PRODUCTION COMPARISON OF CHANNEL CATFISH *ICTALURUS PUNCTATUS*, BLUE CATFISH *I. FURCATUS*, AND THEIR HYBRIDS IN EARTHEN PONDS

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Mingkang Jiang

Certificate of Approval:

Jesse A. Chappell
Assistant Professor
Fisheries and Allied Aquacultures

William H. Daniels, Chair
Associate Professor
Fisheries and Allied Aquacultures

Jeffery S. Terhune
Assistant Professor
Fisheries and Allied Aquacultures

Stephen L. McFarland
Acting Dean
Graduate School

PRODUCTION COMPARISON OF CHANNEL CATFISH *ICTALURUS PUNCTATUS*, BLUE CATFISH *I. FURCATUS*, AND THEIR HYBRIDS IN EARTHEN PONDS

Mingkang Jiang

A Thesis

Submitted to

the Graduate Faculty of

Auburn University

in Partial Fulfillment of the

Requirements for the

Degree of

Master of Science

Auburn, Alabama
December 16, 2005

PRODUCTION COMPARISON OF CHANNEL CATFISH *ICTALURUS PUNCTATUS*,

BLUE CATFISH *I. FURCATUS*, AND THEIR HYBRIDS IN EARTHEN PONDS

Mingkang Jiang

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Signature of Author

____
Date of Graduation

VITA

Mingkang Jiang, son of Lianmin Jiang and Qingzhi Sun, was born on June 19, 1979, in Yantai, Shandong Province, P.R. China. In 2002, he graduated with a Bachelor of Agricultural degree from Dalian Fisheries University, Dalian, Liaoning Province, P.R. China. He then spent one year at the Institute of Hydrology Research Center of Jinan University, Guangzhou, Guangdong Province for graduate study. In April 2004, he entered Auburn University and worked in the Department of Fisheries and Allied Aquacultures as a Graduate Research Assistant.

THESIS ABSTRACT

PRODUCTION COMPARISON OF CHANNEL CATFISH *ICTALURUS PUNCTATUS*, BLUE CATFISH *I. FURCATUS*, AND THEIR HYBRIDS IN EARTHEN PONDS

Mingkang Jiang

Master of Science, December 16, 2005
(B.A., Dalian Fisheries University, 2002)

72 Typed Pages

Directed by William H. Daniels

Two strains of channel catfish (*Ictalurus punctatus*, HS-5 channel and NWAC 103 channel catfish), one strain of blue catfish (*I. furcatus*, D&B blue catfish) and their hybrids (HS-5 channel ♀ × D&B blue ♂, NWAC 103 channel ♀ × D&B blue ♂) were compared for their production characteristics in twenty-five 0.04-ha earthen ponds at a density of 12,500 fish/ha. Mean survival (88.9%) was not significantly different among the five fish groups. HS-5 channel catfish and its hybrid started at larger sizes (56.5 g) and ended up with larger animals (850.5 g) than the other three fish groups (29.4 g and 638.6 g, respectively). D&B blue catfish (CV=29.9) was more uniform than NWAC 103 channel (CV=38.6) and NWAC 103 hybrid (CV=41.8), but it was not significantly different from HS-5 channel (CV=35.4) and HS-5 hybrid (CV=30.3). Better average growth rates were observed on the HS-5 channel catfish (2.76 g/day) and its hybrid (2.87 g/day) than those of the NWAC 103 channel (2.31 g/day), NWAC 103 hybrid (2.30 g/day), and D&B blue (2.03 g/day). The NWAC 103 channel (1.12%) and its hybrid (1.06%) had better mean specific growth rates than those for the HS-5 channel (0.97%), HS-5 hybrid (0.96%), and D&B blue (1.01%). No significant differences were detected among the five fish groups based on the growth rate index (*a*) evaluation, and the overall average growth rate index (*a*) was 1.89. Mean net production among NWAC 103 hybrid catfish (6953 kg/ha), HS-5 channel catfish (8396 kg/ha) and its hybrid (8480 kg/ha) was not significantly different, and they were greater than those of the NWAC 103 channel catfish (5791 kg/ha) and the D&B blue catfish (5774 kg/ha). Mean feed conversions (1.62) were not significantly different among treatments. D&B blue catfish (94%) was the easiest to seine as measured as percentage harvested within the first seine haul. HS-5 channel × D&B blue hybrid catfish (61%) was easier to seine than its parent HS-5 channel catfish (31%).

Processing revealed some differences among fishes. Both the mean head percentages of HS-5 channel × D&B blue hybrid (17.0%) and NWAC 103 channel × D&B blue hybrid (16.5%) were less than those of their parent channel catfish (20.8% and 19.1%, respectively). Both hybrid catfishes had better mean dress-out percentages (HS-5 channel × D&B blue hybrid 72.1% and NWAC 103 channel × D&B blue hybrid 71.8%, deheaded and gutted with skin) than those of their parent channel catfish (67.4% and 69.6%, respectively) and blue catfish (70.2%). No significant differences were detected on the mean skin-on fillet percentages (50.6%) among the five treatments.

The success in the hybrid catfish artificial spawning techniques made the commercial production of hybrid catfish possible. According to the results of the present study, hybrids from different parental stocks performed differently. Further studies on the selection of hybrid catfish and mechanism of heterosis are needed for the commercial production of hybrid catfish.

ACKNOWLEDGMENTS

This experiment was partially funded by the Alabama Catfish Producers Association.

I would like to thank my advisor, Dr. Daniels, and Mr. Harvey J. Pine for their invaluable assistance throughout the whole experiment. I also want to say thanks to Dr. Terhune for fish disease analysis, and Dr. Davis and Dr. Chappell for their help in the final fish processing. Special thanks go to the students who generously donated their time and labor in all phases of the experiment.

Journal format used Journal of World Aquaculture Society

Computer software used Microsoft Word XP, Microsoft Excel XP, SAS 9.1 for Windows.

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I. INTRODUCTION

Catfish farming is currently the largest food fish aquaculture industry in the United States based on the total production weight. Catfish production in the United States during 2004 was an estimated 630 million pounds with a present market value of over 480 million dollars (USDA 2005).

Coincident with the increase in the domestic catfish production are the increased imports of fish products, especially the Vietnamese catfish frozen fillets, which accounted for over 26 percent of the total U.S. frozen fillet market in 2002. Despite an anti-dumping case issued by the Department of Commerce in 2003, which limited the catfish imports and temporarily alleviated the economic woes of catfish farmers, it was not a long-term solution. The production efficiency of catfish farming needs to be increased to continue competing in the global market.

The channel catfish, *Ictalurus punctatus*, is the most important commercially cultured catfish species in the United States. Earthen ponds are the major form of culture plus a small percentage of high-density culture systems, such as cages, pens, tanks, vats, and raceways. Even slight improvements in growth rate, survival, body weight, tolerance to low oxygen, harvestability, or dress-out percentage in channel catfish would result in millions of kilograms of additional production and increased profits. Previous research on the female channel catfish × male blue catfish (*I. furcatus*) hybrid showed the possibility of improving these commercial traits via hybridization. Hybridization between female channel and male blue catfish has produced an outstanding F_1 hybrid. Its reciprocal, the blue female × channel male, is not as good (Chappell 1979; Prather 1965; Dunham and Smitherman 1987).

The hybrid catfish has an increased tolerance to low oxygen and disease resistance compared to the channel catfish. As stocking densities of channel catfish are increased, water quality tends to decline and bacterial infections and mortality tend to increase. For example, channel catfish had heavy infestations of *Flexibacter columnaris* when stocked separately and communally with hybrid catfish (Dunham *et al.* 1990). F_1 hybrid fry survival (100%) was greater than that of channel catfish fry (29.5%) at high densities (741,000 fry/ha). Li *et al.* (2004) detected a significant difference in the survival of one channel catfish (85.4%) and its channel × blue hybrid (93.8%) when stocked at 14,820 fish/ha. At 4,940 to 7,410 fish/ha, survival of F_1 hybrids was also greater than that of channel catfish (Dunham and Smitherman 1987; Dunham *et al.* 1987). The survival was 73.8% for hybrid catfish and 62.0% for channel catfish when they were challenged with an immersion bath of *Edwardsiella ictaluri*. Injections of *E. ictaluri* were lethal only to channel catfish (Wolters *et al.* 1996). Hybrid catfish fry were more resistant to bacterial and parasitic infections than channel catfish fry (Ella 1984). However, the hybrids may have actually been more resistant to the stress of the oxygen depletion than the pathogens since low dissolved oxygen is considered a precursor to bacterial infection (Snieszko 1958) However, hybridizing channel and blue catfish does not increase resistance to channel catfish virus disease (Plumb and Chappell 1978).

Dunham *et al.* (1983) reported that fewer hybrids (7.5%) than the channel catfish (50.5%) died from oxygen depletions induced by formalin treatment in the earthen ponds. When fish were kept in cages, 87.5% of a channel catfish population succumbed due to low dissolved oxygen and only 51.0% of the hybrids died. None of the channel catfish survived the low oxygen in the concrete tank but 67% of the hybrids survived.

Giudice (1966) first noted the potential of the hybrid catfish for better production, but the stocking rates he used were below that utilized currently in commercial catfish culture. Yant (1975) found that the production of hybrid catfish was 556 kg/ha more than that for the channel catfish when stocked at 7400 fish/ha. The hybrid also had a better feed conversion (1.35) than the channel catfish (1.56). Hybrid catfish fingerlings also grew faster to market-size than channel catfish fingerlings at all densities in ponds (Chappell 1979; Brummet, 1986; Dunham *et al.* 1987), especially at higher densities (Argue 1996; Ella 1984; Dunham *et al.* 1990). The positive performance of the channel × blue hybrid in stressful environmental conditions further indicates its potential as an important commercial fish (Smitherman *et al.* 1983).

Recently, Li *et al.* (2004) reported that the channel × blue hybrid consumed more feed, gained more weight, converted feed more efficiently, and had higher net production. Growth rate of the channel catfish × blue catfish hybrid could be 35% better than the channel catfish and the growth improvement through inter-species hybridization was three times better than through mass selection (Dunham and Brummett 1999).

The relatively better harvestability of the hybrid catfish might be of value to both the commercial fish farmer and fee-fishing operations. The channel × blue is much easier to catch by seining (Yant 1975; Dunham *et al.* 1982; Smitherman and Dunham 1985; Dunham and Argue 1998), as well as by hook and line, compared to channel catfish (Tave *et al.* 1981; Dunham *et al.* 1986).

These differences in seinability may be attributed to the relative position of the fish in the water column (Dunham *et al.* 1982). Blue catfish appear to be easier to train to floating feed in ponds than channel catfish (Meyer *et al.* 1973) and seem to be more of a midwater dweller than the channel catfish (Dunham *et al.* 1982).

Processing yield is also an important aspect in aquaculture. The female channel × male blue hybrid has a higher dress-out (deheaded and gutted without skin) and fillet percentage (without skin) than the channel catfish (Yant *et al.* 1975; Argue 1996; Argue *et al.* 2003). Li *et al.* (2004) reported that although no difference in shank fillet yield was detected, the hybrid had higher dress-out yield, nugget yield, fillet moisture and protein and a lower level of fillet fat. Bosworth *et al.* (2004) compared the meat yield and meat quality traits of two strains of channel catfish (NWAC103 line of channel catfish and Norris line channel catfish) and one hybrid catfish (Norris line female channel catfish × Dycus Farm line male blue catfish) and concluded that dress-out and fillet yields were higher than those for the hybrid than for the two channel catfish lines.

The possibility of increased production traits resulting from hybridization of the catfish has long been recognized but has yet to be widely utilized by the industry because of the reproductive isolating mechanism between channel catfish and blue catfish (Tave 1987; Dunham and Smitherman 1987). Recent advances in the hybrid embryo production technology make the popularity of the hybrid catfish feasible (Lambert *et al.* 1999; Dunham, *et al.* 1999; Dunham *et al.* 2000). The purpose of this study was to utilize two channel catfish strains for a side-by-side comparison to determine which catfish is the best one for commercial culture.

The following production traits were compared among channel, blue and hybrid catfish: 1) survival, 2) net production, 3) feed conversion, 4) growth rate, 5) harvestability, 6) carcass characteristics, 7) uniformity of size, and 8) gender differences.

II. MATERIALS AND METHODS

Experimental Fish

Catfishes were produced from two commercial farms. HS-5 channel catfish and D&B blue catfish were provided by Harvest Select (Uniontown, Alabama). NWAC 103 channel catfish was provided by Nobile Fish Farm (Moorhead, Mississippi). The following two hybrid catfish crosses were also artificially made at Harvest Select: NWAC 103 female channel × D&B male blue, HS-5 female channel × D&B male blue. Fry were reared at 250,000 fish/ha in 0.04-ha earthen ponds at the North Auburn Fisheries Unit, Auburn University, for one growing season. All the NWAC 103 channel catfish were highly stressed during the initial transportation to Auburn which resulted in a severe outbreak of columnaris and subsequent high mortalities in the week after they were stocked into the ponds.

Duration of the Experiment

The experiment began with the stocking of fingerlings from this previous study on March 1 and 2, 2004, after over-wintering them together by fish groups. All the fish were harvested from November 29 to December 2, 2004. This was a total growing period of 277 days.

Description of Culture Ponds

The earthen culture ponds were located approximately 8 km north of Auburn, Alabama, on the North Auburn Fisheries Unit. Twenty-five 0.04-ha ponds were used in this experiment. The ponds were approximately 13.8 m wide and 29.2 m long with an average depth of 1.0 m and a maximum depth of 1.5 m. Each pond had an approximated volume of 282 m^3. Ponds were filled from a watershed reservoir thirty days prior to stocking. Water inlets to each pond were covered with a “sock” strainer made of saran netting to prevent entrance of wild fish, fry or eggs.

Ponds were limed with agricultural lime at 9072 kg/ha and liquid lime (CAL-FLO, Burnett Lime Company. Inc. Campobello, SC) at 118.3 L/ha two weeks prior to stocking. Also, 1134 kg/ha of road grade salt was added into each pond three weeks before stocking to increase the chloride concentration in water to about 0.16 g/L. Sufficient water was added periodically to compensate for evaporation and seepage.

Stocking

On March 1st and 2nd, 2004, five hundred fingerling-sized fish were counted by hand and stocked into each pond at 12,500 fish/ha density. Five treatments were assigned randomly to the ponds (five replicates per treatment). They were NWAC 103 channel, HS-5 channel; D&B blue, NWAC 103 female channel × D&B male blue and HS-5 female channel × D&B male blue. Because the fish had been used in the previous year’s study, large variance in growth among different treatments existed. Those with total length smaller than 7.6 cm and bigger than 22.9 cm were excluded from stocking. About fifty fish from each treatment were sampled to determine the initial individual mean weights and total lengths of fish.

Sampling

Ten fish were removed without replacement from each pond four times throughout the whole culture season to monitor for diseases and fish growth as part of a separate study. This occurred at 38, 49, 119 and 246 days after stocking. A 9.14 m, 0.95-cm mesh seine was used to seine the pond. The sampled fish were counted, weighed in bulk and then sacrificed. Total weights of fish in the four samplings were added to the final harvest weight for the gross yield, net production, and feed conversion calculation.

Feeding

Fish were fed commercial floating pellets that contained 32% protein and 4.5% fat (Alabama Catfish Feedmill, Uniontown, Alabama). Fish were fed 1.0, 1.5, 2.0, 2.5 and 3.0 percent of their body weight 6 or 7 days per week depending upon the temperature and feeding reaction (Table 1). Amounts of feed were recalculated weekly assuming a 1.8 feed conversion and 100% survival. Adjustments to feeding amount were made after sampling and fish mortalities.

Fish were fed once a day in the afternoon from March 4 to June 29, 2004, and October 9 to November 26. When fish were feeding very actively, they were fed twice a day June 30 to October 8, with 60% of total daily feed amount in the morning and 40% in the afternoon. A bonus amount of up to 10% of the total daily ration was provided from July 28 to October 8, to support some fast growth. Bonus feed was provided together with the morning feed, if the fish consumed most of the normal morning feed in one minute. Occasionally, feeding was discontinued because of the necessity to eliminate feeding due to low dissolved oxygen (DO) after cloudy or rainy days. The daily feeding amounts were recorded and summed together to calculate the total feed input into each pond. Feed conversion was calculated by total feed input (kg) divided by total wet weight gain (kg).

TABLE 1. Feeding methods for the catfish stocked at 12,500 fish/ha in 0.04-ha earthen ponds and grown for 277 days.

Time period	Percentage of fish weight	Frequency	Bonus
March 4 -- April 10, 2004	1.0%	Six days a week, once a day	No
April 11 -- May 15, 2004	1.5%	Six days a week, once a day	No
May 16 -- May 25, 2004	1.5%	Seven days a week, once a day	No
May 26 -- June 29, 2004	2.5%	Seven days a week, once a day	No
June 30 -- July 27 , 2004	3.0%	Seven days a week, twice a day	No
July 28 -- September 23, 2004	3.0%	Seven days a week, twice a day	Up to 10%
September 24 -- October 8, 2004	2.5%	Seven days a week, twice a day	Up to 10%
October 9 -- November 26, 2004	2.0%	Seven days a week, once a day	No

Pond and Water Quality Monitoring and Management

Five grass carp (*Ctenopharyngodon idellus*) were put into each pond (125 fish/ha) to control aquatic weeds. Aquatic weeds became a problem in ponds E3, E4, E6, E7, E11, E18, E19, E20 and E24. *Chara sp.*, *Najas sp.*, *Pithophora sp*, and *Hydrodictyon sp* were identified as the most abundant weeds. Diquat (Reward, Syngenta), chelated copper (Copper Control, Argent Chemical Laboratories), or Diuron (Karmex® DF, Griffin L.L.C., Valdosta, GA) were applied at rates of 3.7 L/ha, 68 kg/ha, and 21.3 g/ha, respectively according to the type of weeds. The weed in pond E18 was manually removed twice by dip net and surface seining.

A YSI 556 multiprobe oxygen meter (YSI Incorporated, Yellow Springs, Ohio) was used to monitor dissolved oxygen (DO), water temperature, and pH in all ponds at a depth of 0.2 to 0.3 m, in the early morning (07:00 to 07:30) and late afternoon (17:30 to 18:00). Records of DO aided in decision making on whether or not ponds were to be fed and which ponds were to be aerated. Aeration was only used when the oxygen level in the water was 5.0 mg/L in the afternoon and projected to fall below 1.0 mg/L or lower by the next morning. Each pond was equipped with one 0.5-hp spray aerator (Air-o-lator Corp, Kansas City, Missouri) for aeration. Additional aerators were put into a pond to provide extra aeration as needed.

Alkalinity and total hardness were checked monthly with colormetric test kits (LaMotte Company, Chestertown, Maryland), and ammonia-nitrogen and nitrite-nitrogen were checked monthly or as needed with a photometer YSI9100 (YSI Incorporated, Yellow Springs, Ohio). Liquid lime (CAL-FLO, Burnett Lime Company, Inc. Campobello, SC) was applied at 118 L/ha when the alkalinity fell below 50 mg/L.

Gypsum (Piedmont Fertilizer, Auburn, AL) was added to pond E5 on August 9 at 567 kg/ha to reduce inorganic turbidity and allow phytoplankton growth. Alcohol (Fisher Scientific, Pittsburgh, PA) was used in pond M19 on August 19 at 6.25 L/ha to lower the high pH (>10) caused by a heavy phytoplankton density.

Disease Management

When found, all dead fish were removed from ponds and weighed before disposal. Sick fish was weighed, wrapped with moist paper towel, put into a plastic ziplock bag, and sent to the Southeastern Cooperative Fish Disease Laboratory, Auburn University, for further diagnosis.

Columnaris (*Flexibacter columnaris*) was diagnosed as the cause of sixty-nine recorded fish mortalities in pond E6 (NWAC 103 channel) in September and October. HS-5 channel × D&B blue group also had an outbreak of columnaris in pond M19 in early June. Fish in these ponds were fed at 1% percent body weight with medicated feed (Terramycin®) for 10 days combined with a 4 mg/L potassium permanganate treatment. Another 12.5 L/ha of AgriTec™ (Earth Science Laboratories, Inc. Rogers, AR) was applied to E6 to prevent the reoccurrence of columnaris.

Some minor mortalities occurred in pond E15 (NWAC 103 channel) and E17 (HS-5 channel × D&B blue) near the end of the growing season. These fish were also fed at 1% body weight with medicated feed for 10 days combined with a 12.5 L/ha of AgriTec™ to help control the disease. Fish in E17 recovered quickly after the treatment. Dead fish were continually picked out from pond E15 until the time of harvesting. The causative disease in these two ponds was not identified.

Harvesting

Fish were harvested November 29 to December 2. Ponds were partly drained and seined from the deep to the shallow end with a 9.14 m, 0.95 cm mesh seine. Two to three seine hauls were completed on each pond before draining to collect the remaining fish by hand (scrapped). Percentage caught in the first and second seining were calculated by dividing the number of fish caught in the first and second seine by the total number of fish harvested from the pond and then multiplying by 100. All the fish were counted and weighed in bulk on an electronic balance (Wildcat ® WS30VR000, Mettler-Toledo scale & system ltd, Changzhou, Jiangsu, China)as calculated by total number of fish harvested from each pond plus the number of fish sampled from the pond divided the number of fish stocked into the pond and then multiplying by 100.

Growth Rates

Average growth rate was calculated using the following equation:

$$\text{Average growth rate (gram/day)} = (W_f - W_i) / t$$

where W_f is the individual harvesting weight, W_i is the individual stocking weight, and t is the time (days) between W_f and W_i. Specific growth rate was calculated using this equation:

$$\text{Specific growth rate} = (\ln W_f - \ln W_i) \times 100 / t$$

where $\ln W_f$ is the natural logarithm of the individual harvesting weight, $\ln W_i$ is the natural logarithm of the individual stocking weight, and t is the time (days) between $\ln W_f$ and $\ln W_{i.}$ A growth rate index (*a*) (Silverstein *et al.*1999) was also used to evaluate the growth of the five fish groups. This growth rate index (*a*) was calculated as the following equation:

$$\log_e G_w = a - 0.371 \log_e Wm$$

where G_w is the individual specific growth rate in percent per day, Wm is the mean weight of fish in each pond ([pond stocking weight + pond harvest weight] / 2), a is the intercept of the equation, and – 0.371 is a constant developed for channel catfish by Silverstein *et al.* (1999). All three growth rates were used to evaluate the growth of the five fish groups.

Carcass Characteristics

Forty fish were sampled randomly from each pond at harvest time for carcass evaluation. The samples were held on ice in covered square totes (0.8 m × 0.4 m × 0.5 m) until processing. All the fish were weighed on an electronic scale (Ohaus-N1D110 electronic scale, Pine Brook, NJ). Total length was measured to the nearest mm with a measuring board. Fish were sexed by the existence of ovaries or testes.

Of the forty fish sampled from each pond, twenty were deheaded using a commercial bandsaw (Biro Model 22, Biro Manufacturing Company, Marblehead, Ohio) and eviscerated by hand. Dress-out percentage was calculated as the weight of the fish without head and viscera, divided by whole weight. The other twenty fish were filleted on one side by hand. Skin, nugget and ribs were kept on the fillet. Fillet weights were measured (Ohaus-SP4001 electronic scale, Pine Brook, NJ), and fillet percentage was the weight of muscle on one side times two and divided by whole weight of the fish and times 100. Fish were processed on the day of harvest or the next day to limit pre-processing weight loss.

Distributions of final individual weight of each fish group were graphed and coefficients of variation (CV) were calculated to compare the uniformities among different fish groups.

Statistical Analysis

One-way analysis of variance (ANOVA) and general linear model (GLM) were performed using SAS (Version 9.1). T-test was used to compare the difference between genders, and also compare sample weights to population weights for each pond. Data reported as percentages were arcsine transformed before statistical analysis. Actual percentages are presented in the tables instead of the arcsine values for easier interpretation of data. Significant differences ($p < 0.05$) among treatment means were identified with Duncan's multiple range test.

III. RESULTS AND DISCUSSION

Water Quality Characteristics

Mean overall weekly morning and afternoon water temperatures of the catfish ponds are illustrated in Figure 1. Growth of catfish happens when the water temperature is above 13 °C with an optimal range from 27 °C to 30 °C. This range was indicated in Figure 1 by two straight lines. There were about four months when the overall mean water temperature in the afternoon fell into this rang.

Maintaining good dissolved oxygen and pH is important for good catfish growth. An oxygen concentration above 4.0 mg/L is needed for normal catfish growth (Chapman 1992). High afternoon pH will stress the fish and cause a larger portion of toxic, un-ionized ammonia in the water and slow the growth of catfish (Tucker 1985). The number of times that the dissolved oxygen concentration was recorded below 4.0 mg/L and pH went above 9.5 were compared among the five fish groups (Table 2), but no significant differences were detected ($p = 0.1223$ and $p = 0.1150$, respectively). Weekly mean dissolved oxygen and pH in the morning and afternoon during the whole growing season are illustrated in Figures 2 and 3. The overall average number of times that the dissolved oxygen went below 4.0 mg/L was 18 with a range of 7 to 28. These numbers were summarized from a total 277-day grow-out period. Additional aeration during the night helped the oxygen level stay at a level above 4.5 mg/L in the morning (Figure 2). The aquatic weeds and phytoplankton in some of the ponds caused relatively high pH in the afternoon. We tried to control the high pH by weed treatment together with alkalinity management. Occasionally, the pH in some ponds would still go above 9.5, even 10.0. Fish still fed actively at most of the times when this happened because it was a temporary change in pH.

Overall changes in mean alkalinity, total hardness, TAN (total ammonia nitrogen), un-ionized ammonia (NH_3) and nitrite are shown in Table 3. Alkalinity and total hardness values above 50 mg/L were recommended in channel catfish production ponds (Chapman 1992). Liquid lime was used to keep alkalinity and total hardness above these levels. The un-ionized portion in the TAN is the main stressful factor to the fish and it varies with water temperature and pH. Concentration of un-ionized ammonia in channel catfish ponds range from 0 to 1 mg N/L or more (Tucker 1985). In this study, the mean overall un-ionized ammonia concentration was 0.20 mg N/L with a range from 0.03 to 0.50 mg N/L. The range of nitrite concentrations in commercial channel catfish ponds changes from 0 to 4 mg N/L (Tucker and Schwedler, 1983). In present study, the overall nitrite level stayed at low levels from 0.01 to 0.17 mg N/L.

Initial Stocking Weight and Length

Fish were not stocked at equal size. Fifty fish from each treatment were sampled to determine the mean initial individual weights and total lengths of fish and results are presented in Table 4. Both HS-5 channel and its hybrid catfish (HS-5 channel × D&B blue) were larger than the other three groups of fish at the beginning in length ($p < 0.0001$) and weight ($p < 0.0001$). NWAC 103 channel catfish was the smallest fish at that time. Stocking weight distributions of the five fish groups were graphed and shown in Appendixes 1 – 5.

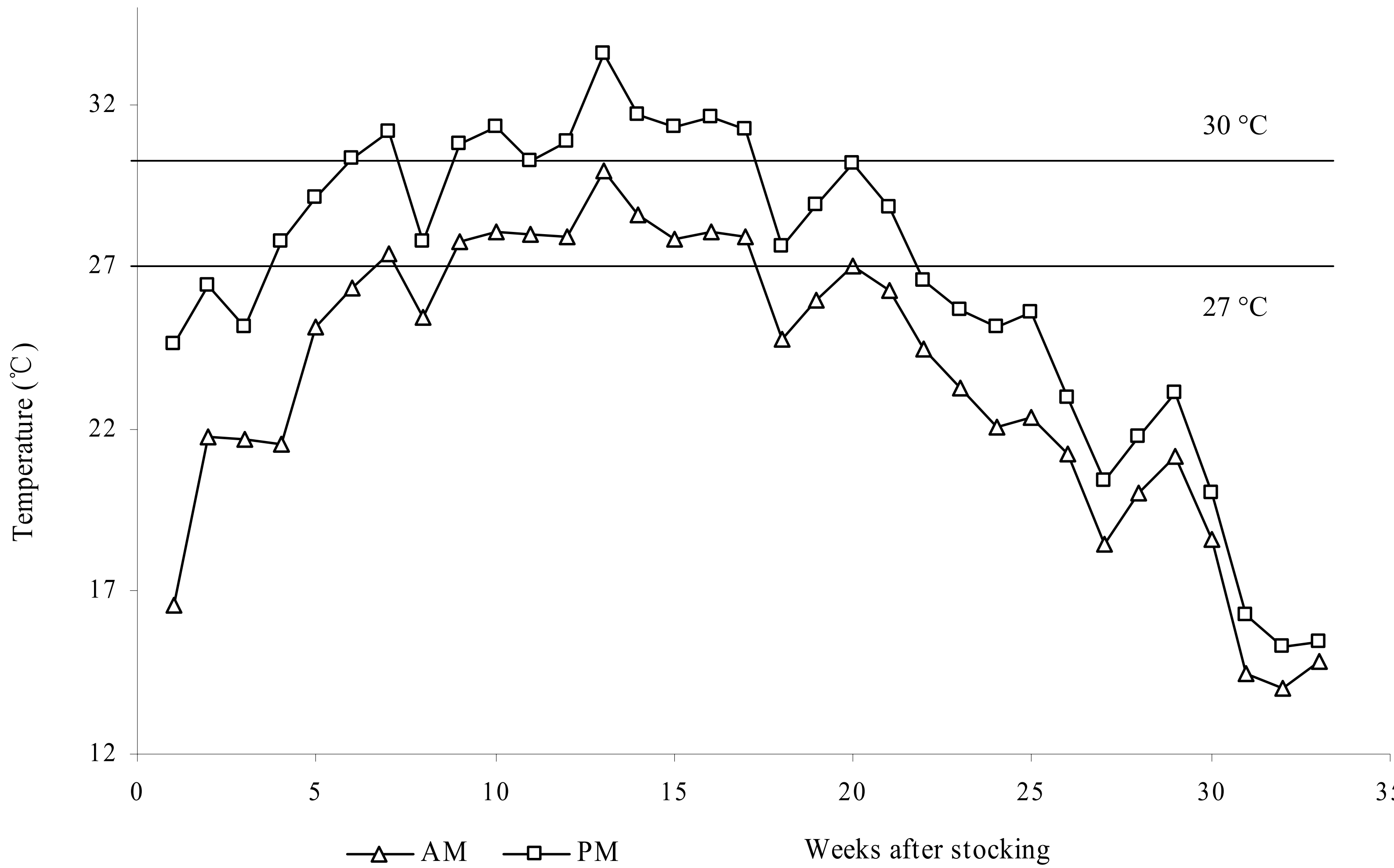

FIGURE 1. Overall change of average morning and afternoon water temperature (°C) in the catfish ponds stocked at 12,500 fish/ha.

TABLE 2. Mean (± SE [1]) times of dissolved oxygen below 4.0 mg/L and pH above 9.5 of catfish ponds stocked at 12,500 fish/ha.

Treatments	n	Times of dissolved oxygen below 4.0 mg/L	Times of pH above 9.5
NWAC 103 channel	5	17 ± 7	50 ± 8
HS-5 channel	5	28 ± 6	36 ± 9
D&B blue	5	18 ± 3	49 ± 7
NWAC 103 channel × D&B blue	5	7 ± 2	29 ± 10
HS-5 channel × D&B blue	5	20 ± 5	22 ± 7

[1] SE = Standard error

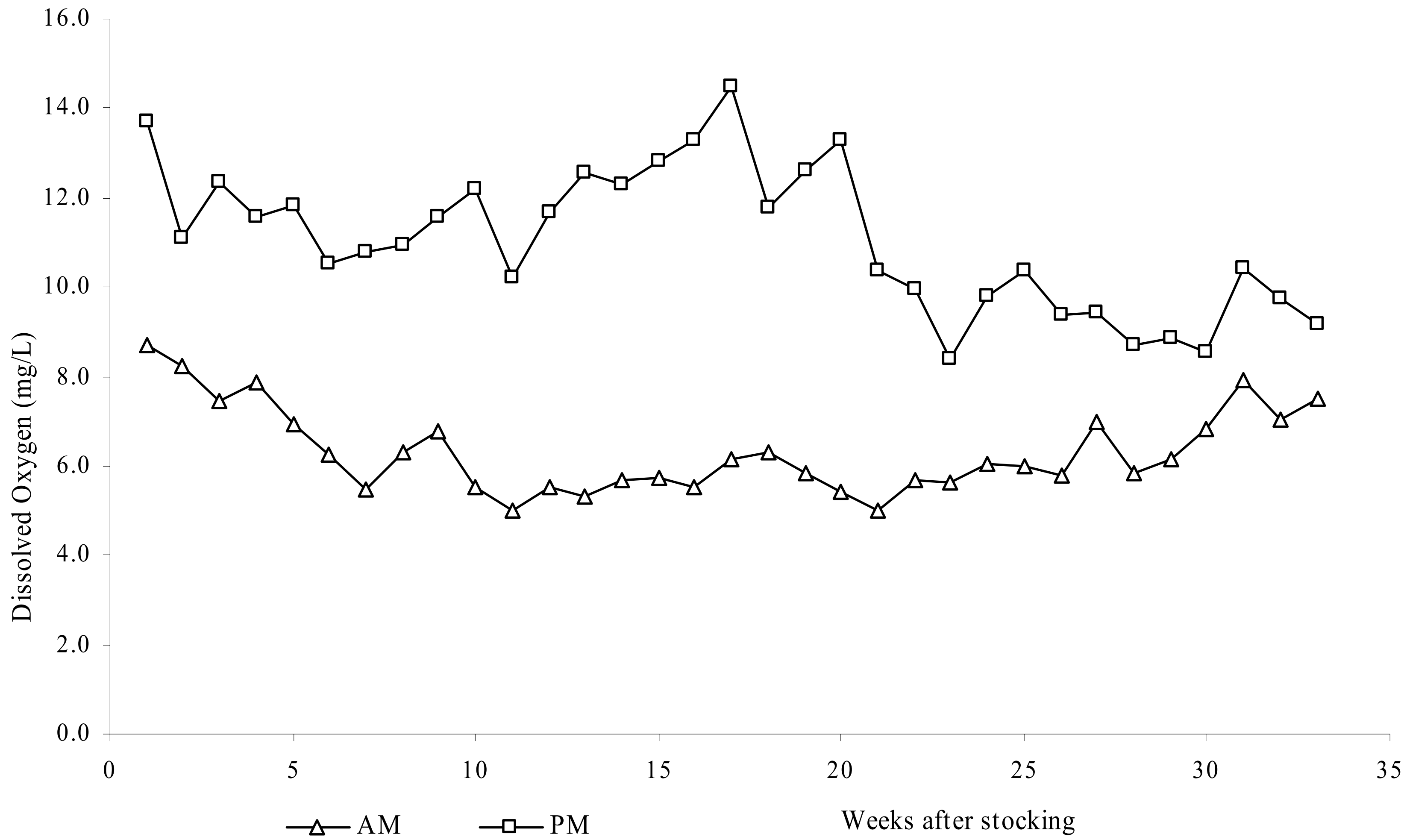

FIGURE 2. Overall change of average dissolved oxygen (mg/L) in the morning and afternoon of catfish ponds stocked at 12,500 fish/ha.

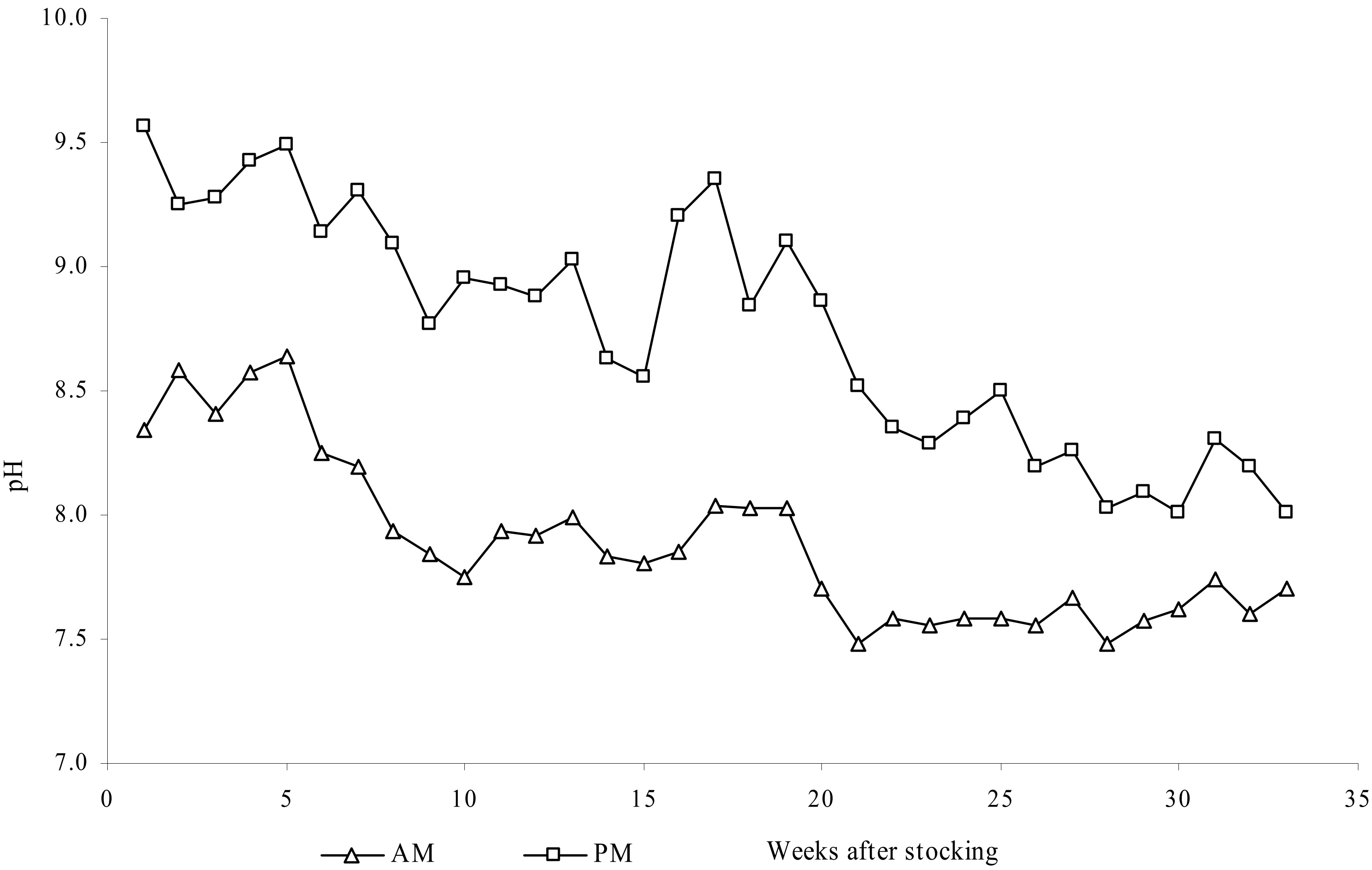

FIGURE 3. Overall change of average pH in the morning and afternoon of catfish ponds stocked at 12,500 fish/ha.

TABLE 3. Mean (± SE [1]) monthly alkalinity, total hardness, TAN (total ammonia nitrogen), un-ionized ammonia, and nitrite of catfish ponds stocked at 12,500 fish/ha.

Month	Alkalinity (mg/L)	Total hardness (mg/L)	TAN (mg N/L)	NH_3 (mg N/L)	Nitrite (mg N/L)
March	47.6 ± 1.9	-	-	-	-
April	65.2 ± 4.7	-	-	-	-
May	51.0 ± 3.7	55.6 ± 4.0	0.09 ± 0.01	0.03 ± 0.00	0.01 ± 0.00
June	67.2 ± 2.7	53.0 ± 2.6	-	-	-
July	76.3 ± 3.0	57.0 ± 2.5	0.18 ± 0.07	0.10 ± 0.04	0.01 ± 0.00
August	77.1 ± 3.0	54.3 ± 2.6	0.38 ± 0.10	0.27 ± 0.07	0.05 ± 0.01
September	89.9 ± 4.6	60.6 ± 2.9	2.28 ± 0.41	0.50 ± 0.09	0.12 ± 0.03
October	81.6 ± 4.2	54.8 ± 2.5	2.35 ± 0.33	0.12 ± 0.02	0.17 ± 0.02

[1] SE = Standard error

TABLE 4. Mean (± SE [1]) individual stocking weight, total length, and sampling number (n) of catfish stocked in 0.04-ha earthen ponds at 12,500 fish/ha and grown for 277days.

Treatments	n	Total length (cm)	Whole weight (g)
NWAC 103 channel	50	14.0 ± 0.3 c [2]	23.0 ± 1.9 c
HS-5 channel	50	19.0 ± 0.4 a	55.3 ± 3.2 a
D&B blue	50	16.4 ± 0.3 b	33.3 ± 2.1 b
NWAC 103 channel × D&B blue	52	16.4 ± 0.3 b	31.8 ± 1.8 b
HS-5 channel × D&B blue	48	19.1 ± 0.3 a	57.7 ± 3.1 a

[1] SE = Standard error
[2] Means within the same columns followed by the same letter are not significantly different based upon general linear model and Duncan's multiple range test ($p > 0.05$).

Survival

There were no significant differences in mean number of fish harvested (404 fish/pond, $p = 0.0759$) and mean survival (88.9%, $p = 0.1322$) among the five fish groups (Table 5). The two hybrids had mean survival of 93.4% (NWAC 103 channel × D&B blue) and 91.4% (HS-5 channel × D&B blue), respectively. D&B blue survived at 88.1% and HS-5 channel catfish at 93.7%. NWAC 103 channel catfish had two replicates with survival at 57.0% (E6) and 64.6% (E15) and the other three replicates at 77.2% (E1), 92.6% (E9), and 98.0% (E12), respectively, which yielded a mean survival of 77.9%.

Mean survival of some fish groups was reduced by disease outbreaks. Columnaris (*Flexibacter columnaris*) was identified as the causative agent in ponds M19 (HS-5 channel × D&B blue) and E6 (NWAC 103 channel catfish). Fish in M19 recovered quickly after medicated feed (Terramycin®) treatment. Fish in E6 continued with some minor mortality and low feeding reaction after using the medicated feed (Terramycin®) and AgriTec™ treatment. Unknown causative agents caused some minor mortalities in pond E17 (HS-5 channel × D&B blue) and E15 (NWAC 103 channel catfish). Fish in E17 recovered with active feeding after the medicated feed (Terramycin®) and AgriTec™ treatment. Fish in E15 continued with less feeding and more dead fish until the end of the study. According to the record of the first year's study, the NWAC 103 channel catfish used in this study had severe outbreaks of columnaris the week after the fry were put into the ponds. Stress resulting from poor handling during transporting to Auburn was identified as an important causative of the disease outbreak.

Table 5. Number of fish stocked, sampled, mean (± SE [1]) number of fish harvested and mean (± SE) survival of catfish stocked in 0.04-ha earthen ponds at 12,500 fish/ha.

Treatments	n	No. of fish stocked	No. of fish removed by sampling	No. of fish harvested	Survival (% population)
NWAC 103 Channel	5	500	40	350 ± 39	77.9 ± 7.9
HS-5 Channel	5	500	40	428 ± 4	93.7 ± 0.8
D&B Blue	5	500	40	400 ± 11	88.1 ± 2.1
NWAC 103 Channel × D&B Blue	5	500	40	427 ± 3	93.4 ± 0.7
HS-5 Channel × D&B Blue	5	500	40	417 ± 21	91.4 ± 4.3
Overall Mean				404	88.9%

[1] SE = Standard error

Varying results on the mean survival rates of hybrid catfish and channel catfish have been reported in previous studies. Ella (1984) and Dunham *et al.* (1990) reported higher mean survival rate of hybrid catfish than its parent channel catfish in the fry stage, in which the hybrid catfish fry were more resistant to *F. columnaris* than its parent stock. Dunham *et al.* (1987) also reported better survival of hybrid catfish than that of its parent channel catfish stocked as fingerlings. Li *et al.* (2004) found better survival in hybrid catfish (94%) than channel catfish (85%). Bosworth *et al.* (2004) found no difference in survival between one hybrid catfish and its parent channel catfish and another channel catfish. Argue (1996) found no significant difference in survival between F_1 hybrid catfish (85%) and channel catfish (77%). Brummett (1986) did not find significant differences in survival among the channel × blue hybrid (88%) and those of the other three channel catfish (AU-K 84%, AU-KS-2 81%, and AU-MS-2 80%). Yant *et al.* (1975) saw no difference in survival between F_1 hybrid and channel catfish fingerlings stocked at 7,400 fish/ha. Dunham and Brummett (1999) also found no significant difference in survival between one hybrid and three channel catfish lines. Significant differences in mean survival rates were not detected in this study either. Variation within treatments could be the possible explanation of this. Despite this, the greatest gap on the survival was 15.8%, which may be important in practical application.

Final Individual Lengths and Weights

The mean individual total lengths and whole wet weights of the five fish groups were significantly different ($p < 0.0001$ and $p < 0.0001$, respectively. Table 6). According to the sampling from the harvest, HS-5 channel catfish (415.5 mm and 828.7 g) and its hybrid (HS-5 channel × D&B blue, 417.6 mm and 872.2 g) had greater mean individual

TABLE 6. Mean (± SE [1]) final individual total length and whole weight of catfish stocked in 0.04-ha earthen ponds at 12,500 fish/ha.

Treatments	n	Total length (mm)		Whole weight (g)	
		Mean ± SE	CV	Mean ± SE	CV
NWAC 103 channel	5	390.8 ± 2.6 b [2]	12.0 ± 0.5 a	687.0 ± 25.5 b	38.6 ± 2.6 ab
HS-5 channel	5	415.5 ± 7.6 a	11.1 ± 0.6 ab	828.7 ± 40.2 a	35.4 ± 2.7 abc
D&B blue	5	379.1 ± 4.8 b	8.6 ± 1.2 c	593.8 ± 16.8 c	29.9 ± 3.9 c
NWAC 103 channel × D&B blue	5	381.7 ± 3.5 b	12.8 ± 0.4 a	635.0 ± 27.2 bc	41.8 ± 1.7 a
HS-5 channel × D&B blue	5	417.6 ± 5.2 a	9.2 ± 0.8 bc	872.2 ± 28.7 a	30.3 ± 2.0 bc

[1] SE = Standard error
[2] Means within the same columns followed by the same letter are not significantly different based upon general linear model and Duncan's multiple range test ($p > 0.05$).

total lengths and weights than those of NWAC 103 channel catfish (390.8 mm and 687.0 g, respectively) and its hybrid (NWAC 103 channel × D&B blue, 381.7 mm and 635.0 g, respectively).

HS-5 channel catfish and its hybrid started at relatively bigger sizes (Table 4) and ended up with larger animals than the other three treatments (Table 6). Dunham *et al.* (1987) reported the channel catfish grew more rapidly to 100 g than the hybrid catfish, but the hybrid catfish grew more rapidly from fingerling size to food size than the channel catfish. Bosworth *et al.* (2004) reported the hybrid had higher stocking weight and harvest weight than its parent channel catfish but not higher than another channel catfish. Jeppsen (1995) found no difference in mean body weight when compared to a selected and a random channel × blue hybrid and stocked communally with their parent species at densities of 7,500 fish/ha and 12,500 fish/ha.

Coefficients of variation (CV) of the final individual lengths and weights were significantly different among the five fish groups ($p < 0.0043$ and $p < 0.0208$, respectively, Table 6). Coefficients of variation (CV) of the final individual weight were used to evaluate the uniformity in the fish groups. D&B blue catfish (CV=29.9) was more uniform than NWAC 103 channel catfish (CV=38.6) and NWAC 103 × D&B blue hybrid (CV=41.8), but not significantly different than those of the HS-5 channel catfish (CV=35.4) and HS-5 channel × D&B blue hybrid (CV=30.3). HS-5 channel × D&B blue hybrid (CV=30.3) was more uniform than NWAC 103 channel × D&B blue hybrid (CV=41.8). Yant (1975) studied the uniformity of catfish by counting the number distributions of catfish in certain length groups and found the hybrid catfish was more uniform than channel catfish. In the present study the uniformity of the two hybrids were not significantly different from their parent stocks. Final size distributions of the five fish groups based on the harvesting sample weight were illustrated in Appendixes 6 – 10.

The mean individual total lengths and whole wet weights of the five fish groups based on gender were also compared (Table 7). Only the NWAC 103 hybrid showed significant differences in total length and whole wet weight based upon gender. This indicates a lack of dimorphism at this age of catfish.

Final sample weights were compared with mean population weights with t-test for each pond (Appendixes 11). Only three ponds (E8, E13, and E14) had significantly differences between the sample weights and the mean population weights.

Growth Rates

Average growth rates, specific growth rates and growth rate index (a) of the five fish groups were calculated for comparison. Average growth rates and specific growth rates were significantly different among the five fish groups, but not the growth rate index (a) ($p < 0.0001$, $p < 0.0001$, and $p = 0.1918$, respectively, Table 8). The HS-5 channel catfish (2.76 g/day) and its hybrid (2.87 g/day) had better average growth rates than the NWAC 103 channel catfish (2.31 g/day) and its hybrid (2.30 g/day). But in the case of specific growth rate, NWAC 103 channel catfish (1.12%) and its hybrid (1.06%) were better than the HS-5 channel catfish (0.97%) and its hybrid (0.96%).

The growth rate index (a), which was first described by Jobling (1983), was used to evaluate the growth of the five fish groups with modifications (Silverstein *et al.*1999). The 'growth potential' of fish declines with increasing body size, but the log-log transformation provides a good linear relation between growth rate and size for fish species (Jobling 1983). Modification to this equation for catfish was made by Silverstein *et al.* (1999), which is

TABLE 7. Mean (± SE [1]) final female and male individual total lengths and whole wet weights of catfish stocked in 0.04-ha earthen ponds at 12,500 fish/ha.

Treatments	Total length (mm)		Whole weight (g)	
	Female	Male	Female	Male
NWAC 103 channel	385.9 ± 4.5	395.6 ± 4.9	652.0 ± 25.4	720.3 ± 29.0
HS-5 channel	414.0 ± 5.0	416.6 ± 4.6	809.2 ± 30.5	842.4 ± 29.2
D&B blue	378.9 ± 3.4	379.3 ± 3.6	590.2 ± 17.6	597.5 ± 18.6
NWAC 103 channel × D&B blue	373.4 ± 5.1 y [2]	389.1 ± 4.6 z	589.9 ± 26.5 y	674.3 ± 26.7 z
HS-5 channel × D&B blue	417.2 ± 4.2	418.1 ± 3.8	880.7 ± 28.5	865.4 ± 25.5

[1] SE = Standard error
[2] Means within the same row under each category followed by different letters are significantly different based upon t-test ($p > 0.05$).

Table 8. Mean (± SE [1]) individual stocking weight, individual harvesting weight, average growth rate, specific growth rate and growth rate index (*a*) of catfish stocked in 0.04-ha earthen ponds at 12,500 fish/ha and grown for 277 days.

Treatments	n	Individual stocking weight (g)	Individual harvesting weight (g)	Average growth rate [3] (g/day)	Specific growth rate [4] (%)	Growth rate index (*a*) [5]
NWAC 103 channel	5	23.0 ± 1.9 c [2]	687.0 ± 25.5 b	2.31 ± 0.14 b	1.12 ± 0.02 a	1.89 ± 0.06
HS-5 channel	5	55.3 ± 3.2 a	828.7 ± 40.2 a	2.76 ± 0.07 a	0.97 ± 0.01 d	1.92 ± 0.02
D&B blue	5	33.3 ± 2.1 b	593.8 ± 16.8 c	2.03 ± 0.04 c	1.01 ± 0.01 c	1.81 ± 0.01
NWAC 103 channel × D&B blue	5	31.8 ± 1.8 b	635.0 ± 27.2 bc	2.30 ± 0.07 b	1.06 ± 0.01 b	1.92 ± 0.02
HS-5 channel × D&B blue	5	57.7 ± 3.1 a	872.2 ± 28.7 a	2.87 ± 0.07 a	0.96 ± 0.01 d	1.91 ± 0.03

$$\text{Log}_e\, G_w = a - 0.371 \log_e W_m$$

The intercept *a* represents the $\log_e G_w$ of a fish of unit size (Silverstein *et al.* 1999) and it is recommended for growth comparing fish with different initial sizes (Jobling 1983; Silverstein *et al.* 1999). Fish size effects could be compensated by using this relationship. Fish in the present study were dissimilar in size at the time of stocking. According to the stocking sampling, mean individual weight of fish varied from 23.0 g (NWAC 103 channel catfish) to 57.7 g (HS-5 channel × D&B blue). No significant difference was detected between the HS-5 channel catfishes and their hybrids using these two growth rates. The overall mean growth rate index (*a*) is 1.89.

Dunham *et al.* (1987) reported the hybrid catfish grew more rapidly from fingerling size to food-size than channel catfish and had the same mean body weight as its parent channel catfish, but not so fast on the fry stage. Argue (1996) also reported that the channel × blue hybrid catfish grew rapidly in the second year but not in the first year. In this study, HS-5 channel catfish and its hybrid catfish started as bigger animals, consumed more feed and had a better average growth rate. Bosworth *et al.* (2004) had the similar situation when three groups of fish (Norris channel × Dycus Farm blue hybrid, Norris line channel catfish and NWAC 103 channel catfish) were stocked at 12,000 fish/ha with different size (27 – 57 g), and significant differences were also not found using the growth rate index (*a*) of the three fish groups.

Dunham and Brummett (1999) reported the difference between hybrid catfish and channel catfish on growth rate could be as big as 35 percent. The biggest difference on average growth rate in this study was about 24 percent (HS5 channel × blue hybrid, 2.87 g/day over NWAC 103 channel catfish, 2.31 g/day).

Net Production

Significant differences existed among the mean net production of the five groups (p = 0.0007) (Table 9). The mean net production of both the HS-5 channel catfish (8396 kg/ha) and its hybrid (8480 kg/ha) was significantly greater than that of the D&B blue catfish, which had a net production of 5774 kg/ha. The production of NWAC 103 hybrid catfish (6953 kg/ha) averaged 1162 kg/ha more than its parent NWAC 103 channel catfish (5791 kg/ha) although not statistically different. At $1.50/kg for catfish, this could mean additional gross revenue of $1743 per ha for the NWAC 103 hybrid catfish than for the NWAC 103 channel catfish. Li *et al.* (2004) reported the net production of hybrid catfish (Gold Kist channel × D&B blue catfish, 7593 kg/ha) was 44 percent more than that of the NWAC 103 channel catfish (5258 kg/ha) when stocked separately at a rate of 14,820 fish/ha. Bosworth *et al.* (2004) found the net production of channel catfish × blue catfish hybrid (4702 kg/ha) was 29 percent better than its parent channel catfish (3640 kg/ha). Yant (1975) found the average net production for channel catfish × blue catfish hybrid was 13.5 percent more than the channel catfish when stocked separately at 3000 fish/acre.

The net production of the HS-5 channel catfish (8396 kg/ha) was 45 percent more than that of the NWAC 103 channel catfish (5791 kg/ha). The net production of the HS-5 hybrid (8480 kg/ha), however, was not significantly different from HS-5 channel catfish but was 22 percent more than that of the NWAC 103 hybrid (6953 kg/ha). Ramboux (1990) reported different net productions existed among four channel × blue catfish hybrids coming from different parent species when stocked separately and communally.

TABLE 9. Mean (±SE [1]) initial, final standing crop and net production of catfish stocked in 0.04-ha earthen ponds at 12,500 fish/ha and grown for 277 days.

Treatments	n	Initial standing crop (kg/ha)	Final standing crop (kg/ha)	Net production[3] (kg/ha)
NWAC 103 channel	5	377 ± 3 d [2]	6168 ± 829 b	5791 ± 827 b
HS-5 channel	5	698 ± 8 b	9094 ± 249 a	8396 ± 251 a
D&B blue	5	456 ± 7 c	6229 ± 212 b	5774 ± 206 b
NWAC 103 channel × D&B blue	5	451 ± 4 c	7403 ± 258 b	6953 ± 256 ab
HS-5 channel × D&B blue	5	754 ± 5 a	9234 ± 556 a	8480 ± 554 a

[1] SE = Standard error
[2] Means within the same columns followed by the same letter are not significantly different based upon general linear model and Duncan's multiple range test ($p > 0.05$).
[3] Net production (kg/ha) = Final standing crop (kg/ha) – Initial standing crop (kg/ha).

Feed Conversion Ratios (FCR)

Mean feed conversion ratios were not significantly different ($p = 0.1006$) among the five fish groups (Table 10). Mean value of FCR of the five fish groups was 1.62, which ranged from 1.52 (NWAC 103 Channel × D&B Blue) to 1.74 (NWAC 103 Channel). The mean FCRs of HS-5 hybrid, HS-5 channel, and D&B blue catfish were 1.61, 1.58, and 1.67, respectively. Bosworth *et al.* (2004) also reported FCRs were not significantly different among one hybrid, its parent channel catfish, and another channel catfish. Li *et al.* (2004) found better FCRs in hybrid catfish (1.84) than channel catfish (1.99) at the stocking rate of 14,820 fish/ha. Yant (1975) reported the feed conversion of hybrid catfish (1.35) was 13.5 percent less than that of the channel catfish (1.56). Chappell (1979) reported the feed conversion of channel × blue hybrid was more efficient than that of their parent channel catfish.

Harvestability

The mean percentage catch of fish in the first seine haul was used to evaluate harvestability (Table 11). Significant differences ($p < 0.0001$) in harvestability existed among the five catfish groups. No significant difference was detected between the two hybrid catfishes (NWAC 103 channel × D&B blue, HS-5 channel × D&B blue) and NWAC 103 channel catfish. D&B blue catfish was the easiest to catch; most of them could be caught in the first seine haul. Better harvestability of blue catfish was reported previously by Dunham and Argue (1998), Dunham *et al.* (1982), and Chappell (1979) because blue catfish seem to prefer the midwater more than the channel catfish (Dunham *et al.* 1982).

TABLE 10. Mean (± SE [1]) weight gain, feed input, and feed conversion of catfish stocked in 0.04-ha earthen ponds at 12,500 fish/ha and grown for 277 days.

Treatments	n	Weight gain (kg)	Feed input (kg)	Feed conversion [3]
NWAC 103 channel	5	232 ± 33 b [2]	390 ± 37 b	1.74 ± 0.10
HS-5 channel	5	336 ± 10 a	530 ± 23 a	1.58 ± 0.03
D&B blue	5	231 ± 8 b	385 ± 12 b	1.67 ± 0.03
NWAC 103 channel × D&B blue	5	278 ± 10 ab	421 ± 8 b	1.52 ± 0.04
HS-5 channel × D&B blue	5	339 ± 22 a	542 ± 28 a	1.61 ± 0.04

[1] SE = Standard error
[2] Means within the same columns followed by the same letter are not significantly different based upon general linear model and Duncan's multiple range test ($p > 0.05$).
[3] Feed conversion = Total feed input (kg/ha) / Net production (kg/ha)

TABLE 11. Mean (± SE [1]) percentages of catfish caught in the first, second and sum of the two seine hauls of catfish stocked in 0.04-ha earthen ponds at 12,500 fish/ha and grown for 277 days.

Treatments	n	Percent catch of the first seine haul [3]	Percent catch of the second seine haul [4]	Percent catch in the first and second seine hauls [5]
NWAC 103 channel	5	72.5 ± 2.7 b [2]	18.0 ± 3.3	90.5 ± 1.8 b
HS-5 channel	5	31.2 ± 5.3 c	21.1 ± 5.3	52.3 ± 9.5 c
D&B blue	5	93.7 ± 1.8 a	5.2 ± 2.0	98.8 ± 0.6 a
NWAC 103 channel × D&B blue	5	69.0 ± 9.6 b	25.7 ± 8.3	94.7 ± 2.3 ab
HS-5 channel × D&B blue	5	61.5 ± 6.5 b	22.5 ± 1.8	84.0 ± 5.9 b

[1] SE = Standard error
[2] Means within the same columns followed by the same letter are not significantly different based upon general linear model and Duncan's multiple range test ($p > 0.05$).
[3] Percent catch of the first seine haul = (No. of fish caught in the first seine haul) / (No. of fish caught in total) × 100.
[4] Percent catch of the second seine haul = (No. of fish caught in the second seine haul) / (No. of fish caught in total) × 100.
[5] Percent catch in the first and second seine hauls = (No. of fish caught in the first seine haul + No. of fish caught in the second seine haul) / (No. of fish caught in total) × 100.

HS-5 channel × D&B blue hybrid catfish was easier to catch than their parent HS-5 channel catfish. HS-5 channel catfish was the hardest to catch. Dunham and Argue (1998), Dunham *et al.* (1982), and Yant (1975) remarked that hybrid catfish was easier to catch than channel catfish, but according to the harvest record HS-5 channel catfish had three ponds with recorded weed problems (E19) or big mud islands (E23, E24), which might have obstructed harvest and could explain the low seinability.

Carcass Characteristics

The mean head percentages were significantly different among the five treatments ($p < 0.0001$ Table 12). HS-5 channel catfish had the biggest head percentage (20.8%) among the five fish groups. Both the head percentage of HS-5 channel × D&B blue hybrid (17.0%) and NWAC 103 channel × D&B blue hybrid (16.5%) were less than those of their parent channel catfish (20.8% and 19.1%, respectively), but not significantly different from that of the blue catfish (17.4%). Ramboux (1990) reported differences in the mean head percentages among four channel × blue hybrid catfish stocked communally into one 0.1-ha earthen pond at a total density of 19,770 fish/ha.

The mean dress-out (deheaded and gutted with skin on) percentages were also significantly different among the five groups ($p < 0.0001$, Table 12). Both hybrid catfishes had better dress-out percentages (HS-5 channel × D&B blue hybrid, 72.1% and NWAC 103 channel × D&B blue hybrid, 71.8%, respectively) than those of their parent channel catfish (67.4% and 69.6%, respectively) and blue catfish (70.2%). Dress-out percentage of the HS-5 channel catfish (67.4%) was smaller than NWAC 103 channel catfish (69.6%) and blue catfish (70.2%), which might be the result of its bigger head. The mean dress-out percentages of NWAC 103 channel catfish (69.6%) and blue catfish

TABLE 12. Mean (± SE [1]) percent head weights, percent dress-out weights, and percent two-side fillet weight of catfish stocked in 0.04-ha earthen ponds at 12,500 fish/ha and grown for 277 days.

Treatments	n	% Head [3]	% Dress-out [4]	% Two-side fillet [5]
NWAC 103 channel	5	19.1 ± 0.6 b [2]	69.6 ± 0.5 b	50.2 ± 0.6
HS-5 channel	5	20.8 ± 0.1 a	67.4 ± 0.5 c	49.4 ± 0.6
D&B blue	5	17.4 ± 0.4 c	70.2 ± 0.6 b	51.1 ± 0.3
NWAC 103 channel × D&B blue	5	16.5 ± 0.5 c	71.8 ± 0.5 a	50.9 ± 0.2
HS-5 channel × D&B blue	5	17.0 ± 0.4 c	72.1 ± 0.5 a	51.4 ± 0.3

[1] SE = Standard error
[2] Means within the same columns followed by the same letter are not significantly different based upon general linear model and Duncan's multiple range test ($p > 0.05$).
[3] % Head = Head weight (g) / Body weight (g) × 100.
[4] % Dress-out (deheaded and gutted with skin) = Dress-out weight (g) / Body weight (g) × 100.
[5] % Two-side fillet = One fillet weight (g) × 2 / Body weight (g) × 100.

(70.2%) were not significantly different from each other. Better dress-out percentages of hybrid catfish than channel catfish was also reported by Yant (1975), Argue (1996), Argue *et al.* (2003), Li *et al.* (2004), and Bosworth *et al.* (2004). Ramboux (2004) found no differences in skinned dress-out percentages when four different channel × blue hybrids were compared. Dunham *et al.* (1983) found higher dress-out percentage in blue catfish than channel × blue hybrid and channel catfish and the F1 hybrid had 1.3% less dress-out percentage when compared to their parent channel catfish. Chappell (1979) also reported that both the channel and blue parents are better than channel × blue hybrid for dress-out percentage and the hybrid catfish was 3.6% less than its parent channel catfish.

No significant differences were detected in the mean fillet percentages among five treatments (p = 0.0534, Table 12). The overall mean fillet percentages of all fishes was 50.6%. Ramboux (2004) found differences existed in fillet (skinned and without abdominal wall) percentage when four different channel × blue hybrids were communally stocked into one 0.1-ha earthen pond at a total density of 19,770 fish/ha. Differences were not detected here between the two hybrids. Higher fillet (skinned) percentage (45.7%) of hybrid catfish than channel catfish (43.1%) was also reported by Argue (1996). Li *et al.* (2004) compared the nugget and shank fillet percentage of one channel × blue hybrid and channel catfish and found no difference in the shank fillet percentage but a higher nugget percentage in hybrid catfish.

Bosworth *et al.* (2004) reported higher skin-on and skin-off fillet yields in one channel × blue hybrid (Norris line channel catfish × Dycus Farm line blue catfish) than its parent channel catfish (Norris line channel catfish) and the other channel catfish

(NWAC 103 channel catfish). Fillets in his study were processed with a machine and the skin-on fillet yield of the hybrid catfish ranged from 54.1% (female) to 53.3% (male).

The mean head percentages, dress-out percentages, and two-side fillet percentages were also compared based on female and male fish (Table 13). The head percentages of the two channel catfish males (NWAC 103 channel, 19.9%, $p = 0.0335$, and HS-5 channel, 21.7%, $p = 0.0004$, respectively) were greater than those for the female (18.2% and 19.7%, respectively). The dress-out percentages of female NWAC 103 channel catfish (70.2%, $p = 0.0190$) and D&B blue catfish (70.9%, $p = 0.0382$) were greater than those for their males (69.0% and 69.4%, respectively). Female HS-5 channel catfish (50.5%, $p = 0.0053$) had greater two-side fillet percentage than its male catfish (48.8%). The two hybrids did not show any significant differences between the female and male on these three parameters. Bosworth *et al.* (2004) reported the greater head percentage in male NWAC 103 channel catfish (25%) than female ones (22.9%), but female ones had greater skin-on dress-out (64.4%) and skin-on fillet percentage (51.5%) than male NWAC 103 channel catfish (63.1% and 50.2%, respectively). In present study, only the two-side fillet percentage was not significantly different between the male and female NWAC 103 channel catfish. Head percentages (18.2% and 19.9%, respectively) were smaller and dress-out percentages (70.2% and 69.0%, respectively) greater than those in the study of Bosworth *et al.* (2004) (22.9% and 25.0%, 64.4 and 63.1%). Fish in both studies were deheaded by machine. The position of cutting may have influenced the final results.

TABLE 13. Mean (± SE [1]) percent head weights, percent dress-out weights, and percent two-side fillet weights of catfish stocked in 0.04-ha earthen ponds at 12,500 fish/ha and grown for 277 days.

Treatments	% Head [3]		% Dress-out [4]		% Two-side fillet [5]	
	Female	Male	Female	Male	Female	Male
NWAC 103 channel	18.2 ± 0.5 y [2]	19.9 ± 0.5 z	70.2 ± 0.3 y	69.0 ± 0.4 z	50.3 ± 0.4	50.2 ± 0.5
HS-5 channel	19.7 ± 0.4 y	21.7 ± 0.4 z	67.9 ± 0.6	67.1 ± 0.3	50.5 ± 0.4 y	48.8 ± 0.4 z
D&B blue	17.2 ± 0.3	17.7 ± 0.4	70.9 ± 0.3 y	69.4 ± 0.6 z	51.4 ± 0.3	50.9 ± 0.3
NWAC 103 channel × D&B blue	16.3 ± 0.2	16.8 ± 0.3	71.7 ± 0.3	71.9 ± 0.3	50.4 ± 0.6	51.2 ± 0.4
HS-5 channel × D&B blue	16.8 ± 0.3	17.1 ± 0.4	72.2 ± 0.3	72.1 ± 0.2	51.9 ± 0.4	51.0 ± 0.3

[1] SE = Standard error
[2] Means within the same row and within each category followed different letters are significantly different based upon t-test ($p > 0.05$).
[3] % Head = Head weight (g) / Body weight (g) × 100.
[4] % Dress-out (deheaded and gutted with skin) = Dress-out weight (g) / Body weight (g) × 100.
[5] % Two-side fillet = One fillet weight (g) × 2 / Body weight (g) × 100.

IV. CONCLUSIONS

Based on the present study, the following conclusions could be drawn:

1. HS-5 channel catfish and its hybrid started as bigger fish and ended up with bigger animals than the other three fish groups.

2. D&B blue catfish was more uniform than NWAC 103 channel catfish and its hybrid. HS-5 hybrid was more uniform than NWAC 103 hybrid.

3. HS-5 channel catfish and its hybrid had better average growth rate than NWAC 103 channel catfish and its hybrid, but NWAC 103 channel catfish and its hybrid had better mean specific growth rate than HS-5 channel catfish and its hybrid. No significant differences were detected based on the mean growth rate index (*a*).

4. Mean net production among HS-5 channel catfish, HS-5 channel × D&B blue catfish, and NWAC 103 × D&B blue catfish was not significantly different.

5. D&B blue catfish was the easiest to catch by seine. HS-5 channel × D&B blue catfish was easier to catch by seine than its parental HS-5 channel catfish.

6. HS-5 channel × D&B blue catfish and NWAC 103 channel × D&B blue catfish had smaller mean head percentages and greater mean dress-out percentages than their parent stocks.

7. Mean feed conversion ratios, survival rates, and two-side fillet percentages were not significantly different among the five fish groups.

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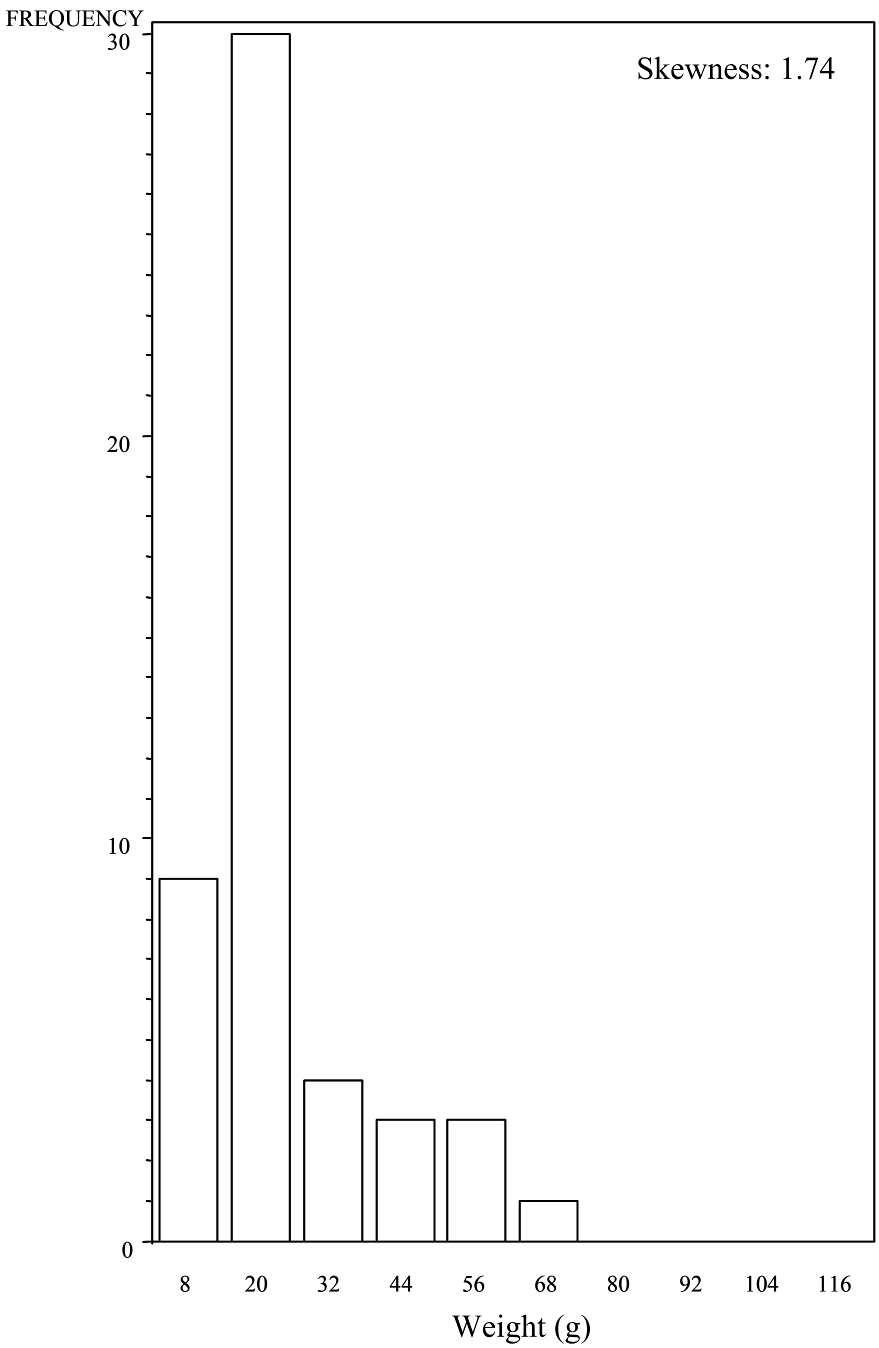
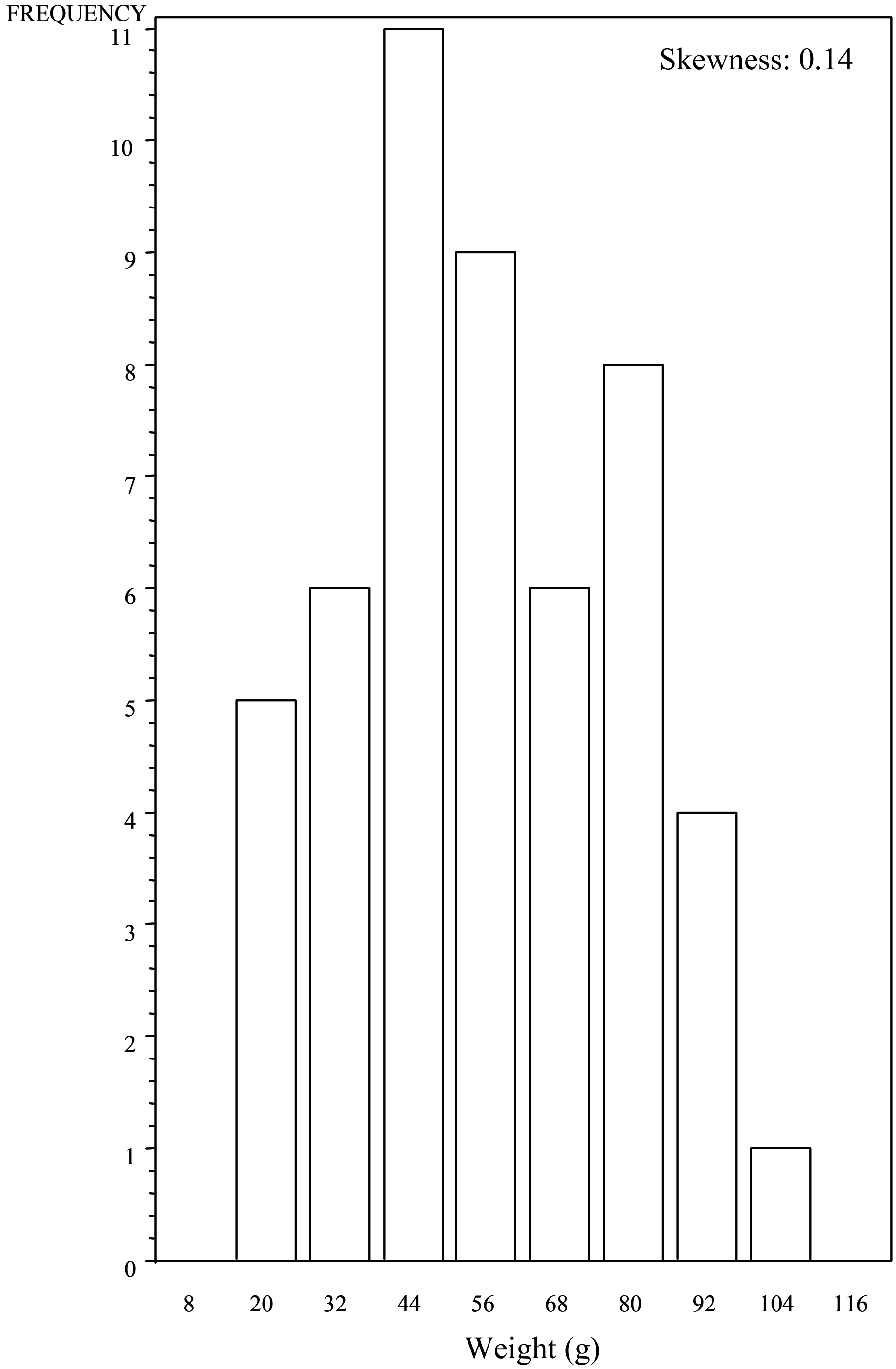
V. APPENDIXES

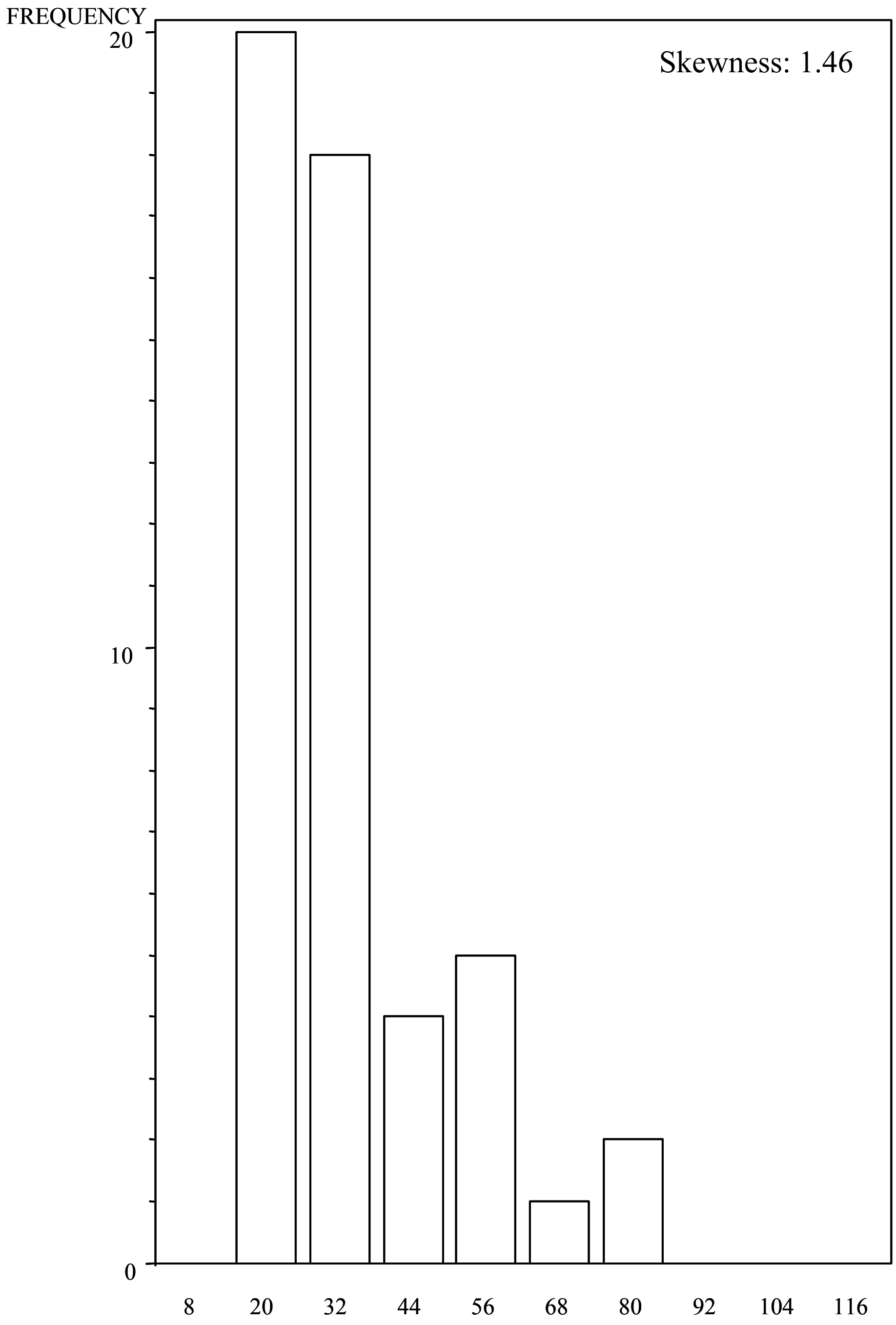
Appendix 1. Initial size (weight, g) distribution of NWAC 103 channel catfish stocked in 0.04-ha earthen ponds at 12,500 fish/ha.



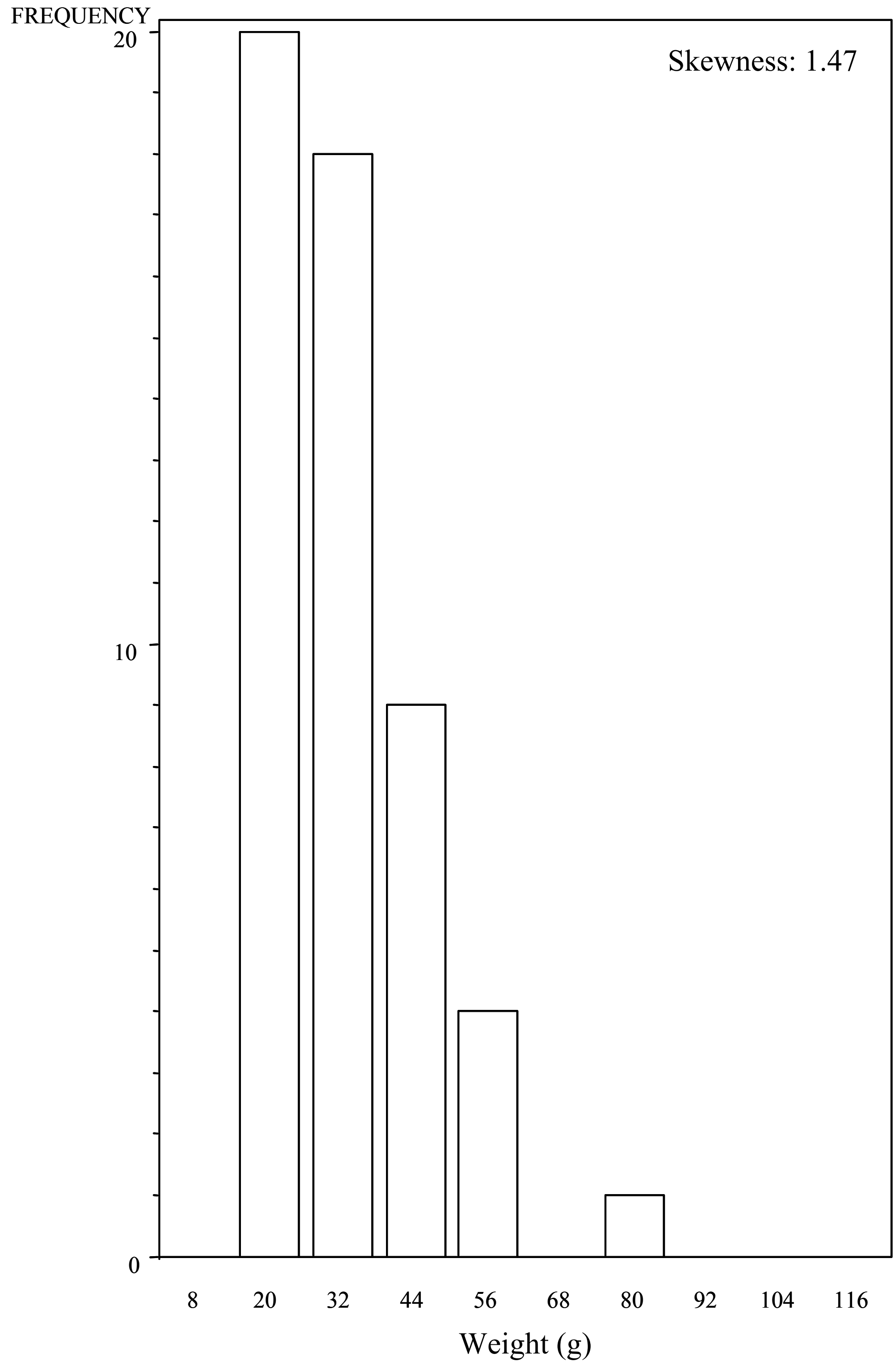
Appendix 2. Initial size (weight, g) distribution of HS-5 channel catfish stocked in 0.04-ha earthen ponds at 12,500 fish/ha.



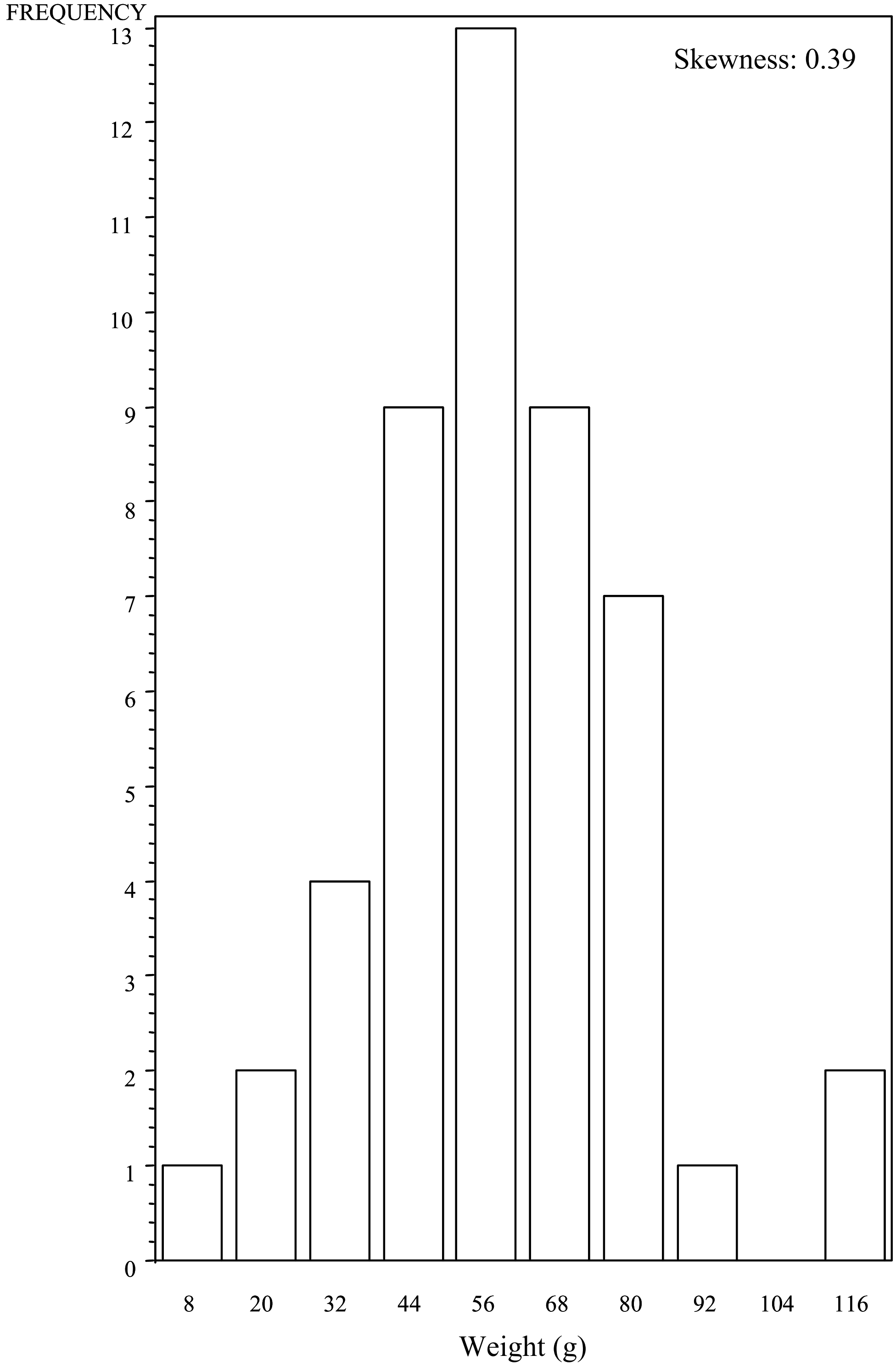
Appendix 3. Initial size (weight, g) distribution of D&B blue catfish stocked in 0.04-ha earthen ponds at 12,500 fish/ha.



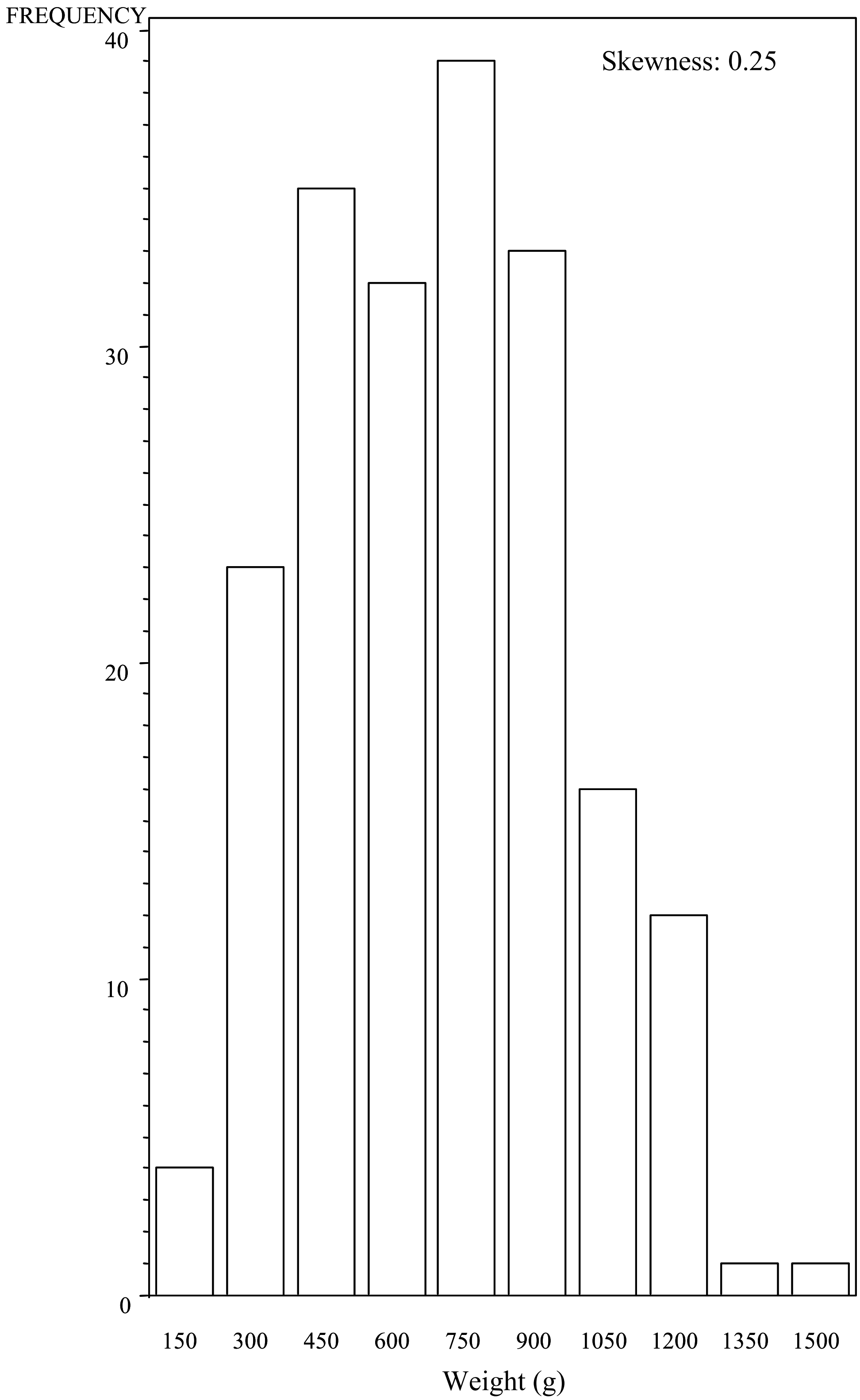
Appendix 4. Initial size (weight, g) distribution of NWAC 103 channel × D&B blue catfish stocked in 0.04-ha earthen ponds at 12,500 fish/ha.



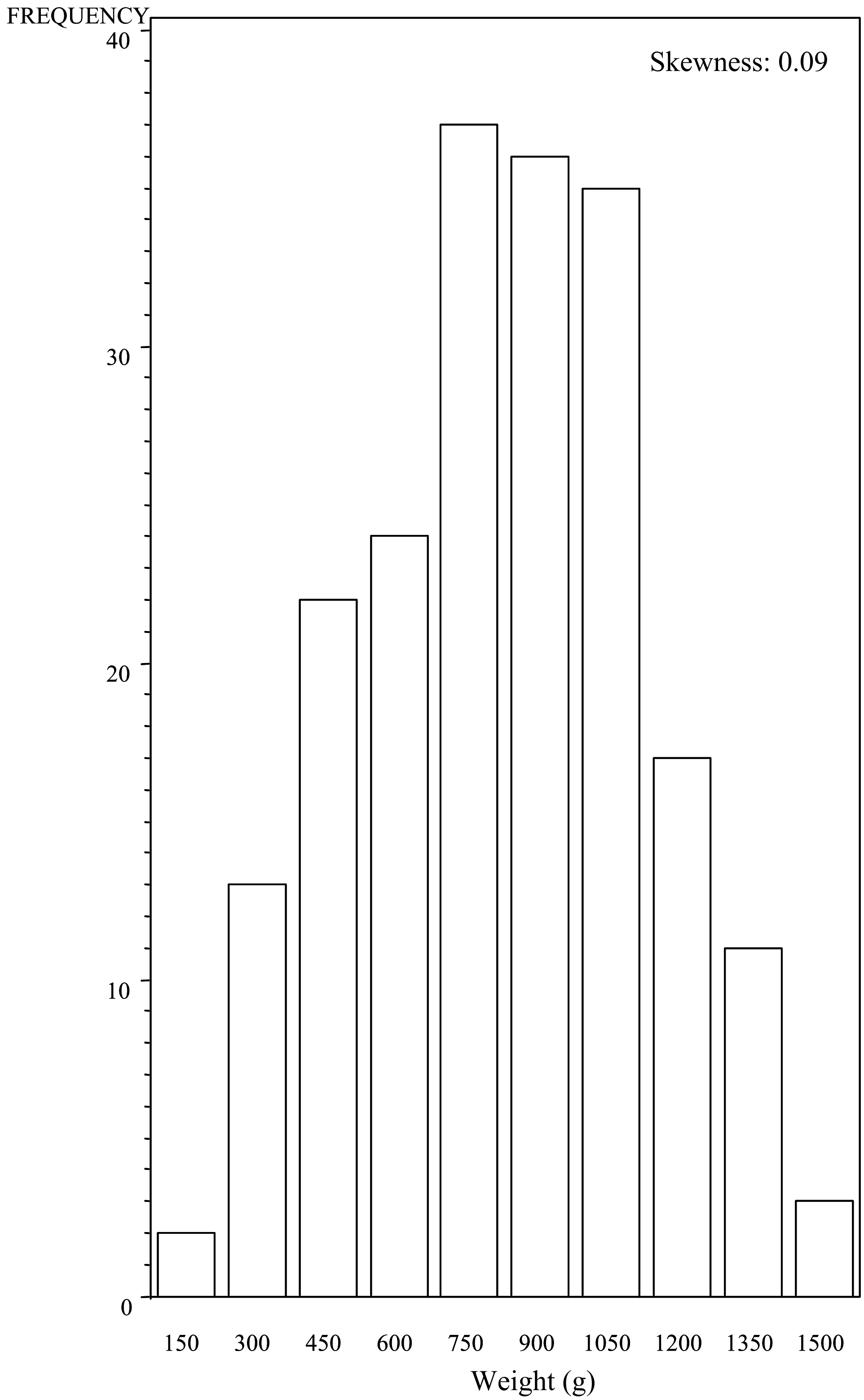
Appendix 5. Initial size (weight, g) distribution of HS-5 channel × D&B blue catfish stocked in 0.04-ha earthen ponds at 12,500 fish/ha.



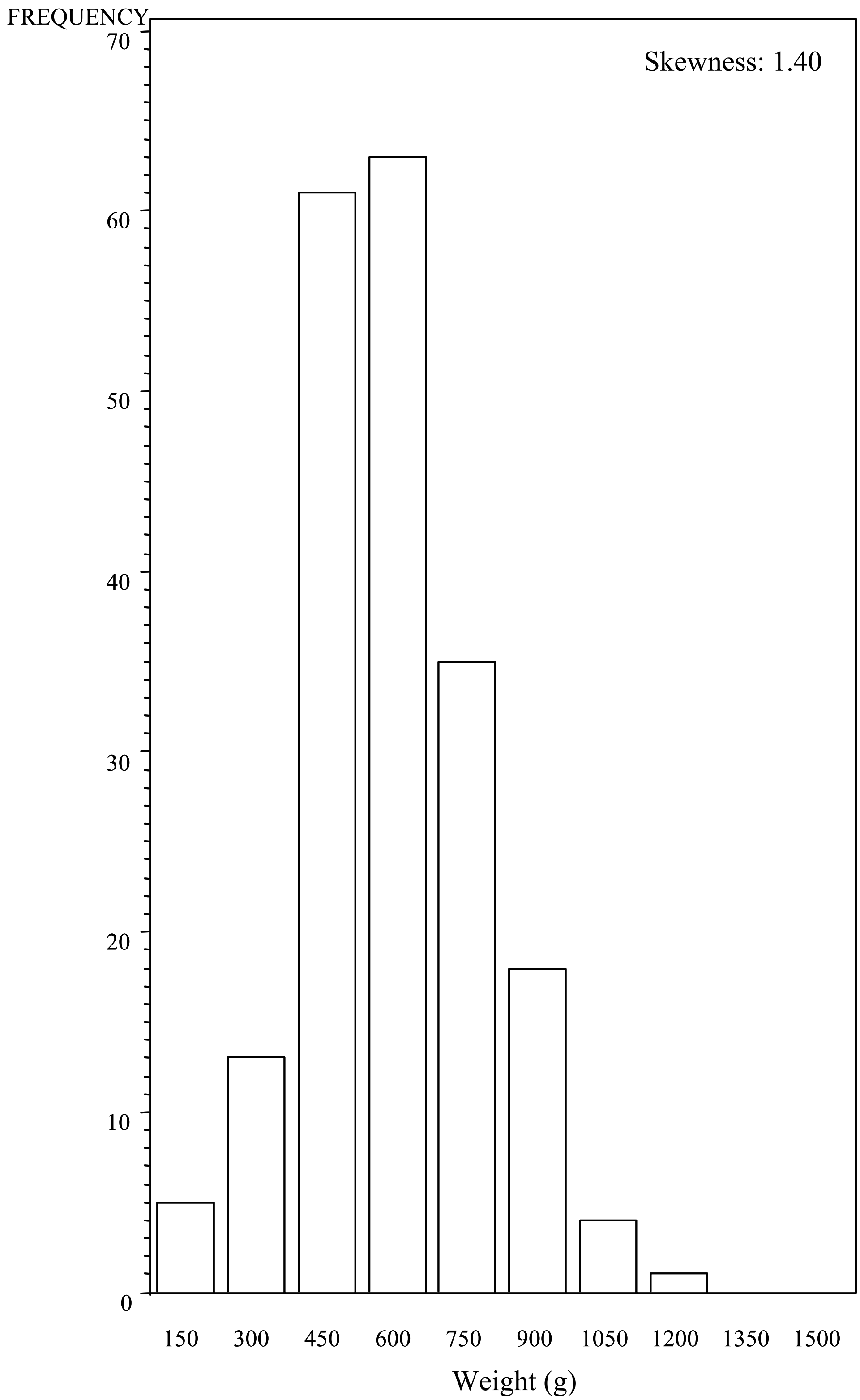
Appendix 6. Final size (weight, g) distribution of NWAC 103 channel catfish stocked in 0.04-ha earthen ponds at 12,500 fish/ha.



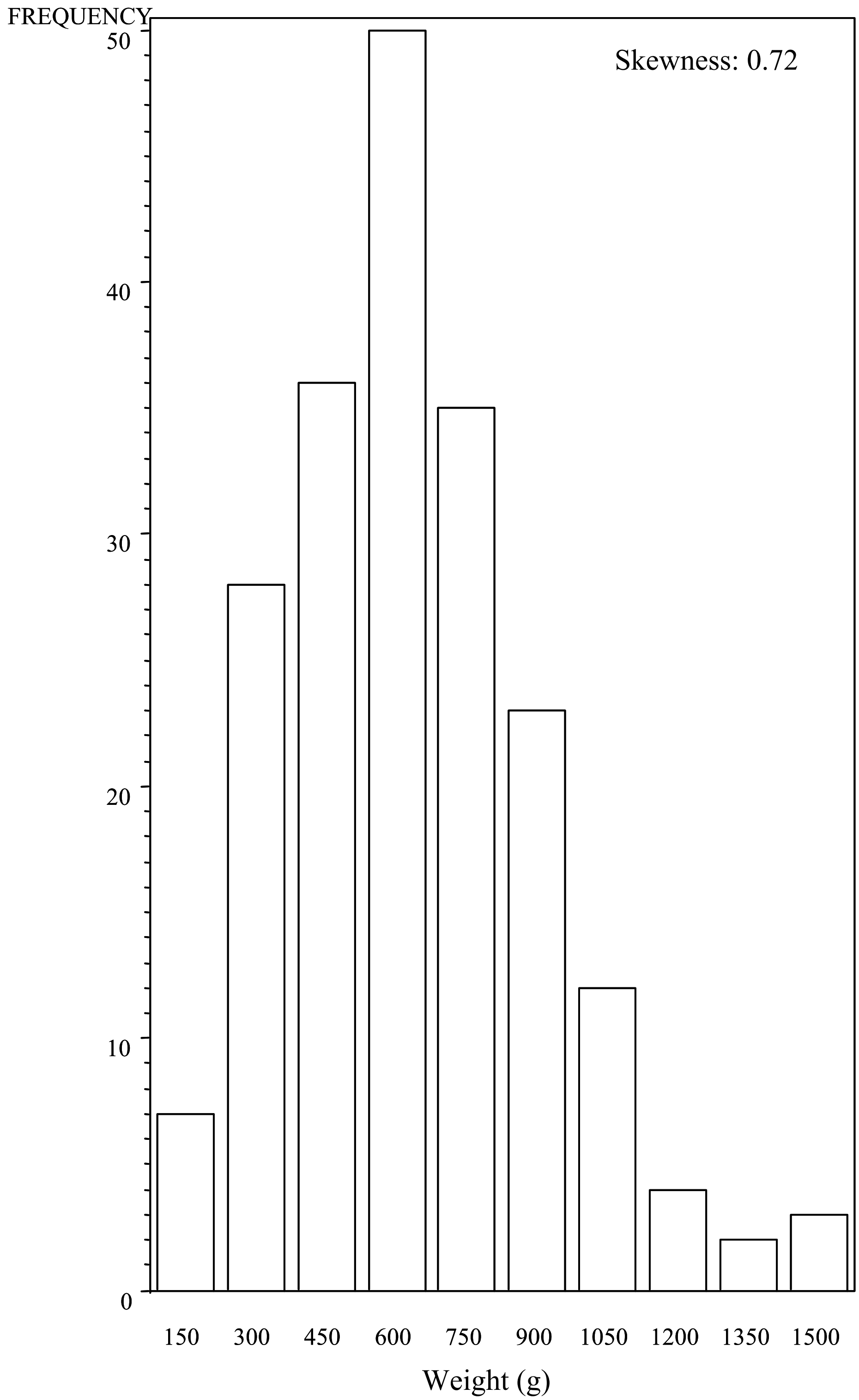
Appendix 7. Final size (weight, g) distribution of HS-5 channel catfish stocked in 0.04-ha earthen ponds at 12,500 fish/ha.



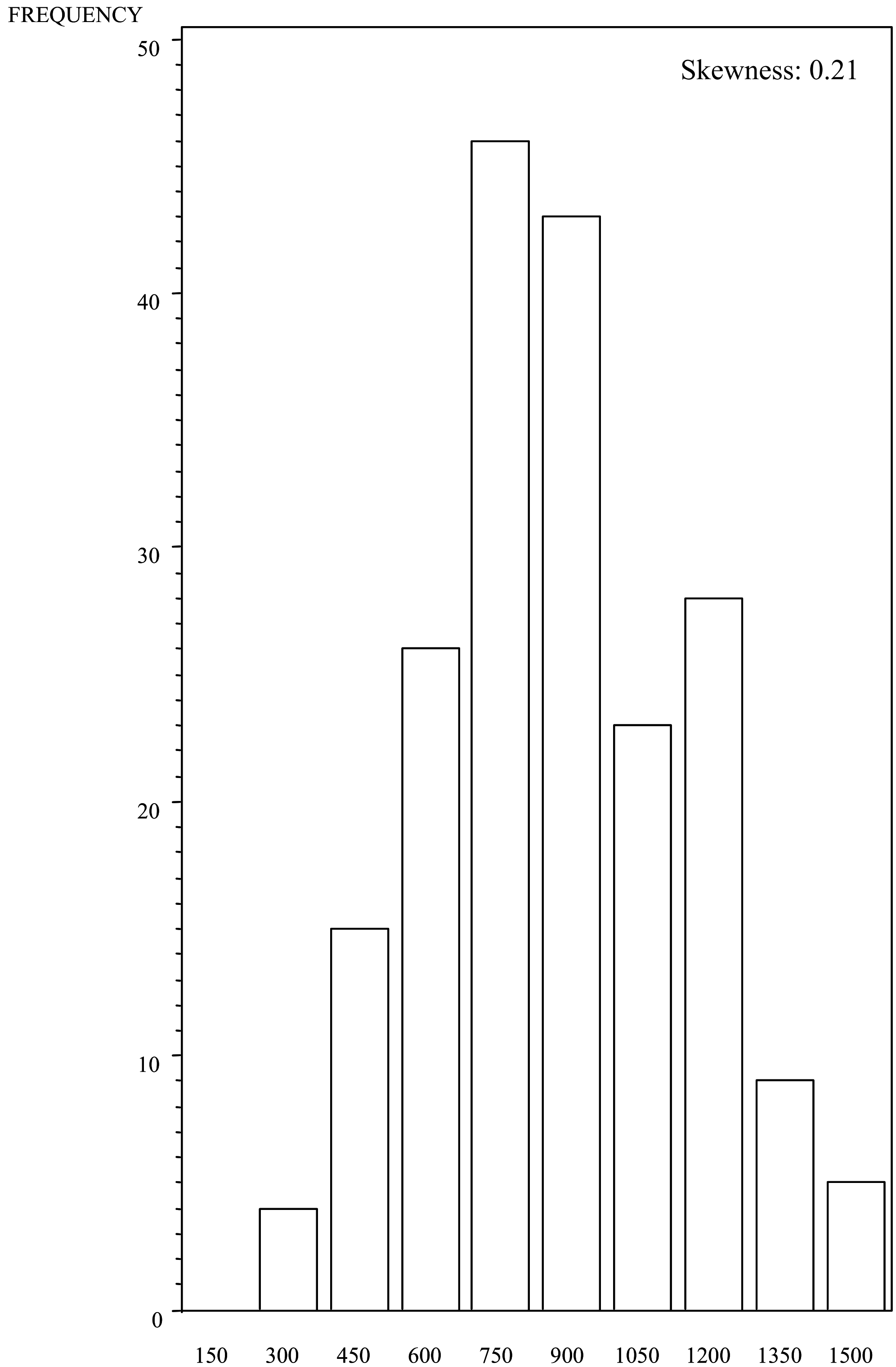
Appendix 8. Final size (weight, g) distribution of D&B blue catfish stocked in 0.04-ha earthen ponds at 12,500 fish/ha.



Appendix 9. Final size (weight, g) distribution of NWAC 103 channel × D&B blue catfish stocked in 0.04-ha earthen ponds at 12,500 fish/ha.



Appendix 10. Final size (weight, g) distribution of HS-5 channel × D&B blue catfish stocked in 0.04-ha earthen ponds at 12,500 fish/ha.



Appendix 10. Comparison of final sample weights to mean population weights for each catfish pond stocked at 12,500 fish/ha.

Pond	Treatment	Mean sample weight (g)	Mean population weight (g)	*p* value
E01	NWAC 103 Channel	719.5	772.2	0.3103
E02	HS-5 Channel × D&B Blue	902.2	909.5	0.8705
E03	HS-5 Channel	933.1	883.7	0.2705
E04	D&B Blue	645.2	625.1	0.3828
E05	D&B Blue	611.8	582.3	0.3212
E06	NWAC 103 Channel	697.3	665.9	0.4091
E07	D&B Blue	543.6	610.4	0.0820
E08	HS-5 Channel × D&B Blue	970.8 y [1]	889.2 z	0.0322
E09	NWAC 103 Channel	676.1	648.4	0.5652
E10	HS-5 Channel × D&B Blue	837.7	841.3	0.9412
E11	D&B Blue	582.5	608.1	0.3764
E12	NWAC 103 Channel	745.9	715.6	0.4753
E13	NWAC 103 Channel × D&B Blue	600.2 y	702.6 z	0.0069
E14	NWAC 103 Channel × D&B Blue	625.1 y	721.9 z	0.0468
E15	NWAC 103 Channel	596.1	546.2	0.1405
E16	NWAC 103 Channel × D&B Blue	712.0	686.4	0.5894
E17	HS-5 Channel × D&B Blue	813.6	793.3	0.6053
E18	D&B Blue	585.8	570.6	0.4617
E19	HS-5 Channel	879.8	826.1	0.2475
E20	HS-5 Channel	855.2	824.8	0.4977
E21	NWAC 103 Channel × D&B Blue	559.5	628.6	0.0720
E22	NWAC 103 Channel × D&B Blue	678.0	619.4	0.1719
E23	HS-5 Channel	766.6	802.1	0.5248
E24	HS-5 Channel	709.0	765.3	0.1698
M19	HS-5 Channel × D&B Blue	836.8	839.3	0.9507

[1] Means within the same row followed by different letters are significantly different based upon t-test ($p > 0.05$).