Commercial evaluation of largemouth bass (*Micropterus salmoides*) production in traditional earthen ponds versus split-pond production systems

by

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Abstract

Largemouth bass (LMB; *Micropterus salmoides*) production for the food fish market is growing in the US. Traditionally, LMB producers in the US have relied on traditional earthen ponds (TP) as their primary production system. LMB producers using TP face challenges such as low survival, slow growth, poor food conversion ratio (FCR), bird depredation, water quality problems, and disease. The culture of LMB in split-pond systems (SPS) has potential to improve many of the inefficiencies documented by commercial LMB producers using traditional earthen pond systems. An on-farm experiment was conducted at American Sport Fish in Montgomery, Alabama. A total of eight ponds were used in the study, including (mean ± standard deviation) four TP (1.0 ± 0.0 acre) and four SPS (0.59 ± 0.27 acres). Fish were stocked in July 2023. Fish weights and lengths were obtained at stocking and thereafter monthly until harvest. Pond water samples were collected weekly from study ponds for water quality analysis. Study ponds were harvested in October 2023 when LMB reached stocker size. An enterprise budget was developed from fixed and variable costs to compare production costs of raising LMB fingerlings to stocker sizes using SPS and TP. This study found that there were no significant differences in survival rates ($P = 0.279$) between LMB raised in SPS and TP; however, differences were observed in fish size distribution at harvest. Research revealed that SPS was more profitable than TP despite the initial investment costs needed to convert TP to SPS.

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LMB	Largemouth Bass
SPS	Split-Pond System
TP	Traditional Pond
IAP	Intensively Aerated Pond
IPRS	In-Pond Raceway System

Introduction

Aquaculture is a rapidly growing industry estimated to have a 20% growth increase in global production over the next decade accounting for 55% of global seafood production by 2033 (OECD/FAO, 2024). The consumption of fish, crustaceans, mollusks, and other aquatic animals (capture fisheries and aquaculture combined) represents roughly 17% of total animal protein consumed worldwide (FAO, 2018). Together, capture fisheries and aquaculture yield an estimated 171 million tons, constituting a first-sale value of $232 billion, with aquaculture comprising roughly 50% of the reported yield (FAO, 2018). Hence, aquaculture plays an ever-increasing role in food security, the environment, and human health (Fry et al., 2016). The aquaculture sector offers excellent opportunities for technological innovation to sustainably meet the protein demands of a global population (Waite et al., 2014). New developments and innovative production techniques will be essential to keep up with the rapidly increasing demand of the aquaculture industry.

The production of Largemouth Bass (LMB, *Micropterus salmoides*) on a commercial scale is a subject of growing interest by farmers due to the growing demand for LMB by U.S. consumers and recreational fish stocking by private, state, and federal agencies. There are different markets available for LMB producers. As of 2018, 195 farms in the U.S. produced LMB, including farms producing food-size fish, fry/fingerlings, stockers, and broodstock (USDA NASS, 2018). The live weight of LMB food-size fish production was reported to be close to 3.8 million pounds (USDA NASS, 2018). In the last USDA NASS Census of Aquaculture, Ohio had the most LMB farms (20), while Arkansas and California led the U.S. in terms of LMB production and sales. A total of 31 states reported having at least one LMB producer in their state (USDA NASS, 2018).

Largemouth Bass are one of the most popular sportfish in the U.S. Natural propagation of LMB for stock enhancement began in the early 1890s (Worth, 1895) and continues today. The 2017 U.S. Census of Aquaculture reported that commercial farms sold nearly 8.4 million fry, fingerlings, and pond-stockers with annual sales of $5.5 million. In addition to LMB produced for recreational and stock enhancement markets, 71 farms produced nearly 1,900 tons of food-size fish with an estimated value of $21.9 million (USDA, 2018). Recently, total production and sales of LMB in the U.S. ranked 5th, following catfish, trout, tilapia, and hybrid striped bass. At $5.79 per pound, the market price of food-size LMB was higher than $0.97 to $3.78 per pound for catfish, trout, tilapia, and hybrid striped bass during the same time frame (USDA, 2018).

Increased awareness of U.S. consumers for healthy/nutritious fish products (i.e., high omega-3 concentrations and other micronutrients) has resulted in the development of live and fresh niche markets. Large-scale expansion of the LMB food fish industry in the U.S. has excellent potential. In recent years, LMB culture has increased significantly in China, where production was reported to be 152,000 metric tons in 2013 (Zhou and Liu, 2019). This is slightly less than the production reported in 2018 by the U.S. catfish industry (159,421 metric tons), the largest aquaculture industry in the U.S. by production volume.

The production of LMB starts with the spawning of LMB broodstock, which usually occurs in indoor or outdoor large tanks or vats (Coyle and Matthews, 2019; Quintero et al., 2019). Spawning mats are placed throughout the tanks as spawning substrate for LMB. The mats containing fertilized LMB eggs are then moved to earthen ponds. These ponds are prepared by being fertilized to seed zooplankton in the earthen ponds before spawning mats are transferred (Coyle and Matthews, 2019; Quintero et al., 2019). Fingerlings are harvested from ponds once they reach about 5-8 cm in size (Quintero et al., 2019). The harvested fingerlings are brought indoors for 3-4 weeks and feed-habituated (Coyle and Matthews, 2019; Quintero et al., 2019). Once the fingerlings readily feed on commercial pelletized feeds, they are transferred back to earthen ponds for the remainder of the grow-out period when they are ready for harvest (Quintero et al., 2019; Tidwell et al. 2019).

During grow-out, most U.S. farmers use earthen ponds. Traditional earthen pond culture (TP) consists of ponds that utilize pond aeration at night to combat the depletion of dissolved oxygen levels and maintain an adequate level of oxygen saturation (Green and McEntire, 2017). The duration of grow-out is dependent on the target market of the commercial producer. For instance, many LMB fingerlings sold to grow-out operations for the recreational market are typically grown to a market size of about 2.54 to 5.08 centimeters (1 to 2 inches) to prevent a loss of stock due to cannibalism, which is common for LMB fingerlings when they reach this size (Davis and Lock, 2007). Farmers targeting a stocker-size bass to sell to food fish grow-out facilities aim for 12.7 to 15.2 cm (5-6 in) or larger fish. Fingerling and stocker-size LMB sold to grow-out facilities can be raised in one production season. However, food fish production of LMB can take much longer (Quintero et al., 2019; Tidwell, 2019).

The point in the production cycle when feed-habituated LMB fingerlings are transferred back to ponds is when much of the mortality reported by commercial producers occurs. While mortality happens at all stages of the production cycle [note: LMB destined for the foodfish market typically take two growing seasons (18 to 24 months) to reach the target market size desired by consumers], LMB in the 5.08 - 15.2 cm (2–6-in) range appear to be most vulnerable to predation, particularly to piscivorous waterbirds, snakes, and turtles. In addition to depredation, other factors, including water quality, disease, and harmful algae blooms, result in additional mortality in TP production systems. It is typically difficult to harass piscivorous waterbirds, such as Great Blue Herons (*Ardea herodias*), Great Egrets (*A. alba*), Double-crested Cormorants (*Phalacrocorax auritus*), American White Pelicans (*Pelecanus erythrorhynchos*), Wood Storks (*Mycteria americana*), Pie-billed Grebes (*Podilymbus podiceps*), and other species in TP that tend to be quite large (Dorr et al. 2024). Farmers can obtain lethal take permits for some species (such as herons and egrets) through the U.S. Fish and Wildlife Service and managed by USDA Wildlife Services, but for some species (e.g. wood storks), no permits can be obtained. Hence, commercial farmers often use pyrotechnic devices to harass birds, but large earthen ponds make this difficult to accomplish effectively (Dorr et al. 2024).

Due to the shortcomings and challenges LMB producers face in producing LMB for foodfish and recreational markets in TP, many farmers have become interested in alternative intensive pond-based production systems. The three primary alternative systems extensively tested by the U.S. catfish industry include the in-pond raceway system (IPRS), intensively aerated ponds (IAP), and split-pond production systems (SPS). These alternative systems have been extensively tested within the U.S. catfish industry (Bott et al., 2015; Kumar et al., 2018, 2021; Quintero et al., 2021; Hegde et al., 2022). These alternative intensive production systems have been met with different levels of acceptance and adoption by commercial producers (Kumar et al., 2021; Hegde et al. 2022).

The production of fish using IPRS allows producers to grow a greater number of fish in a small culture area (Brown et al., 2011). Brown et al. (2011) reported increased yield using IPRS compared to traditional earthen pond culture. IPRS are often installed within a traditional earthen pond and have the potential for high yield while also being easily accessible at harvest, as seining the entire pond is not required. While easier to harvest, the compact nature of IPRS compared to TP caused an increased occurrence of disease outbreaks in the catfish industry (Roy and Brown, 2016; Roy et al., 2019), and one commercial LMB farmer in Arkansas that has used the system reported high incidences of columnaris. IPRS are currently being used to produce LMB in China

(Wang et al., 2020a; Wang et al., 2020b; Liu et al., 2022) but have not been adopted by catfish farmers and only a handful of LMB farmers in the U.S. (Kumar et al., 2021).

Intensively aerated ponds (IAPs) are one of the easiest pond-based aquaculture systems for TP conversion (Bott et al., 2015), and conversion to IAP costs less than other intensive pond-based production systems (Kumar and Engle, 2017; Quintero et al., 2019). Intensively aerated ponds allow for higher-density fish culture than TP due to the use and implementation of multiple aerators to get the overall horsepower of the pond to exceed 11.0 kW/ha (Kumar et al., 2018; Quintero et al., 2019). Intensively aerated ponds have also been found to produce more proportionate weight distributions in every fish size class compared to those produced in SPS and TP (Quintero et al., 2019).

The U.S. catfish industry has widely accepted and adopted SPS (Kumar, 2016; Kumar et al., 2018; Kumar et al., 2021; Hedge et al., 2022). Ideally, SPS are divided into two pond zones with about 10-20% of the pond used for the actual culture/production area and 80-90% used as a waste treatment area (Kumar et al., 2016). During the day water is circulated between the two pond zones; however, at night, an aerator is used to prevent low dissolved oxygen rates in the culture section of the pond, and water circulation between the two pond areas is stopped (Kumar et al., 2016). Split-pond systems are designed to allow fish farmers to maintain better water quality in their ponds throughout the grow-out process (Kumar et al., 2016), and yields achieved in these systems are often 2-3 times more than possible in TP when culturing catfish (Kumar et al., 2016). Following the successful implementation of SPS by the catfish industry, this system is now being examined for further use in the production of other fish species, including LMB, Golden Shiners (*Notemigonus crysoleucas*), and even Pacific White Shrimp (*Litopenaeus vannamei*) (Smith and Stone, 2017; Whitis and Teichert-Coddington, 2017; Quintero et al., 2019). Currently, there are several commercial farms (Alabama and Arkansas) using SPS to raise LMB, as a food fish or as stockers for other food fish producers in other states, and a few additional farms in the Midwest region of the U.S.

The use of SPS for LMB production presents a significant opportunity for LMB commercial farmers to reduce mortality during a short fingerling to stocker production run or a longer multi-year grow-out production phase. The inherent design of SPS allows producers to have better control of bird depredation. Confining fish in 15-20% of the pond (fish culture zone of the SPS) makes it easier to deter birds. Likewise, improved water quality documented in SPS systems is attractive for commercial producers as nitrogenous wastes can be better controlled. Farmers have also noted that achieving higher feed efficiency in SPS is easier than in TP. Finally, disease events are easier to treat and manage when fish are confined to 15-20% of the pond in the fish culture zone compared to being spread out in larger earthen ponds. Fish mortalities due to disease or water quality issues can be tracked more efficiently when fish are confined to a smaller culture area. Thus, maintenance of more accurate inventory records is easier to achieve.

Water quality management for LMB production is similar to that of other Centrarchid species. For practical purposes, most commercial farmers raising fingerlings and foodfish attempt to maintain dissolved oxygen levels above 4.0 mg/L for food fish production. However, acceptable DO concentrations and percent saturation can vary depending on water temperature (Tomasso, 2019). Split ponds typically allow for more efficient DO management than TP, as fish are concentrated in a smaller area that is easier to aerate efficiently (Tucker et al., 2014). However, during critical times such as a power failure, there is less response time to manage low DO situations than TP, as fish are housed in larger volumes of water in open earthen ponds. Ideal water temperatures for LMB growth have been reported to be between 26-28.6°C (Tidwell et al., 2003; Diaz et al., 2007). Commercial LMB producers have reported a lack of feeding during the hotter summer months due to increased pond water temperatures in TP (Fantini et al., 2021; Tuttle et al., 2022). Farmers must manage LMB ponds for nitrogenous wastes, particularly ammonia. Largemouth bass are not very susceptible to nitrite toxicity (Palachek and Tomasso, 1984; Tomasso and Grosell, 2005). As with most other aquatic species, ammonia can be toxic to LMB, particularly in culture water of pH greater than 8. Hence, commercial producers must be cognizant of the percent of unionized ammonia in solution at different temperatures and pH of culture water (Tomasso, 2019). While water quality has been widely studied in TP with LMB, less information is available on water quality dynamics in SPS with LMB.

Largemouth Bass are susceptible to various bacterial, viral, and fungal diseases, as well as parasitic infections (Mitchell and Durborow, 2019). Common bacterial diseases reported by commercial LMB farmers include motile *Aeromonas* Septicemia, Columnaris, and Edwardsiellosis (Mitchell and Durborow, 2019). Motile *Aeromonas* Septicemia is usually caused by *Aeromonas hydrophila*, although other *Aeromonas* species can be problematic (Mitchell and Durborow, 2019). Clinical signs often include exophthalmia, hemorrhagic lesions at the base of fins and on the skin, distended abdomen, and swelling and hemorrhaging of internal organs, among others (Mitchell and Durborow, 2019). *Flavobacterium covae* and other *Flavobacterium* species cause Columnaris and are often observed on the gills or skin of fish. Handling stress can cause columnaris, and this disease commonly appears in holding vats on commercial LMB farms, mainly after fish have been harvested from the pond and transferred to holding vats prior to being sold to the market (Kelly et al., 2023). Poor water quality can also result in columnaris infections. Edwardsiellosis is caused by *Edwardsiella tarda*, characterized by muscle tissue necrosis, and often manifests in summer months when pond water temperatures exceed 30°C (Mitchell and Durborow, 2019). Largemouth Bass virus is an iridovirus that has been widely studied, particularly common in natural systems (Grizzle and Brunner, 2003; Maceina and Grizzle, 2005) but has not often been identified on commercial farms. Largemouth Bass are also susceptible to fungal infections, particularly winter saprolegniasis (winter kill; *Saprolegnia* spp.) when water temperature drops below 15ºC (Mitchell and Durborow, 2019). Largemouth Bass are susceptible to many different parasitic infections, which include but are not limited to *Ichthyobodo* spp., Ich (*Ichthyopthirius multifilis*), tapeworms, *Epistylis* spp., gill flukes, yellow grubs, eye flukes, and anchorworm (*Lernae* sp.) (Mitchell and Durborow, 2019). The health of LMB has not yet been assessed or monitored in a formal study using SPS. Hence, a comprehensive health monitoring program and assessment during a commercial production run using SPS would be valuable information for commercial producers seeking to invest in this alternative intensive-pond based production system.

Production cost data for commercial LMB farms is limited (Robinette, 1999; Engle and Southworth, 2013). Engle and Southworth (2013) determined that the cost of producing LMB fingerlings varied greatly depending on the management scenario. Hence, we suspect costs of production between TP and SPS used for production of LMB will also vary, as notable differences between these production systems likely influence fixed and variable costs. Economic analysis performed on SPS in the catfish industry revealed that there was a preference for single-batch management, and that on small farms, large fixed costs can become a roadblock to adopting new technologies, such as SPS, since they are capital-intensive and require considerable upfront investment (Kumar et al., 2021). Technologies that have the perception of higher upfront costs are perceived to have a lower economic benefit overall (Kumar et al., 2021). This study also found that farmers would be more receptive to adopting alternative production technologies as more research becomes available to provide proven results on their effectiveness and economic benefit (Kumar et al., 2021).

Enterprise budgets provide a simplified measure of profitability of a specific production activity or enterprise (Engle, 2010). They are used to establish an idealized and best-case scenario version of the production costs associated with the proposed activity/enterprise and the potential profitability of that production activity/enterprise (Engle, 2010). An enterprise budget is an estimate of a farm's profitability based on an estimate of all the expenses and income associated with that specific enterprise (Engle, 2010). When developing an enterprise budget, it needs to be created with a specified size and type of production unit (Engle, 2010). The production system, species that will be cultured, and the critical production and inputs need to be accounted for (Engle, 2010). Details such as the size of fish stocked, stocking density, and yield of a marketable-sized product are required to construct an enterprise budget (Engle, 2010).

Pond renovations must be made to increase the productivity for farmers and producers to maximize their investment (Kumar and Engle, 2017). More information is needed on the best pathways to transition farms to newer technology (Kumar and Engle, 2017; Hegde et al., 2022). Commercial producers need to know what amount of their limited resources should be invested and/or allocated toward new farm production technologies to obtain the greatest return on their initial investment (Kumar and Engle, 2017).

In summary, developing a SPS for LMB food fish production represents a significant opportunity for commercial producers to improve survival, growth, production, and efficiency of their farming operations, and will hopefully lead to higher profits and a more sustainable industry. The following objectives were used to test the viability of using SPS for production of LMB.

Objectives

This study was designed to (1) evaluate the production performance of LMB raised in commercial scale SPS compared to TP, (2) evaluate the water quality and fish health metrics of LMB cultured in SPS and TP, and (3) use enterprise budgets to compare the economic feasibility of raising LMB in commercial SPS and TP.

Materials and Methods

This study was conducted on a commercial farm (American Sport Fish) near Montgomery, Alabama. Eight ponds were used for the study, including four TP and four SPS (Figure 1). The SPS used in this experiment were designed similar to SPS used by the commercial catfish industry but on a smaller scale. The fish culture and waste treatment zones of the pond were separated by the construction of a levee. On one end of the divider levee there was a 30 cm (12 in) diameter drainpipe which allowed passive flow from the fish waste treatment zone to the fish culture zone. On the other end was a 2-HP paddlewheel aerator (Pentair – manufactured in China) placed in small of opening of the levee to move water from the fish culture zone to the waste treatment zone. To separate the fish culture zone and the waste treatment zone at the location of the aerator a 0.48 cm (3/16 in) mesh material (Memphis Net and Twine, Memphis, Tennessee) was used. The TP used in this study were 1-acre earthen ponds (4-5 feet deep) that have been used to produce LMB at American Sport Fish for many years. These TP are typical of what many LMB producers use for production of LMB.

Traditional and SPS ponds in the experiment were stocked throughout the first two weeks of July with feed-trained LMB fingerlings (5.08 to 7.68 cm; 2-3 in) sourced from American Sport Fish. LMB were tempered to the pond water, and then stocked. Mean length and mean weight ± standard deviation were 6.01 ± 0.75 cm and 4.16 ± 1.35 g, respectively. Split ponds were stocked at an average density of 11,653 fingerlings/acre while TP were stocked at 10,000 fingerlings/acre (Table 1). The targeted market size of the LMB stockers at the end of the trial was 20.32 cm (8 in) fingerlings or larger.

Throughout the study, feed was offered to fish multiple times per day via three automatic fish feeders (Texas Hunter LM175, San Antonio, TX). Feed rates were set at 9 kg per pond per day. This was supplemented by at least one additional daily feeding each day to observe fish behavior and monitor for any potential problems. Fish were fed a 48% protein and 18% lipid LMB feed from Skretting (Tooele, UT), starting with a 5.5 mm pellet feed and eventually up to a 9.5 mm pellet feed by the end of the production run. The ponds were dyed using Brandt Pond Dye (Brandt, Tampa, FL) to prevent zooplankton blooms. This is standard practice at American Sport Fish since it has been observed that reducing natural food in ponds prevents some smaller fish from going off-feed and trying to survive on zooplankton. The dye can also help prevent wide swings in DO.

Ponds were sampled monthly throughout the 3-month trial to track growth of LMB fingerlings. Sampling was completed in the early morning to minimize stress on sampled fish due to higher temperatures in the afternoon. Approximately 30 fish were sampled from each pond using a seine to determine length (cm) and weight (g). At harvest, 50 individual length and weight samples of LMB were measured from each pond (Figure 2).

Water samples were collected weekly from each pond, placed on ice in a cooler, and transported to E. W. Shell Fisheries Research Center, Auburn, AL for water quality testing. Water samples were collected from three different locations in each pond, with samples from each split pond having water taken from the outflow of water from the production basin into the waste basin (designated F samples), at the inflow of water from the fish culture basin into the waste basin(designated W samples), and the opposite end of the waste basin (designated O samples) (Figure 1). For the TP, three water samples were randomly selected around each pond and then sampled at those same locations at each successive sampling event.

Total ammonia nitrogen and nitrite nitrogen were tested weekly, while total alkalinity, total hardness, salinity, chloride, and nitrate nitrogen were tested monthly. Additional weekly water parameters measurements included dissolved oxygen (DO), temperature, and pH. Water samples were transported on ice from American Sport Fish to E. W. Shell Fisheries Center and the Alabama Fish Farming Center (AFFC). Weekly pH testing was carried out using a YSI pH10A pH and temperature pen that was regularly calibrated as needed. The salinity of each sample site was determined using a YSI Pro Plus (Xylem/YSI, Yellow Springs, OH). Total ammonia nitrogen (TAN) was conducted according to the methods used in Jescovitch et al. (2017) and Boyd (2019). Total ammonia nitrogen, nitrite nitrogen, total hardness, total alkalinity, and nitrates were analyzed using a YSI 9300 Photometer (Xylem/YSI, Yellow Springs, OH) based on methods used by Jescovitch et al. (2017), while chlorides were tested at the AFFC according to Bridgewater et al. (2017).

During monthly fish sampling, a sub-sample of five fish per pond (per vat for the samples collected before ponds were stocked) was removed for a fish health check and transported on ice to the AFFC Fish Diagnostic Laboratory in Greensboro, Alabama. A fish disease examination was completed on each fish. The presence and severity of any abnormalities or ailments were noted based on a 1-5 scale, with 5 being the most severe/intense. At the end of the production cycle, both SPS and TP were harvested using a seine to determine survival (%) and individual size distribution.

Survival and individual size distribution were achieved by counting and grading every single fish harvested from ponds. It is worth noting that American Sport Fish does not obtain a total weight of fish per pond. Instead, individual fish are counted and graded. This is because carrying out batch fish weights at harvest during warmer months would stress the fish and potentially result in a disease event. Hence, fish are not handled extensively during harvest to avoid stress.

Economics Analysis

An enterprise budget was developed to compare the economics of raising LMB fingerlings to stocker sizes in TP and SPS. Enterprise budgets were constructed to estimate the production costs, net returns to the operator, and breakeven yields (BEY) for the two production systems. The unit of budget analysis was a 1-acre pond. Fixed costs included accounting for the insurance (hazard/liability/compensation coverage), legal/accounting/tax, interest on investments, and depreciation on a 120-acre farm. The capital cost of a 120-acre farm was estimated and the depreciation was calculated using the straight-line method. The additional investment cost of converting TP to SPS was estimated, and the depreciation on the additional investment was added to the fixed costs in the budget.

Variable costs, such as the cost of feed, cost of stocker size fingerlings (2 inches), cost of labor, chemicals (dyes and herbicides), electricity, repairs and maintenance, fuel, phone, office supplies (furnishings and computers), and any interest on the operating cost of the farm was also calculated and accounted for.

Two separate enterprise budgets were constructed to compare how the different measurements of the fingerlings at harvest impacted net returns. This was accomplished by grading every fish harvested from all eight ponds using standard industry graders and by using individual lengths and weights obtained from a small sample population from each pond.

Statistical Analysis

Data were analyzed using SAS statistical analysis software (v.9.4; SAS Institute Inc., Cary, NC, USA). A series of repeated measures ANOVA models were used to compare water quality in the split pond zone which housed fish, split pond zone that received initial fish waste, split pond zone that was opposite of the fish waste, and TP. Next, a two-tier approach was employed to compare weight, length, and condition factor of the fish from the SPS compared to TP. First, linear regressions were generated for each pond. Next, t-tests were used to compare the slope of the lines between SPS and TP. For survival and size distribution data, a one-way ANOVA was performed. Percentage data were log-transformed prior to analysis. Alpha was set at 0.05, and ANOVA assumptions were tested. Fish health data was analyzed using a Fisher's exact test.

Results

Morning and afternoon daily DO levels were within ranges commonly associated with pond production of largemouth bass (Figure 3). Weekly pond water sampling revealed no significant differences among SPS and TP treatments for DO ($P > 0.05$) (Table 2). DO levels ranged from 6.01 ± 2.14 mg/L and 5.85 ± 2.30 mg/L in SPS and TP treatments, respectively. Significant differences were observed among treatments in temperature ($P = 0.0022$), pH ($P = 0.0094$), total ammonia nitrogen ($P = 0.0007$), and nitrite ($P= 0.0068$). Throughout the study, pH ranged between 8.31 ± 0.78 (SPS) and 8.45 ± 0.86 (TP). Total ammonia nitrogen ranged from 0.21 ± 0.23 mg/L and 0.17 ± 0.16 mg/L in the SPS and TP treatments, while nitrite ranged from 0.14 ± 0.18 mg/L (NO_2-N) and 0.12 ± 0.13 mg/L (NO_2-N) in SPS and TP treatments, respectively.

The fish culture zone of the SPS had the highest level of TAN in the study (0.21 mg/L), followed by pond water from TP (0.17 mg/L). As expected, total ammonia nitrogen was lowest in both waste treatment zone locations (Zone W: 0.12 mg/L; Zone O: 0.071 mg/L). Post-hoc analysis revealed no differences in TAN between pond water in the fish culture zone of the SPS and TP ($P >0.05$). Values for total ammonia nitrogen remained within acceptable limits for the culture of LMB throughout the study in both SPS and TP.

Monthly pond water sampling revealed no significant differences in total hardness, total alkalinity, salinity, and chlorides ($P > 0.05$) among treatments (Table 2). Total hardness was 142.19 ± 107.64 mg/L in the SPS treatment and 115.21 ± 30.47 mg/L in the TP treatment. Total alkalinity was slightly higher in the SPS treatment (267.19 ± 58.91 mg/L) than in the TP treatment (245.73 ± 39.90 mg/L), albeit there were no significant differences. Salinity was very similar among treatments and ranged from 0.25 ± 0.07 ppt (SPS) to 0.26 ± 0.02 ppt (TP). Chlorides were also similar among treatments, ranging from 66.56 ± 31.13 (SPS) to 61.04 ± 9.77 (TP). A significant difference was observed in nitrate ($P = 0.0280$) among different pond zones and TP. However, no significant difference was observed in nitrate concentrations in the fish culture zone of SPS and

TP. Nitrates were extremely low and ranged from 1.41 ± 0.66 mg/L in the SPS to 1.73 ± 0.88 mg/L in TP.

Monthly sampling of LMB revealed that LMB cultured in the SPS had significantly faster growth in terms of total length and mean weight but not condition factor compared to TP (Figure 4). Unfortunately, analysis of the pond growth data in this study was complicated, as not all fish were stocked on the same day, and fish that were stocked were not the same size when the experiment was initiated. Due to space constraints in the hatchery at American Sport Fish, there was no way for the hatchery on the farm to simultaneously produce and have enough fingerlings available to stock all eight ponds on the same day. Hence, different cohorts of fish were used to stock ponds as new fingerlings became available. However, analyses of the slopes of growth curves revealed better growth performance of fingerlings raised in SPS than TP (Figure 4).

There were no significant differences in survival rates ($P = 0.279$) between LMB raised in SPS (70%) or TP (58.7%) (Figure 5). At the conclusion of the study, 83% of the fish cultured in SPS attained the 20.32 cm to 25.4 cm (8-10 in) size category, 15.25% fell within the 15.24 cm to 20.32 cm (6-8 in) size category, and the remaining 1.75% were within the 15.24 cm (6 in) or less size category. There were significant differences in fish size distribution at harvest between LMB raised in SPS and TP (Figure 6).

At harvest, more LMB fell within the most desirable size category (20.32 – 25.4 cm; 8-10in) in SPS (83%) compared to TP (16%) ($P < 0.001$). In the SPS treatment, 15.25% of the LMB fell within the medium size category (15.24 – 20.32 cm; 6 – 8 in), while there were higher numbers of LMB (59.5%) in the TP treatment ($P < 0.001$). Finally, SPS had the lowest distribution (1.75%) in the smallest size category (under 15.24 cm; 6 in), while TP had a much larger distribution (24.75%) in this least profitable category ($P < 0.001$).

No significant differences were observed in fish health metrics during routine sampling of LMB cultured in SPS and TP. However, it is worth noting that the sample size was quite low. Hence, there could be potential for a significant difference to be observed if a more representative sample of the experimental population was taken. It is also worth noting that ponds A12 and B4 (SPS treatment) had columnaris infections, resulting in a lower survival rate for those ponds (A12 45%; B4 71.4%) compared to the other two SPS ponds. Interestingly, despite this disease issue, the SPS treatment still had numerically higher survival and overall better growth performance.

Following construction of both enterprise budgets, it was interesting to note the size distribution of the fish produced in relation to the market price of those individuals. Table 3 shows the fish size category distributions that both SPS and TP produced in relation to the market price/value of each size category of LMB. Split-pond systems had the highest number of total individuals in the 20.32 cm (8 in) plus bass size category, with the highest market price of $3.20, with 18,524 individual fish compared to the 2,711 individuals in the same size category of TP. This resulted in a yield of $59,277 per acre of the 20.32 cm (8 in) bass in SPS, compared to a yield of only $8,674 per acre of the 20.32 cm (8 in) bass in TP. Fish size categories distributions for SPS and TP based on a sub-sample of harvest data are included in Table 4.

Two separate enterprise budgets were constructed based on different sources of fish size structure data: grader data that accounted for every fish in the pond (Table 5) and data from a sub-sample of fish at harvest (Table 6). The enterprise budget constructed from the grader data is likely more accurate and revealed higher revenue of $71,125 per acre compared to TP, which had a revenue of $42,635 per acre. Split-pond systems and TP had similar total variable and fixed costs. SPS had a higher variable cost of $30,091 per acre compared to $27,986 per acre cost of TP, due mainly to increased electricity use due to the constant paddlewheel aeration to move water in the SPS. Split-pond systems had an income of $41,033 above variable costs per acre, while TP had an income of $14,649 above variable costs per acre. Total fixed costs of SPS were slightly higher than that of TP, with SPS costing $3,246 per acre compared to the $2,678 per acre of TP.

The total costs associated with SPS were also slightly higher ($33,338 U.S. dollars per acre) than that of the TP ($30,664 U.S. dollars per acre) due to the interest on investments, which were calculated at a ten percent interest rate. Despite having both higher fixed and variable costs, SPS produced a net return over twice that of the TP. The SPS produced a net return of $37,787 per acre compared to $11,972 per acre in TP. Therefore, SPS were more profitable even after accounting for the costs of converting TP to SPS.

Split-pond systems were less profitable when using the sub-sample of length and weight data to construct the enterprise budget, but was still more profitable than TP. Using the sub-sample of length and data, SPS had higher revenue per acre ($63,749) than TP ($48,439). Under this scenario, SPS had an income of $33,658 above variable costs per acre, while TP only had an income of $20,453 above variable costs per acre. SPS produced a net return of $30,411 per acre compared to $17,775 per acre in TP.

Discussion

This study revealed better performance of LMB raised in SPS than TP. While this was not evident statistically in terms of survival, effects were most pronounced in terms of economic profitability, which was related to the size distribution of fish reared in SPS versus TP and size differentiated prices. Using SPS to culture LMB resulted in a higher percentage of fish in the largest and most desirable size category (20.32 cm to 25.4 cm; 8 -10in), and more profit for the producer. Hence, the culture of LMB in SPS appears to be a promising production strategy for commercial producers seeking to increase profits compared to culture in TP.

Farmers who culture fish in TP rely on algal photosynthesis to maintain water quality (Tucker et al., 2014). This method of water quality management is the most sustainable and cost-effective water quality control method used in the aquaculture industry, which is one of the main factors driving its popularity (Tucker et al., 2014). Increased algal photosynthesis directly relates to ammonia removal due to an increase in the overall rate of detoxification (Farrelly et al., 2015). However, these systems are limited by the energy available from sunlight alone, and this low photosynthetic efficiency requires the use of large areas for waste treatment in relation to total water volume (Tucker et al., 2014). This results in much lower densities of aquatic animals that can be stocked in these photosynthetic dependent ponds compared to more intensive alternative production systems (Tucker et al., 2014).

Previous studies in the catfish industry have documented the ability of SPS to maintain more stable water quality compared to TP due to the assimilation of nitrogenous wastes in the waste treatment zone of the SPS (Farrelly et al., 2015; Jescovitch et al., 2017; Quintero et al., 2021; Cheatham et al., 2023b). This trend was observed in the current study, with TAN being the lowest in the waste treatment zones of the SPS, with a significant difference being observed between the fish culture zone and the waste treatment zones of the SPS (Table 2).

In a study by Tidwell (1998), where LMB were cultured in 0.04 ha TP, and stocked at two densities of 6,175/ha and 12,350/ha, both treatments experienced high survival rates of 93.9% and 91.7%, respectively (Tidwell et al., 1998; Tidwell, 2019). In this study, the survival rate for LMB in TP was much lower than those in the study by Tidwell (1998), although the present study was carried out in much larger commercial size ponds, the fish survival in split ponds ranged from 45-84.3%, while survival rates ranged from 48.4-67.1% in TP. Two of the SPS experienced serious columnaris infections, resulting in low survival rates of 45% (SPS A12) and 71.4% (SPS B4). However, previous studies on farms have also reported large ranges in survival (Bott et al. 2015; Hanson et al. 2020). Smith and Stone (2017) observed survival rates that ranged from 87-100% in Golden Shiners that were overwintered in SPS. Survival rates of LMB in SPS found in this study (70.1%) were comparable to previous studies carried out with LMB cultured in SPS. Quintero et al. (2019) reported a survival rate of 79.4% in SPS, 73.2% in TP, and 70.8% in IAP following culture of LMB in a research scale study in Arkansas. In a study that compared four different SPS designs, hybrid catfish (*Ictalurus punctatus* (♀) × *Ictalurus furcatus* (♂)) fingerlings were produced using SPS equipped with either a slow rotating paddle wheel, a modified paddlewheel, a screw-pump, and an axial-flow pump as water moving devices and resulted in survival rates of 90%, 86%, 73%, and 81%, respectively (Cheatham et al., 2023b). Cheatham et al. (2023b) found that the SPS allowed for better control of production, higher fish yields, and cost efficiencies through economies of scale, with SPS profitability being sensitive to fish yields, fish price, and feed prices of the current market. In that same study, the feed cost was cited as the largest proportion of the total cost of production in SPS, with the feed costs ranging from 40-43% of the total costs of the SPS in the experiment (Cheatham et al., 2023b).

Automated feeders were used throughout this study to feed LMB cultured in both SPS and TP. Using automated feeders can reduce the labor cost needed for the husbandry of LMB. Split-pond systems can be fed more efficiently than TP (Cheatham et al., 2023b). This is primarily because cultured fish are confined to a smaller area in a fish culture zone of an SPS compared to a larger earthen pond in which fish are more spread out (Tucker et al., 2014; Farrelly et al., 2015; Brown et al., 2016; Jescovitch et al., 2017; Kumar and Engle, 2017; Smith and Stone, 2017; Quintero et al., 2021). This increase in feeding efficiency is partially responsible for the improved production observed by farmers who adopted this production technology.

In this study, SPS was superior for growing LMB compared to TP, as evidenced by the size distribution data at harvest. Along with their ease of harvest, SPS have the advantage of better inventory control and can reduce costs associated with aeration and chemical treatments (Tucker et al., 2014; Jescovitch et al., 2017; Smith and Stone, 2017; Quintero et al., 2019; Quintero et al., 2021; Roy et al. 2021). In some cases, SPS can be fitted with streamers or permanent covers to deter bird depredation more easily than their TP counterparts due to the small size of the fish culture zone (Quintero et al., 2021). The study by Quintero (2021) demonstrated how SPS might effectively have higher carrying capacities to raise fingerlings than TP, which are traditionally used for fingerling production (Quintero et al., 2021). Although the cost to convert to SPS is significant, both this study and the Quintero (2021) study demonstrated that SPS has several cost-saving benefits for immediate and long-term production needs.

LMB size distribution in SPS and TP were not exactly comparable to the results found in Quintero et al. (2019) in Arkansas. Quintero et al. (2019) revealed the size distributions of LMB raised using three different production strategies, including TP, IAP, and SPS. They found that LMB cultured in IAP had an even distribution of fish across size categories, while LMB cultured in TP had the highest distribution of fish in the larger size categories, and SPS had a higher distribution within the lower and middle size categories. It is important to note that Quintero et al. (2019) aimed to produce foodfish, while this study focused on the production of stocker-size fish for the foodfish market. Hence, the systems were managed differently, particularly with regard to feed inputs. In the Quintero et al. (2019) study, LMB were fed to achieve maximum weight (more aggressive feeding), while in the present study the goal was to achieve a fish length that would maximize profit for the production of stocker size fish.

There will always be inherent risks associated with aquaculture production. Therefore, it is necessary to determine the most beneficial combination of minimizing economic risks while increasing the potential yields to determine best practices for aquaculture production (Cheatham et al., 2023a). Cheatham (2023a) found that variations in the total yields of a production system were the primary contributor for determining the economic risk of aquaculture production strategies under a variety of market conditions. Unlike the Quintero et al. (2019) study, this trial revealed that SPS had the highest distribution of LMB in the largest size category of 20.32 cm to 25.4 cm (8-10 in) compared to TP, and this contributed to higher profitability of SPS compared to TP (Tables 3 & 4).

To track growth throughout the study, LMB were sampled monthly, and a subsample of fish was also measured during harvest. Sampling data at harvest revealed a discrepancy between sampling data and the resulting size distribution following grading at harvest. Throughout the study, only 729 LMB were sampled out of 67,500 LMB stocked in all eight ponds. While our pond bank sample numbers did not match the grader numbers achieved at harvest, we only sampled 1.1% of the fish population. A greater number of fish should have been sampled to obtain a more representative sample of the population. Unfortunately, significant effort was needed by farm personnel to sample ponds to secure a sufficient number of fish for the monthly samples. Capture was difficult and inconsistent (especially in larger TP) due to a smaller seine used for monthly sampling compared to the larger commercial seines used at harvest. Hence, it is likely that there was sampling gear bias based on the monthly sampling data. Data obtained from individually counting and grading fish at harvest using commercial graders is inherently more accurate.

The superior profitability of the SPS compared to TP is related to the size distribution of fish at harvest (Table 3 & 4). These size class distributions show the relationship between the price of each size category being sold in relation to the number of individuals produced in that size category for both SPS and TP. Table 3 shows the size distribution of individual graded counted fish (the more realistic scenario), while Table 4 shows the distribution based on the small sample of fish that were measured at harvest. Although there are some obvious price fluctuations between them, both enterprise budgets demonstrated SPS to be more profitable than TP.

While some grader bias is possible, American Sport Fish used industry-tested and proven techniques for grading their fish (Kelly and Heikes, 2013). When carrying out a study such as this, there is always the possibility of gear bias, be that of graders or seines. Catching some of the larger fish during monthly sampling events was challenging. Larger, faster fish likely escaped the seine nets during the sample pulls, causing the shift in the estimated size distributions. The grader data represents the total amount of fish harvested (every single fish), while the lengths and weights data only represent part of the total harvest data (<1% of the total fish). Commercial farmers seeking to track growth in commercial ponds, both SPS and TP, should ensure their seining techniques are sound or the number of seine pulls is sufficient to secure a more accurate sample for monthly sampling if they intend to accurately track growth throughout the production cycle. Sampling fish out of the SPS took way less time and was more efficient due to fish being confined in a much smaller area compared to an open earthen pond. The markedly different profits of SPS and TP could be due to various factors, including reduced labor costs, more efficient feeding, ease of harvest, and improved harvest size distribution of LMB in the most profitable size category. This was also observed in Quintero et al. (2021), where the advantages of using SPS for catfish production were highlighted. Much like Quintero et al. (2021), this study found that although the costs to convert the SPS to TP were significant, there were several long-term cost saving benefits to SPS, such as the ability to support higher carrying capacities, that resulted in higher yields than TP, increasing SPS profitability in comparison to TP.

The SPS is a more capital-intensive production option than the TP and requires additional costs, such as initial startup costs to convert TP to SPS and increased operating costs due to increased electrical usage. However, the greater proportion of fish produced in the larger size categories using SPS offset the operating costs and allowed for SPS to be more profitable than TP.

Although this study found SPS to be more profitable than TP, there are some factors to this study that could impact the profitability of SPS on other farms. For example, the farm where this study was carried out has a hatchery and a grow-out facility. This allowed production of LMB fingerlings for grow-out at a lower price than a farm that does not possess the means to produce its own fingerlings in an on-site hatchery. American Sport Fish is also an established and well-known business with established market connections and relationships with providers/companies which facilitates the sale of fish. Farms that are just starting up and are still in the process of establishing themselves might not have access to market channels. Therefore, SPS at a newer, farm might not be as profitable within the first few production cycles as this study was.

Another advantage this study had was that American Sport Fish had some existing tools and heavy equipment available that they used to convert TP to SPS. Cheatham et al. (2023) found that the economic risks for farmers were relatively lower on larger farms for all production strategies compared to smaller farms. Kumar and Engle (2017) reported that farm size was found to be a significant factor, and farmers were able to better manage the costs associated with capital intensive investments due to their ability to more easily access lines of credit, input supplies, human capital and their ability to bear risk. This could be another factor influencing the potential investment costs of converting TP to SPS on a farm that is not as well established.

Another factor that could impact the profitability of using SPS to culture commercial species is the target species being produced, and the size of the fish produced in relation to their market price. For example, in this study, the most desirable and profitable LMB size category was the largest size in the 20.32 cm to 25.4 cm (8-10 in) range. However, in the catfish industry, the largest size class is not what farmers are hoping to produce since processors will only pay a premium price for fish that are within premium market size (0.57-1.81 kg; 1.25-4 lbs) since anything larger than that cannot be run through existing processing equipment at the plant, causing farmers to lose money when fish grow beyond the desirable range for the catfish market (Palmer et al. 2024). Commercial farms seeking to intensify production by converting TP to SPS or any other intensive-pond based production system should address all of these factors related to target markets.

Conclusions

Largemouth Bass production for the foodfish market is growing in the US. In the past, LMB producers in the US relied on TP as their primary production system for culturing this species. LMB producers are beginning to evaluate alternative intensive pond-based production systems, such as those being used in the commercial catfish industry, to combat low survival, slow growth, poor food conversion ratio, losses to bird depredation, water quality problems, and disease issues that have been pervasive when using TP. This study confirms there is indeed promise in SPS for commercial production of LMB. Farmers seeking more intensive production using alternative production systems should consider SPS a viable alternative. This commercial demonstration trial achieved a more profitable size distribution in treatments where LMB were raised in SPS compared to TP. Economic analysis revealed this to be true despite the initial investment costs required to convert TP to SPS.

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Table 1. Total production area and stocking density for each pond in the SPS and TP treatments used to raise Largemouth Bass fingerlings to stocker size.

	SPS				**TP**			
	A12	A13	A14	B4	A1	A2	A5	A6
Total Pond Area (Acres)	0.46	0.59	0.98	0.32	1.0	1.0	1.0	1.0
Fish Zone (SPS)	0.16	0.27	0.25	0.15	-	-	-	-
Waste Zone (SPS)	0.30	0.32	0.73	0.17	-	-	-	-
# Fish / pond	5,000	10,000	7,500	5,000	10,000	10,000	10,000	10,000
Pond Stocking Density (fish/acre)	10,869	16,949	7,653	15,625	10,000	10,000	10,000	10,000
SPS Fish Culture Zone Stocking Density (fish/acre)	31,250	37,037	30,000	33,333	-	-	-	-

Table 2. Weekly and monthly water quality in SPS and TP at American Sport Fish during a production cycle raising fingerlings Largemouth Bass to stocker size. Values represent the mean ± standard deviation of values. Values with different subscripts are significantly different. Note: SPS – Fish represents the fish culture zone of the SPS; SPS Waste Initial represents the waste treatment zone of the SPS closest to the fish culture zone; SPS Waste Opposite represents the waste treatment zone on the opposite side of the SPS furthest away from the fish culture zone.

	SPS - Fish	SPS - Waste Initial	SPS - Waste Opposite	TP	P-Value
Temp (°C)	29.60 ± 2.51^{b}	29.24 ± 2.70^{a}	29.45 ± 2.17^{ab}	29.90 ± 2.44^{b}	0.0022
DO (mg/L)	6.01 ± 2.14	5.83 ± 1.77	6.58 ± 2.00	5.85 ± 2.30	0.0930
pH	8.31 ± 0.78^{a}	8.39 ± 0.86^{ab}	8.61 ± 1.02^{b}	8.45 ± 0.86^{ab}	0.0094
TAN (ppm)	0.21 ± 0.23^{b}	0.12 ± 0.13^{a}	0.07 ± 0.08^{a}	0.17 ± 0.16^{ab}	0.0007
Nitrite (ppm NO2-N)	0.14 ± 0.18^{b}	0.10 ± 0.07^{ab}	0.08 ± 0.06^{a}	0.12 ± 0.13^{ab}	0.0068
Total hardness (ppm CaCO3)	142.19 ± 107.64	109.69 ± 59.59	95.31 ± 35.89	115.21 ± 30.47	0.1826
Total alkalinity (ppm CaCO3)	267.19 ± 58.91	240.63 ± 47.04	234.06 ± 54.01	245.73 ± 39.90	0.1047
Salinity (ppt)	0.25 ± 0.07	0.25 ± 0.07	0.24 ± 0.07	0.26 ± 0.02	0.8402
Nitrate (ppm)	1.41 ± 0.66^{ab}	1.34 ± 0.69^{a}	1.33 ± 0.67^{a}	1.73 ± 0.88^{b}	0.0280
Chlorides (ppm)	66.56 ± 31.13	65.94 ± 31.63	68.44 ± 33.10	61.04 ± 9.77	0.9785

Table 3. Largemouth Bass (LMB) size class distributions produced by SPS and TP in relation to the market price of each size class of LMB. Values in this table were obtained using commercial graders and every single fish harvested and graded.

		SPS			TP		
	Price/Unit	**Number of Individuals**	**$/Acre**	**$/Hectare**	**Number of Individuals**	**$/Acre**	**$/Hectare**
8" Plus	$3.20	18,524	$59,277	$146,471	2,711	$8,674	$21,432
6"- 8"	$2.40	4,589	$11,015	$27,217	10,482	$25,157	$62,162
≤6"	$2.00	416	$833	$2,058	4,403	$8,805	$21,757
Total		23,530	$71,125	$175,747	17,595	$42,635	$105,351

Table 4. Largemouth Bass (LMB) size class distributions produced by SPS and TP in relation to the market price of each size class of LMB. Note: these values were determined using sample length and weights that were measured at harvest on October 2, 2023.

		SPS			TP		
	Price/Unit	**Number of Individuals**	**$/Acre**	**$/Hectare**	**Number of Individuals**	**$/Acre**	**$/Hectare**
8" Plus	$3.20	9,237	$29,557	$73,034	7,955	$25,454	$62,897
6"- 8"	$2.40	14,013	$33,632	$83,103	9,258	$22,219	$54,903
≤6"	$2.00	280	$560	$1,385	383	$765	$1,890
Total		23,530	$63,749	$157,522	17,595	$48,439	$119,690

Table 5. An enterprise budget for Largemouth Bass culture from fingerling to stocker size detailing quantity per year, price per unit, price or cost per acre per year, and the percent of the total cost of the SPS compared to TP at American Sport Fish based on grader data following harvest.

Enterprise budget for Split Pond and Traditional Pond Bass Production - 120 Acre Farm									
Annual costs and returns		**Split Ponds**				**Traditional Ponds**			
Item	**Unit**	**Quantity**	**Price/unit**	**Price or Cost**	**% of TC**	**Quantity**	**Price/unit**	**Price or Cost**	**% of TC**
Gross receipts									
8" Plus Bass	#	18,524	$3.20	59,277		2,711	$3.20	8,674	
6"- 8" Bass	#	4,589	$2.40	11,015		10,482	$2.40	25,157	
6" Under	#	416	$2.00	833		4,402.5	$2.00	8,805	
Total	#	23,530		**71,125**		17,595		**42,635**	
Variable costs (VC)									
Feed (35-38% protein sinking)	Pounds	5,760	1.38	7,949	0.24	5,760	$1.38	7,949	0.26
2 inch fingerlings	#	30,000	0.288	8,640	0.26	30,000	0.288	8,640	0.28
Labor	hours	228	17	3,876	0.12	234	17	3,978	0.13
Chemicals (Dye and Herbicides)	acre	1	2,004	2,004	0.06	1	2,004	2,004	0.07
Electricity	hours	9,072	0.25	2,268	0.07	1,008	0.25	252	0.01
Repairs and maintenance	acre	1	1050	1,050	0.03	1	1050	1,050	0.03
Fuel	acre	1	900	900	0.03	1	900	900	0.03
Phone	acre	1	180	180	0.01	1	180	180	0.01
Office supplies/furnishing/computers	acre	1	489	489	0.01	1	489	489	0.02
Interest on operating capital	$	27,356	10%	2,736	0.08	25,442	10%	2,544	0.08
Total variable costs ($/acre)				**$30,091**	0.90			**$27,986**	0.91
Income above variable costs				**$41,033**				**$14,649**	
Fixed costs									
Insurance (Hazard /liability/compensation coverage)	acre	1	921	921	0.03	1	921	921	0.03
Legal/accounting/tax	acre	1	138	138	0.00	1	138	138	0.00
Interest on investments	$/acre	15,566	0	1557	0.05	14,524	10%	1,452	0.05
Interest on SPS investments	$/acre	4,100	10%	410	0.01	0	10%		
Depreciation	$/acre	221		221	0.01	166		166	0.01
Total fixed costs ($/acre)				**$3,246**	0.10			**$2,678**	0.09
Total cost ($/acre) (TC)				**$33,338**				**$30,664**	
Net returns to operator ($/acre)				**$37,787**				**$11,972**	
Breakeven Price (BEP)									
BEP/VC	$/fish			$1.28				$1.59	
BEP/TC	$/fish			$1.42				$1.74	
Breakeven yield (BEY)									
BEY/VC	#			9,955				11,549	
BEY/TC	#			11,029				12,654	

Table 6. An enterprise budget for Largemouth Bass culture from fingerling to stocker size detailing the quantity per year, price per unit, price or cost per acre per year, and the percent of the total cost of the SPS compared to TP at American Sport Fish based on the length and weight data obtained at harvest in a sub-sample.

Enterprise budget for Split Pond and Traditional Pond Bass Production - 120 Acre Farm									
Annual costs and returns		**Split Ponds**				**Traditional Ponds**			
Item	**Unit**	**Quantity**	**Price/unit**	**Price or Cost**	**% of TC**	**Quantity**	**Price/unit**	**Price or Cost**	**% of TC**
Gross receipts									
8" Plus Bass	#	9,237	$3.20	29,557		7,955	$3.20	25,454	
6"-8" Bass	#	14,013	$2.40	33,632		9,258	$2.40	22,219	
6" Under	#	280	$2.00	560		382.5	$2.00	765	
Total	#	23,530		**63,749**		17,595		**48,439**	
Variable costs (VC)									
Feed (35-38% protein sinking)	Pounds	5,760	1.38	7,949	0.24	5,760	$1.38	7,949	0.26
2 inch fingerlings	#	30,000	0.288	8,640	0.26	30,000	0.288	8,640	0.28
Labor	hours	228	17	3,876	0.12	234	17	3,978	0.13
Chemicals (Dye and Herbicides)	acre	1	2,004	2,004	0.06	1	2,004	2,004	0.07
Electricity	hours	9,072	0.25	2,268	0.07	1,008	0.25	252	0.01
Repairs and maintenance	acre	1	1,050	1,050	0.03	1	1,050	1,050	0.03
Fuel	acre	1	900	900	0.03	1	900	900	0.03
Phone	acre	1	180	180	0.01	1	180	180	0.01
Office supplies/furnishing/computers	acre	1	489	489	0.01	1	489	489	0.02
Interest on operating capital	$	27,356	10%	2,736	0.08	25,442	10%	2,544	0.08
Total variable costs ($/acre)				**$30,091**	0.90			**$27,986**	0.91
Income above variable costs				**$33,658**				**$20,453**	
Fixed costs									
Insurance (Hazard /liability/compensation coverage)	acre	1	921	921	0.03	1	921	921	0.03
Legal/accounting/tax	acre	1	138	138	0.00	1	138	138	0.00
Interest on investments	$/acre	15,566	10%	1,557	0	14,524	10%	1,452	0.05
Interest on SPS investments	$/acre	4,100	10%	410	0.01	0	10%		
Depreciation	$/acre	221		221	0.01	166		166	0.01
Total fixed costs ($/acre)				**$3,246**	0.10			**$2,678**	0.09
Total cost ($/acre) (TC)				**$33,338**				**$30,664**	
Net returns to operator ($/acre)				**$30,411**				**$17,775**	
Breakeven Price (BEP)									
BEP/VC	$/fish			$1.28				$1.59	
BEP/TC	$/fish			$1.42				$1.74	
Breakeven yield (BEY)									
BEY/VC	#			11,107				10,166	
BEY/TC	#			12,305				11,138	

Figure 1. Map of the TP (A1, A2, A5, & A6) and SPS (A12, A13, A14, & B4) used for a study to culture Largemouth Bass fingerlings to stocker size at American Sport Fish in Montgomery, Alabama. Note: Letters represent locations in which water samples were collected (Table 2): F: Fish culture zone of the SPS, W: Initial waste treatment zone of the SPS; O: Waste treatment zone opposite and furthest from the fish culture zone of the SPS.

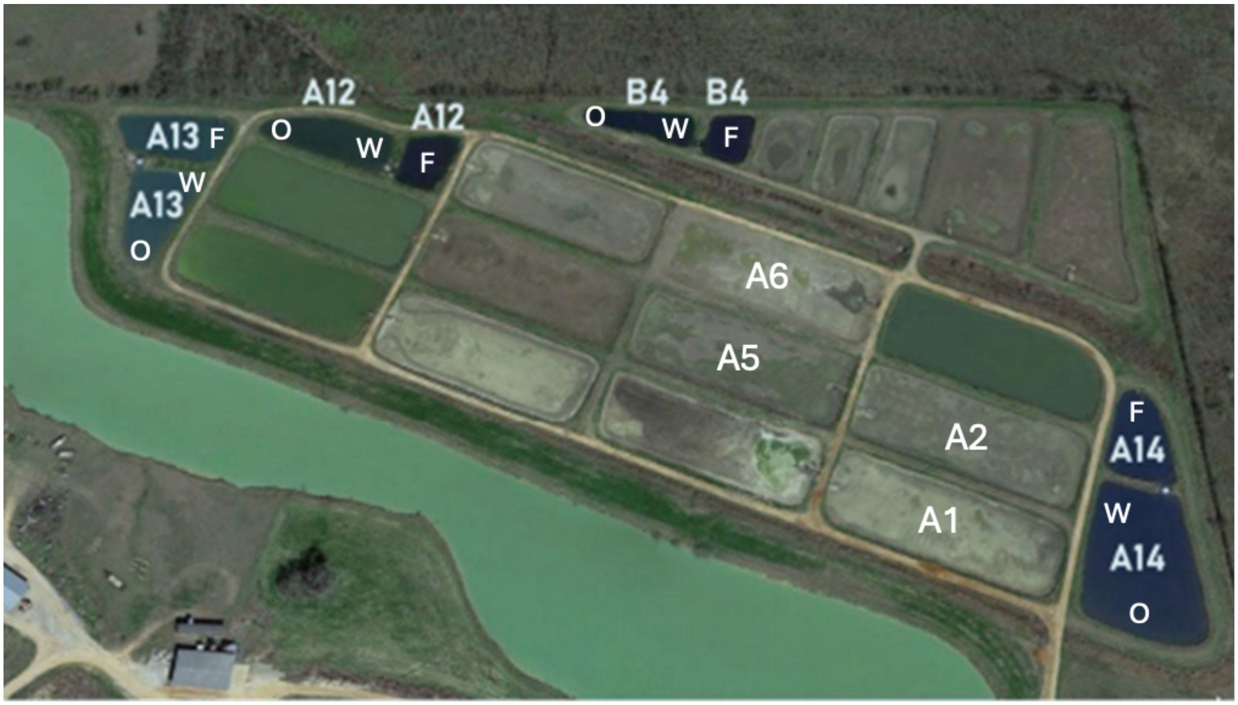

Figure 2. Flow chart showing the location and timeline of Largemouth Bass samples collected for the length and weight measurements, as well as fish health sample collections.

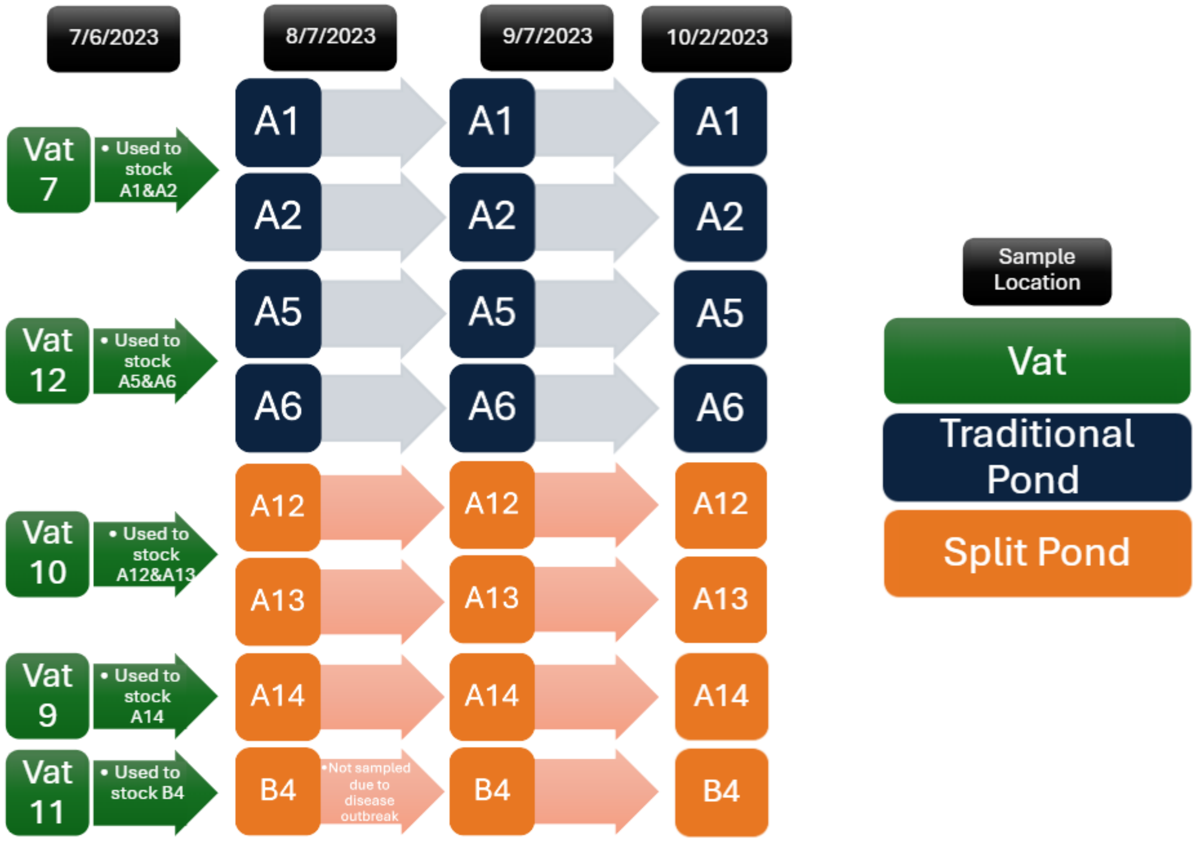

Figure 3. Daily morning and evening dissolved oxygen (DO) concentrations of SPS and TP in a study that cultured Largemouth Bass fingerlings to stocker size at American Sport Fish (July 6, 2023 - October 2, 2023).

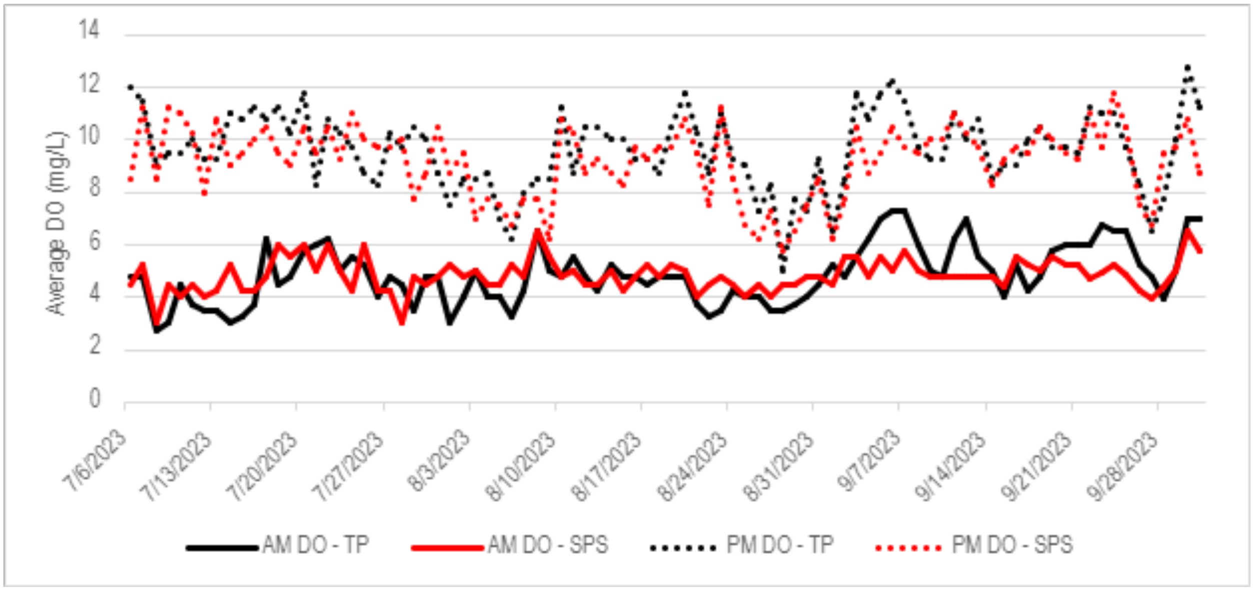

Figure 4. Linear regressions for total length (A), weight (B), and condition factor of Largemouth Bass (LMB) obtained from pond sampling data throughout the production cycle of raising fingerlings to stocker size. Slopes of lines obtained from linear regressions for total length (D), weight (E), and condition factor (F) of LMB obtained from pond sampling data throughout the production cycle of raising fingerlings to stocker size. Values with different letters were significantly different from each other (P < 0.05).

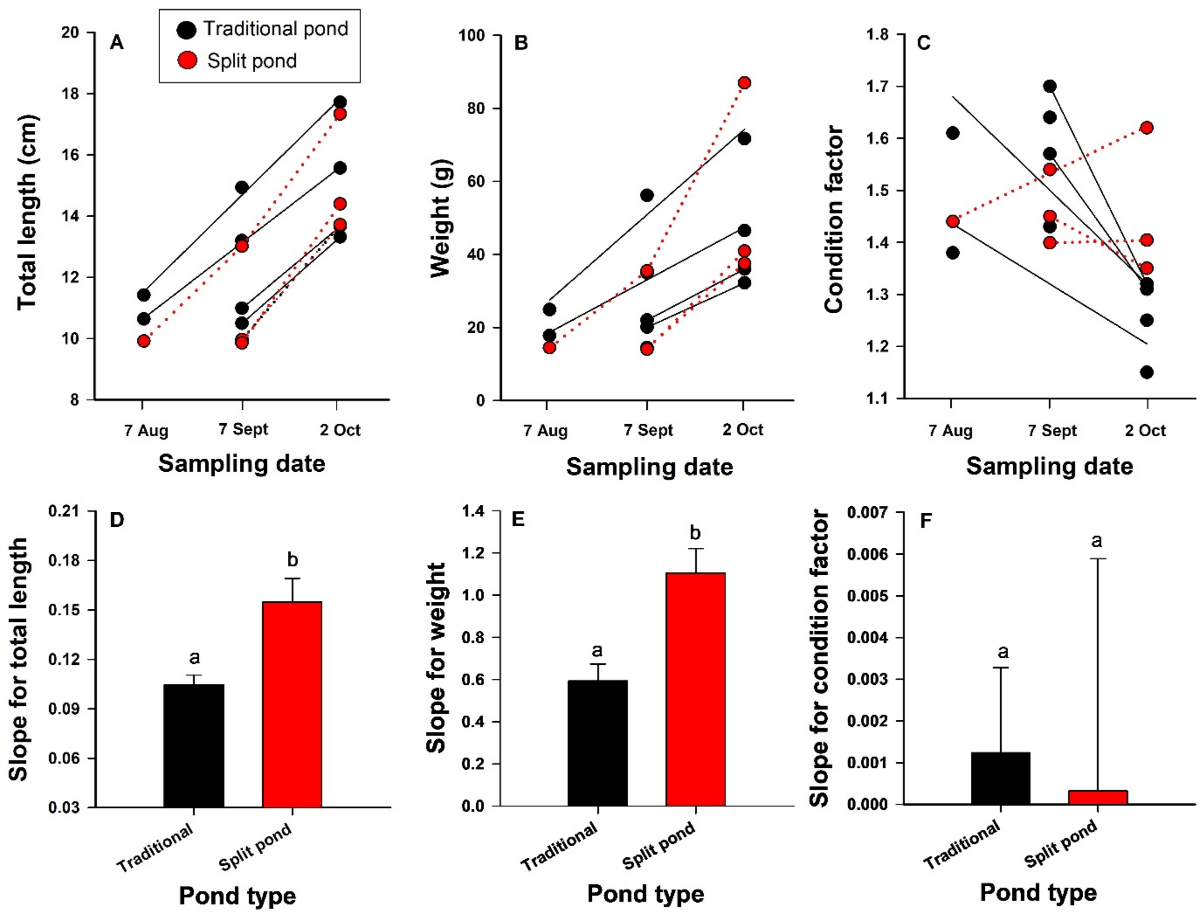

Figure 5. Survival (%) of Largemouth Bass in SPS compared to TP following culture of fingerlings to stocker size at American Sport Fish in Montgomery, Alabama.

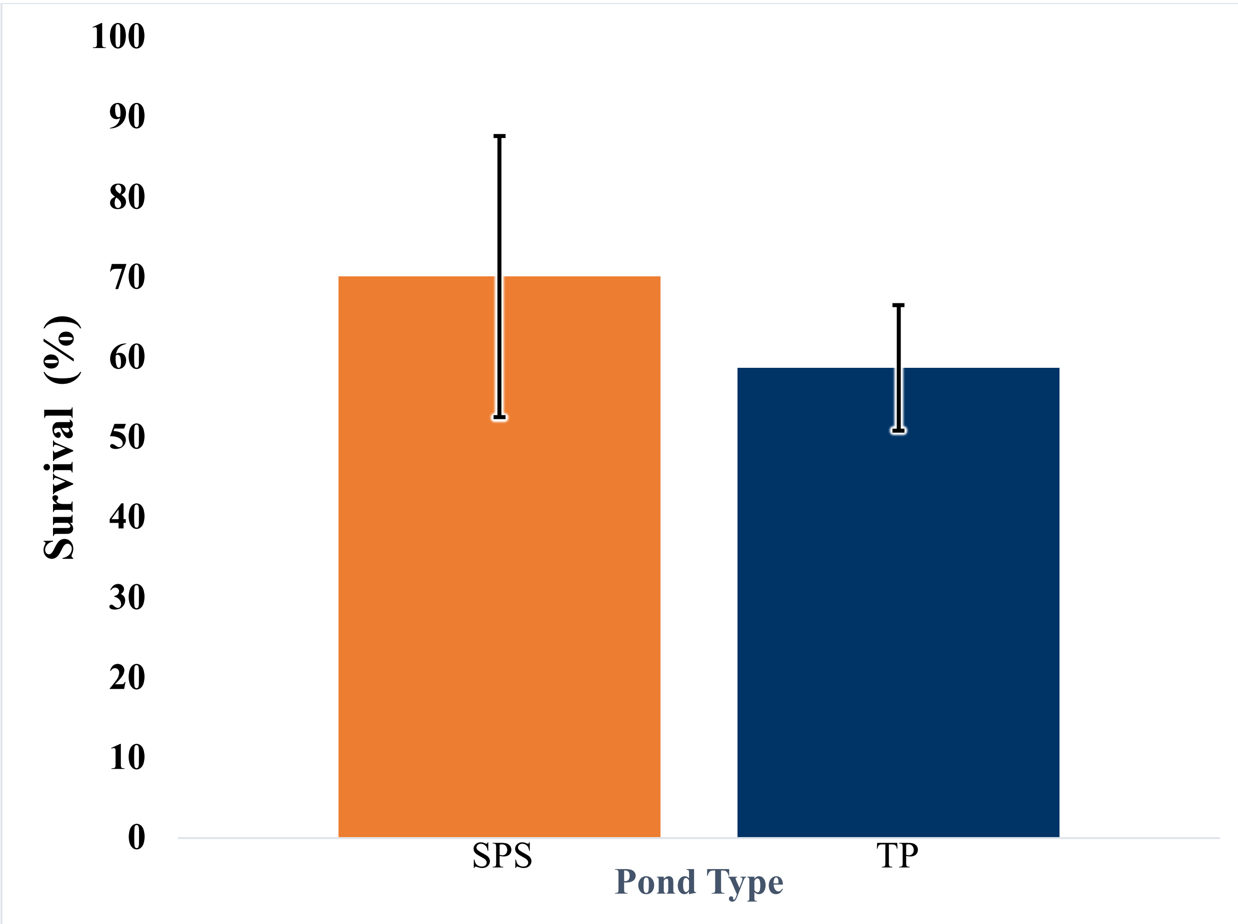

Figure 6. Size distribution of Largemouth Bass at harvest for SPS and TP at harvest following grading in a study that cultured fingerlings to stocker size at American Sport Fish in Montgomery, Alabama.

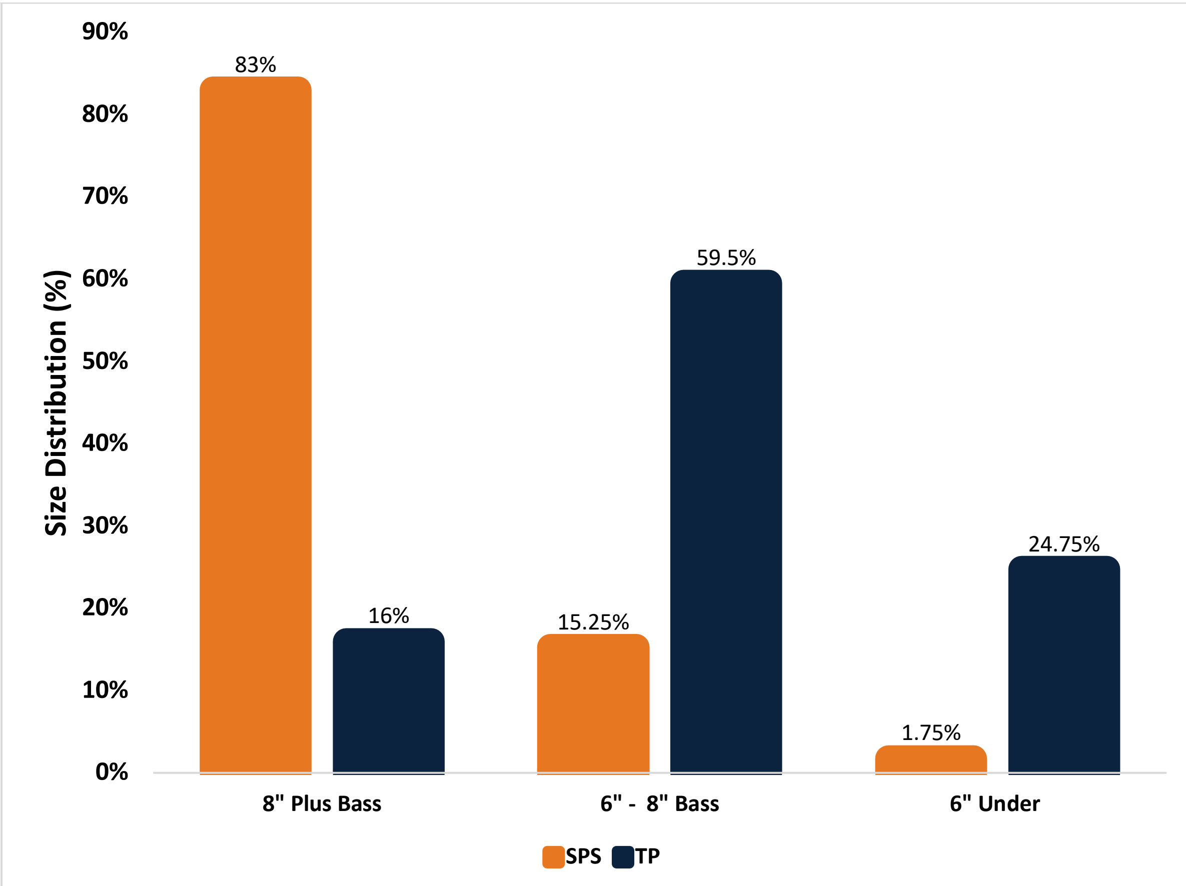

Figure 7. Size distribution of Largemouth Bass at harvest for SPS and TP based off of the lengths and weights measurements from sampling at the harvest in a study that cultured fingerlings to stocker size at American Sport Fish in Montgomery, Alabama.