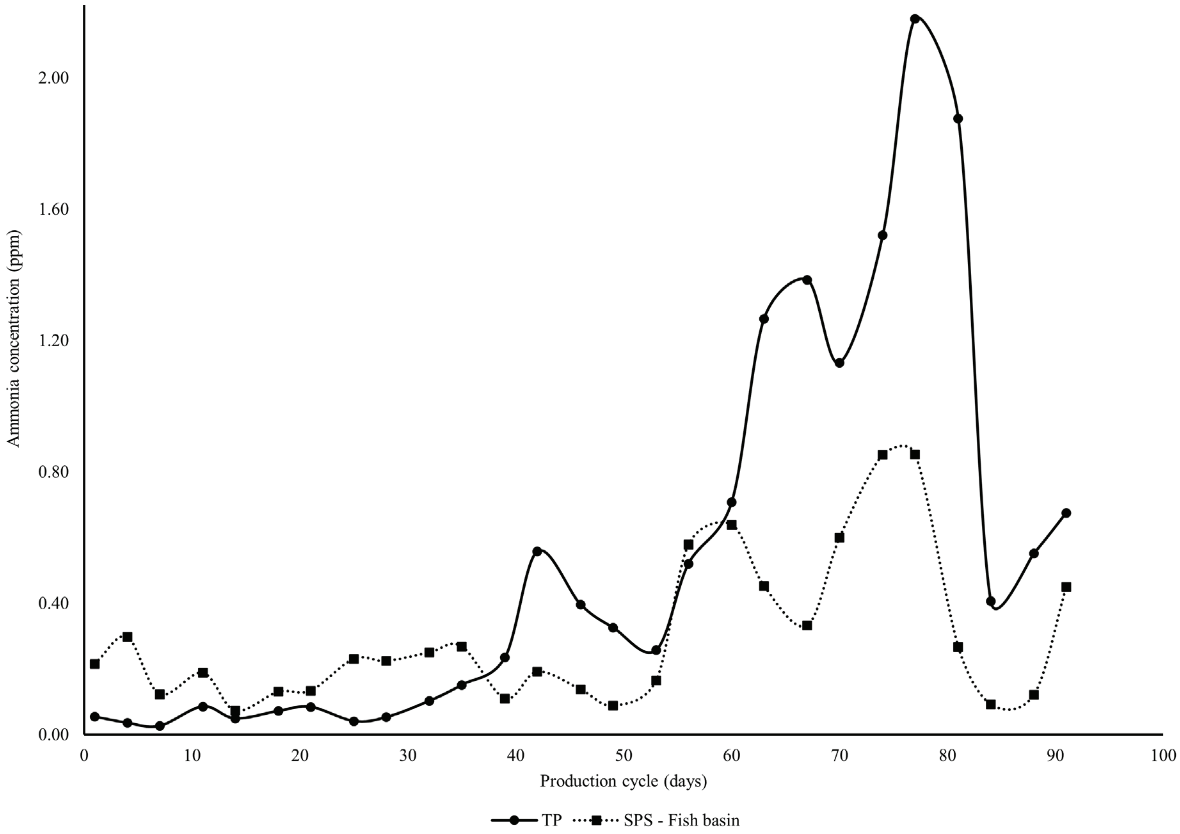

Figure 1. Mean total ammonia nitrogen (ppm) in pond water used to culture channel catfish fingerlings in traditional ponds (TP; solid line with round marker) and split pond systems (SPS; dotted line with square marker).

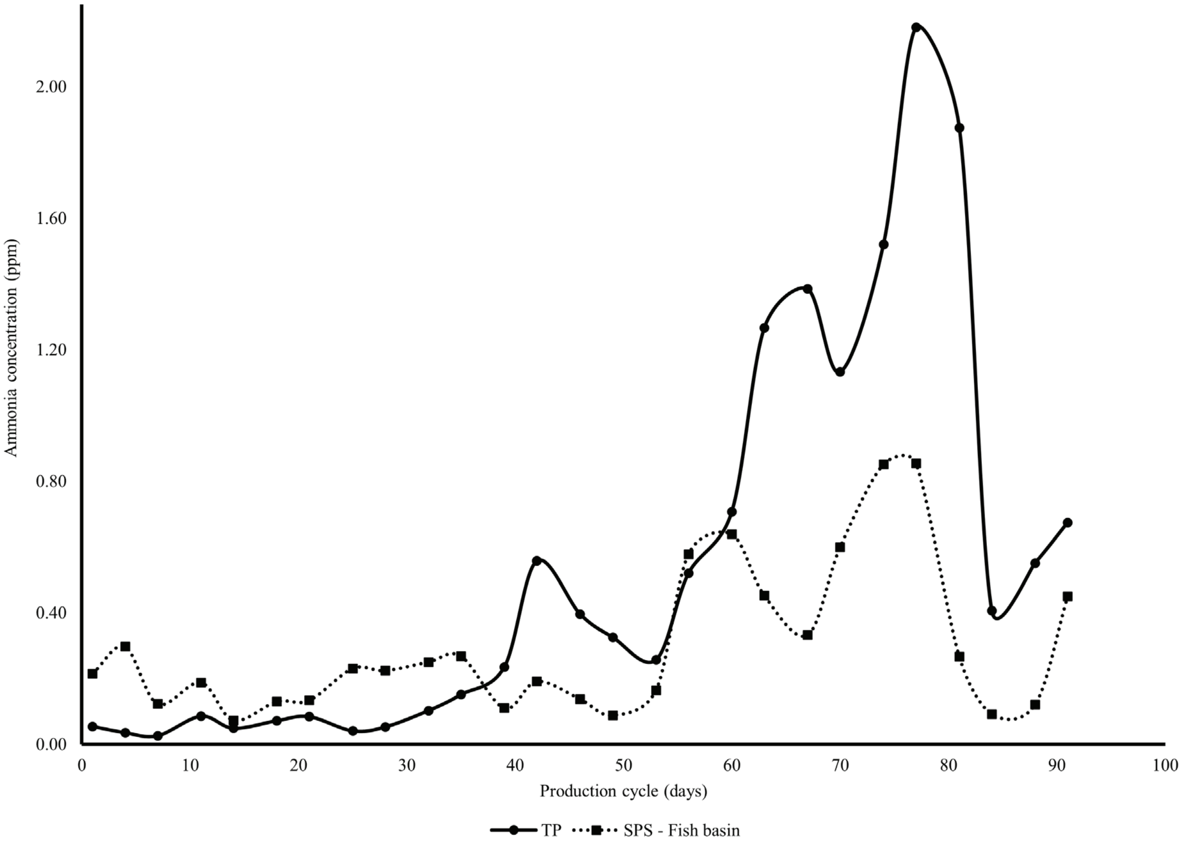

Figure 2. Mean nitrite nitrogen (ppm) in pond water used to culture channel catfish fingerlings in traditional ponds (TP; solid line with round marker) and split pond systems (SPS; dotted line with square marker).

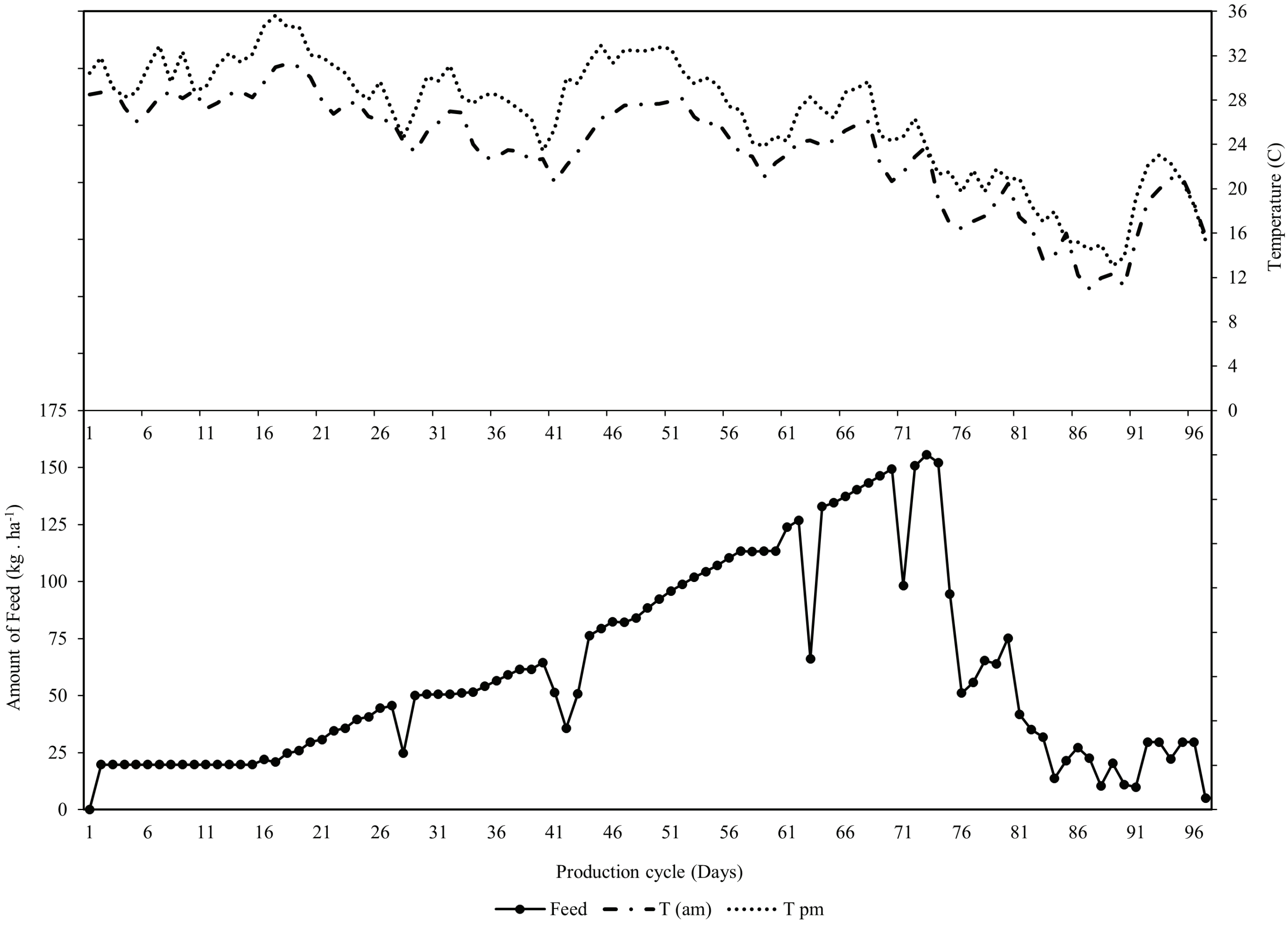

Figure 3. Mean amount of feed (solid line with round marker) offered to channel catfish fingerlings as a function of temperature in the morning (dash dot line) and afternoon (dotted line with round marker) in traditional ponds and split-pond systems.

Table 3. Initial production parameters for channel catfish fingerlings raised in traditional ponds (TP) and split-pond systems (SPS) using three replicate ponds.

System	Pond	Stocking density (fish ha^{-1})	Average individual weight (g)	Biomass (kg ha^{-1})
TP	1	197,302	3.18	628.2
	2	198,266	0.88	173.9
	3	202,322	0.85	172.8
	Mean	199,297	1.64	325.0
SPS	1	197,959	3.10	613.1
	2	203,635	0.85	173.9
	3	201,534	0.63	127.3
	Mean	201,043	1.53	304.8

Table 4. Mean values for stocking density, initial biomass, final biomass, initial weight, final weight, specific growth rate (SGR), weight gain ratio (WGR), Fulton's condition factor (K), survival, feed conversion ratio (FCR) and yield of channel catfish fingerlings cultured in traditional ponds (TP) and split pond systems (SPS) (Mean values ± SE).

	TP	SPS	*t*	*P*
Stocking density (fish/hectare)	199300 ± 1537	201038 ± 1659	0.77	0.4851
Initial biomass (kg)	13.15 ± 6.14	12.33 ± 6.26	−0.09	0.9303
Final biomass (kg)	243.07 ± 29.62	206.70 ± 21.79	−0.99	0.3796
Initial weight (g)	1.64 ± 0.77	1.53 ± 0.79	−0.10	0.9254
Final weight (g)	44. 18 ± 2.68	41.08 ± 1.28	−1.04	0.3554
SGR - % day^{-1}	3.53 ± 0.48	3.58 ± 0.53	0.07	0.9471
WGR - %	3861.0 ± 1369.2	4221.6 ± 1635.6	0.17	0.8740
K	12.38 ± 0.06	11.37 ± 0.04	−13.92	0.0002
Survival (%)	69 ± 12	63 ± 9	−0.47	0.6642
FCR	1.06 ± 0.04	1.16 ± 0.05	1.57	0.1909
Yield (kg ha^{-1})	6004.4 ± 732.0	5107.7 ± 538.5	−0.99	0.3796

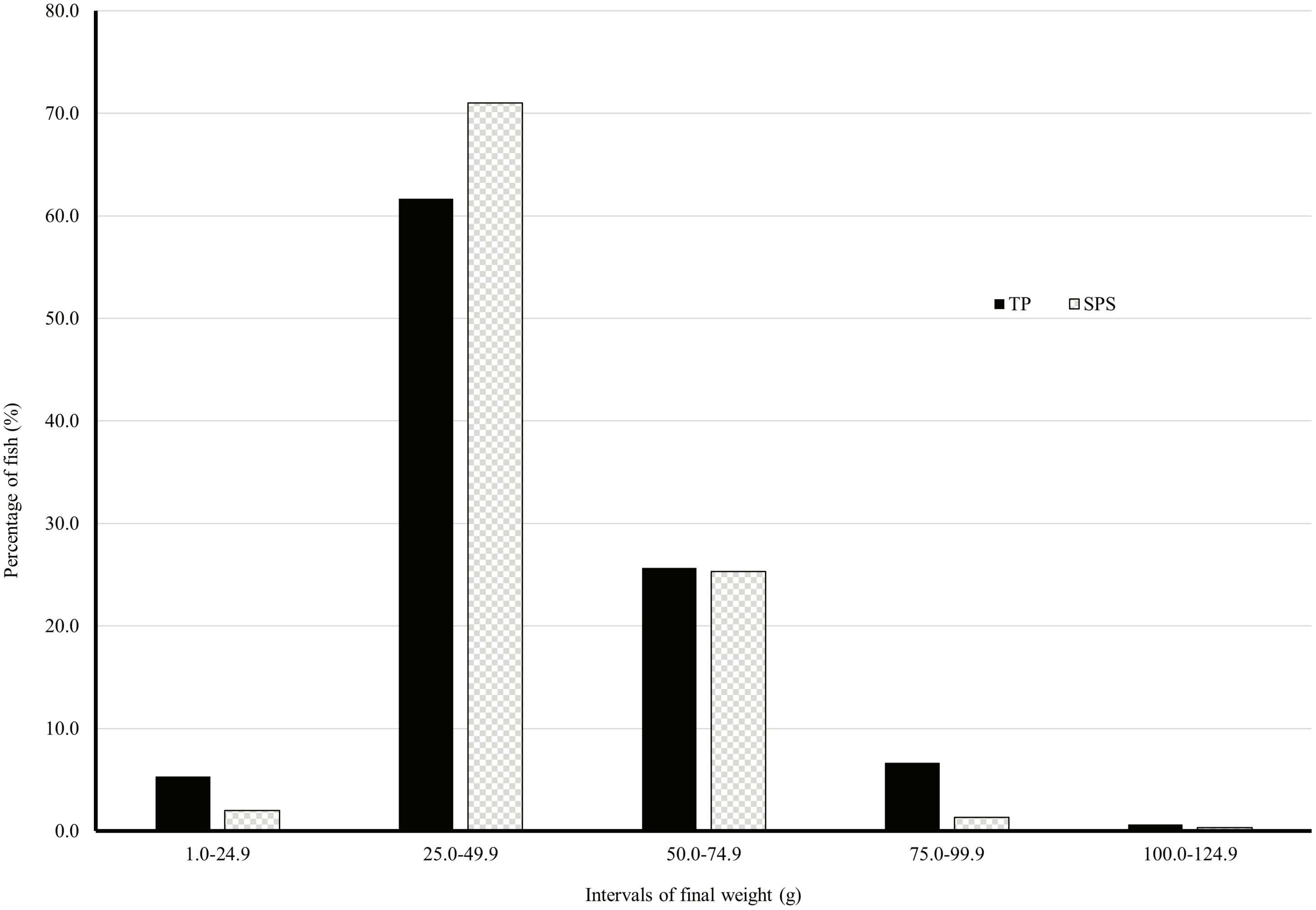

Figure 4. Plot for frequency distribution of average individual weight (g) at harvest of 300 channel catfish fingerlings measured in traditional ponds (TP; black bar) and split-pond systems (SPS; stippled bar) following 99 days of culture.

Distributions of final weights differed between production systems ($\chi^2 = 17.5218$, $P = 0.0015$; Likelihood ratio $\chi^2 = 18.6785$, $P = 0.0009$), with fish ranging from 10.4 to 102.6 g in TP, and 18.9 to 119.0 g in SPS. Few fish in either treatment were in the largest two groups and smallest group (Figure 4). Most fish were in the 25.0- to 49.9-g group for both production systems, with 62% in the TP and 71% in the SPS. Both treatment groups had approximately 25% of fish produced fall into the 50.0- to 74.9-g group (Figure 4).

Discussion

Enhancing catfish production has become a priority for U.S. aquaculture producers, and has been approached from different angles including hybrid production, genetic selection, improved feeds, best management practices, and optimization of production systems (Losinger et al. 2000, Engle 2003, Johnson et al. 2014, Kumar et al. 2016, 2018). However, scant attention has been given to the evaluation of alternative pond-based production systems for fingerling production, primarily because the large scale in which most commercial farmers produce fingerlings is already profitable (Engle and Valderrama 2001). This study demonstrated that SPS might effectively have higher carrying capacities to raise fingerlings than traditional fingerling ponds. Evaluation of different pond production systems was conducted using the same number of fingerlings for both systems (approximately 200,000 fingerlings ha^{-1}). However, because fish stocked in SPS were concentrated in a single zone, the relative density within that zone was much higher (approximately 1 million fish ha^{-1}).

Although the difference in average individual fish weight at stocking was considerable (Table 3), the gap in the fish weight between treatments was considerably reduced following the first two weeks of culture. This likely confirms the strong potential for compensatory growth in channel catfish, which also displayed a higher specific growth rate during this period. In this case, compensatory growth occurred after a period of growth depression due to overcrowding conditions, rather than the typical growth depression induced by complete or partial food deprivation (Kim and Lovell 1995, Gaylord and Gatlin 2000, Ali et al. 2003). By the end of the study, mean final individual weight, SGR, and WGR were similar between production systems.

The lower K observed for channel catfish raised in SPS compared to fish cultured in TP may be the result of fish swimming against a constant flow of water, rather than deterioration of water quality. Fish raised in SPS swam against a current for a minimum of 12 h day^{1} when the paddlewheel was in use. A similar effect was observed by Quintero et al. (2019) in a largemouth bass study where K was lower in fish cultured in an SPS compared to those raised in TP.

Yields in this study were considerably higher than those reported by Engle and Valderrama (2001) for a similar stocking density. Differences between these studies may be related to a higher crude protein feed (50% vs. 32%) and the more aggressive feeding protocol used in the present study. The use of high crude protein feed may have impacted the performance of the channel catfish. Total yield, final individual average weight, and the fingerling length reached with the high stocking density used in this study outperformed the expected yield, fish weight and size estimations with recommended fry stocking rates from agricultural extension publications (Engle and Valderrama 2001, Engle 2004). Higher production and yields have also been attained in SPS used to raise food-size fish compared to TP (Kumar et al. 2016, Kumar et al. 2018). The results from this study and the apparent similarity between raising fingerlings and food fish in SPS reinforces that SPS can be used successfully to raise fingerlings at high densities, albeit this production system is a better alternative for smaller private hatcheries and state/ federal hatcheries than for large scale commercial hatcheries that supply fingerlings to food fish producers.

The FCRs found in this study were slightly higher than reported by Engle and Valderrama (2001). Higher FCRs in SPS could have been a result of overfeeding fish; with smaller fish culture areas, fish had better access to feed. More aggressive fish tend to consume food first, leaving smaller amounts of feed for smaller and less aggressive fish. This theory is reinforced by the final fish weight distribution observed in these two production systems. Fingerlings raised in SPS were more uniform, with a lower CV for individual weights (28.8%) compared to fish raised in TP (35.9%), and with 71% of the fish falling between 25 and 75 g, compared to 62% from the TP.

Survival rates observed in this study were significantly higher than those found by Engle and Valderrama (2001) for fish stocked at similar densities. Higher survival in our study was likely due to covering the ponds with netting, which prevented bird depredation. Most fish loss in our study was due to outbreaks of *Flavobacterium columnare*, a bacterial disease.

Although the cost to convert a TP to a SPS is expensive, several cost savings are associated with using a SPS. Engle and Valderrama (2001) demonstrated that raising smaller channel catfish fingerlings at higher densities costs less and is less risky from an economic standpoint. Using the SPS to raise channel catfish and/ catfish hybrid fingerlings would enable state/federal hatcheries with limited space for ponds to raise more fish in a confined area than TP. Additionally, the fish culture unit enables these hatcheries to cover just a portion of the pond (the fish culture unit) to prevent bird depredation. There are also advantages in terms of monitoring inventory and in aeration efficiency if an aerator becomes necessary. It is easier to treat diseased fish because fish are confined to a smaller pond area, and only the fish culture unit would need to be treated rather than the whole pond as with TP. It is also substantially easier and more efficient to harvest fish in SPS versus TP because the fish are confined to a much smaller area.

The use of high protein feed likely played a significant role in the excellent performance of channel catfish fingerlings in both production systems evaluated in this study. A higher stocking density in SPS should be evaluated to determine if higher densities of channel catfish fingerlings can be raised in this production system. The evaluation of hybrid catfish fingerlings production could also be of interest, as hybrid catfish typically demonstrate faster growth and attain larger sizes than channel catfish (Dunham et al. 2008, Green and Rawles 2010). Subsequent studies using different stocking strategies may help elucidate the impact of these intensive pond-based culture systems on fingerling size variability.

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