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Full Length Research Paper

Effect of stocking density on growth and survival of Nile tilapia (*Oreochromis niloticus*, Linnaeus 1758) under cage culture in Lake Albert, Uganda

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In Uganda fish is a great source of animal dietary protein, however, natural stocks continue to decline. Therefore, aquaculture provides a viable option to bridge the increasing fish supply-demand gap. Accordingly, a study was conducted from March to August 2016 to investigate the effect of stocking density on the growth performance, and survival of Nile tilapia (*Oreochromis niloticus)* in floating net-cages to contribute to aquaculture production in Uganda. Nile tilapia fingerlings, with an average weight of 4.07 g were stocked in 8 m^3 cages at three different stocking densities; 200, 250, and 300 fish/m^3, and fed on a locally formulated commercial feed for 180 days. At the end of the experimental period, results showed that fish stocked at lower densities were heavier than those stocked at higher densities. The mean final weights of fish were; 150.79±85.71, 127.82±68.43 and 118.73±49.29 g in cages stocked with 200, 250 and 300 fish/m^3, respectively. The mean final weight in lower density (200 fish /m^3) treatments was significantly higher (P<0.05) than that of higher density (300 fish/m^3) treatments. The mean relative condition factor of fish ranged from 1.02 to 1.06, but was not significantly different (P>0.05) among the stocking densities. Survival rate and stocking density were negatively correlated. The best survival rate (94.19%) was obtained in low stocked cages (200 fish/m^3) compared to 92.98% in highly stocked cages (300 fish/m^3). The results of this study suggest that 200 fish/m^3 of a cage, is the best stocking density in terms of fish growth parameters.

Key words: Aquaculture, animal protein, per capita, livelihood, yield.

INTRODUCTION

Fisheries and aquaculture play an important role as sources of food and income, and is thus critical in addressing global human food and nutrition insecurity, and economic demands (FAO, 2016). In 2013, fish contributed about 17% of the animal protein to the global human population, while the global per capita fish consumption reached 20 kg in 2014 (FAO, 2016). Additionally, fisheries and aquaculture was a source of livelihood for 56.6 million people globally in 2014 (FAO, 2016). In Uganda, fisheries and aquaculture sector significantly contributes to economic growth. The sector contributed 3% to Gross Domestic Product (GDP) in the 2015-2016 financial year. Additionally, it directly employed over 1.2 million people, generated greater than 89 million USD in export earnings, and accounted for up to 50% of animal protein food (MAAIF, 2016a). However, the global fish production from wild fish stocks has generally stagnated, with most fisheries already fully exploited or over-exploited (FAO, 2014, 2016); yet human population is increasing, thus widening the fish demand-supply gap. In Uganda, this has been accompanied by a decline in per capita fish consumption to as low as 8 kg (MAAIF, 2017) which is below the 17 kg recommended by FAO (2012). With the fast growing human population, to about 35 million people (UBOS, 2016); this per capita fish consumption will further decline due to increase in the fish demand-supply gap. Therefore, aquaculture provides one of the plausible solutions for increasing fish production, and will subsequently lessen this demand-supply gap. Moreover, Uganda has a significant potential for aquaculture development, since it has numerous water bodies that cover up to 20% of the country's total surface area (MAAIF, 2012). It also has favourable climate, good culture species such as *Oreochromis niloticus*, and availability of raw materials for feed (NAFIRRI, 2012).

As such, the Government of Uganda through her Agriculture Sector Strategic Plan (ASSP) 2016-2020, recognised the need to promote and support aquaculture in order to boost fish production to at least 300,000 tonnes annually by 2020 (MAAIF, 2016b). Cognizant of the need to meet this projected fish production target, augmenting investment in cage fish culture is one of the viable approaches that Uganda could adopt. This is because cage fish culture is known to increase fish production (Gentry et al., 2017), and can therefore result into higher returns. It, however, requires adherence to best practices including, adopting an ideal fish stocking density, in order to maximize production efficiency. Stocking density is critical since it directly influences the economic viability of fish culture enterprises (Osofero et al., 2009; Baldwin, 2010).

Stocking density directly affects the growth rate and survival of fish, and subsequently the productivity of the fish culture operations (North et al., 2006; Osofero et al., 2009; Pouey et al., 2011; Mensah, 2013). In tilapia culture, better growth performance and survival rate are obtained in lower stocking densities (Sorphea et al., 2010). On the other hand, a positive relationship between stocking density and yield of Nile tilapia was reported by Watanabe et al. (1990), Cruz and Ridha (1991), Alemu (2003) and Gibtan et al. (2008). These studies reported higher yields with increasing stocking density. Therefore, stocking densities that result into higher fish yields, and subsequently higher economic returns from a cage culture enterprise, are ideal for catalysing cage aquaculture development. However, the inadequacy of empirical information on stocking densities that result into high growth and survival rates accompanied with higher yield continues to constrain cage fish culture productivity in Uganda. Consequently, the farmer's capacity to operate cage culture systems is low, resulting into low cage fish production (Mbowa et al., 2016, 2017). Therefore, this study investigated the effects of stocking densities on the growth performance and survival of Nile tilapia (*O. niloticus)*, reared in cage facilities, to contribute to the available cage aquaculture technical information, towards increasing cage production in Uganda.

MATERIALS AND METHODS

Selection of study site

The study was conducted from March to August 2016 at Butiaba fish landing site, Piida Bay (20241.72 N and 313352.59 E) on Lake Albert in Buliisa District, Uganda (Figure 1). This experimental site is located in the Lake Albert Crescent Zone (LACZ) at an altitude of 616 m above sea level, approximately 68 km from the town of Hoima. Consideration of this area for the experiment was based on the baseline site suitability survey. The site is well suited for cage culture of Nile tilapia, because it is partly sheltered with an average depth of 8 m, water flow rate of 48 cm/s, pH of 7.5, Dissolved oxygen concentration 6.88 mg/L and temperature of 27.8°C, which are all within the prescribed parameters for cage fish farming (Howerton, 2001; Queensland Water Quality Guidelines, 2009).

Experimental design

Cages of 8 m^3 (2 m × 2 m × 2 m), with metallic frames and an enclosure of 10 mm mesh size Nylon butane treated netting material, with 1 mm mesh size nylon cage liners were used during this experiment. The cages were secured in blocks (three per block) and fitted with cage liners as nursery cages for the small sized fish at the time of stocking. The cages were thereafter randomly stocked with monosex male Nile tilapia fingerlings, of uniform average body weight (4.07 g). The fingerlings were stocked at densities of 200, 250, and 300 fish/m^3 per cage, with each stocking density having 2

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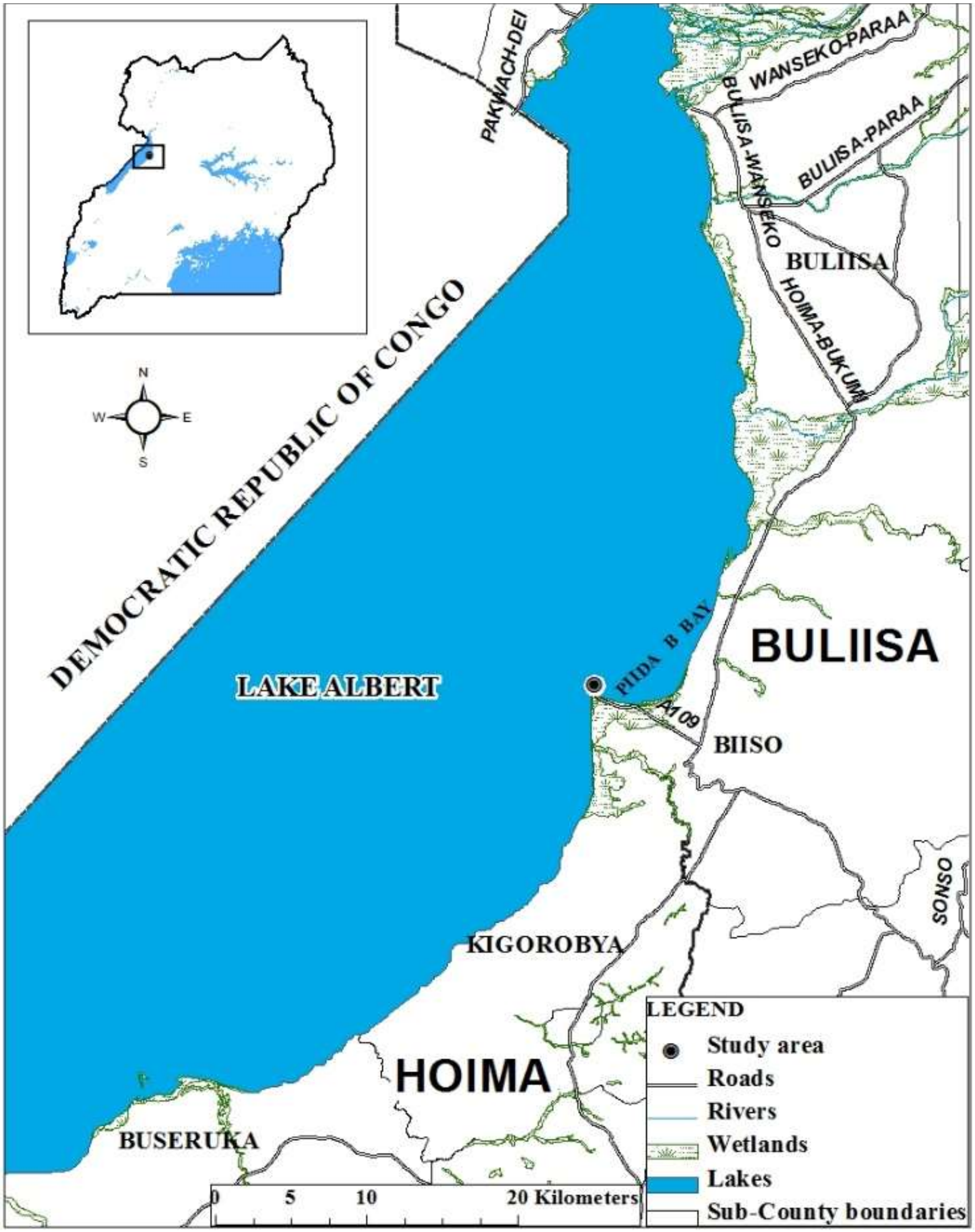

Figure 1. Location of Piida Bay on Lake Albert, where the experiment was conducted.

replicates. These stocking densities were based on an aquaculture policy brief, which suggested that fish stocking densities in a cage rearing facility can be high as 300 to 600 fish/m^3 (NAFIRRI, 2012). After two months of the experiment, the liners were removed from the cages because the fish had increased in size. Further, this was meant to abate clogging that would inhibit appropriate water exchange.

A locally produced commercial floating fish feed of 35 and 30% Crude Protein (CP) levels (based on the manufacturer's provided information) was used during the experiment. The 35% CP feed was in crumble and 2 mm pellet form, while the 30% CP feed was in a 3 mm pellet form. These different forms of the feed were adjusted based on the average body weight of the fish, and their gape (mouth) size. The 35% CP feed was initially fed to the fingerlings for a period of 3 months, while the 30% CP feeds were administered for the remaining experimental period. The fish were feed three times per day, from 09:00 am, at an interval of four hours.

Data collection

Water quality parameters

Physico-chemical parameters (Water temperature, pH, and dissolved oxygen concentration) were measured monthly within the cages, during fish sampling in the morning hours (0900-1100 h) of the experimental period. Water temperature and Dissolved Oxygen were measured using a digital probe (YSI model, 550A), while pH was measured using a digital combo pH meter (Hanna model, H1 98129).

Fish sampling

The fish in all cages were randomly sampled at the end of every month between 08.00 – 11.00 h from March - August 2016 from cages using a scoop net (1 mm mesh size). Thirty live fish were randomly scooped out of each cage unit. Their Total length (TL) and Standard (SL) length, and individual live body weights were measured using a measuring board, and an electronic weighing scale (Model JZC-TSC-03;V5.1-2010, Minimum: 2 g, Maximum: 3000 g), respectively. The cages were also inspected and cleaned during fish sampling.

Growth analysis

Growth changes in the fish were calculated based on the following parameters; Mean Weight Gain (MWG), Condition factor, Survival Rate and Feed Conversation Ratio (FCR).

Mean weights

Monthly mean weight of fish for each stocking density was determined by averaging the individual weights of a sample of 30 individual fish in each cage. MWG was calculated as:

$MWG = Wt_2 – Wt_1$

Where, Wt_1 = Mean Initial weight of fish, Wt_2 = Mean Final weight of fish.

Calculation of relative condition (K_n)

A total of 1,068 *O. niloticus* individuals were used in the calculation of Relative Condition Factor (RCF). To compare fish condition among cages with different stocking densities, relative condition factor (the ratio of observed individual fish weight to expected weight of an individual of a given length), was calculated using the formula: $Kn = W/aL^b$ (Le Cren, 1951); where W is observed individual fish weight, L is observed individual fish total length, "a" is the intercept of the length-weight regression and "b" is the slope of the regression line. The values of a and b were obtained from the overall length-weight relationship ($W=aL^b$) derived by pooling data for all the cages across stocking densities. Length and weight data were log-transformed and the resulting linear regression fitted by Least Squares Method using weight as the dependent variable. A minimum of 30 individuals per stocking density was considered acceptable for computing the RCF.

Feed conversion ratio (FCR)

The amount of feed used to produce 1kg of the fish biomass was calculated as:

FCR =Weight of feed given (g)/Fish weight gain (g)

Survival rate

Daily fish mortalities were recorded during the experimental period. At the end of the culture period, all the cages were emptied and the number of fish in each cage determined. The percentage survival rate was calculated as;

Survival Rate (%) = [Number of fish at harvest / Total Number of fish stocked] × 100.

Statistical analyses

One-way analysis of variance was used to test for differences in means of the growth performance and relative condition factor of fish, for the different stocking densities (200, 250 and 300 fish/m^3). Turkey's post-hoc test was used for multiple comparisons, to study any difference among treatment means. All statistical analyses were performed with SPSS for Windows (version 20.0) at 0.05 level of significance.

RESULTS

Water quality

The mean values of key water quality parameters monitored throughout the study are shown in Table 1. Temperature and Dissolved Oxygen concentration ranged from 27.45±0.47 to 27.46±0.48 (°C) and 3.44±0.80 to 3.63±0.67 (mg/L) respectively, while pH ranged from 7.52±0.36 to 7.67±0.32. There were no significant differences in temperature (p=0.987), Dissolved oxygen concentration (p=0.451) and pH levels (p=0.124) across the different stocking densities in all cages.

Fish growth performance

The mean final weight, mean weight gain, mean relative condition, percentage survival rates and FCR of fish in all the treatments at harvest are presented in Table 2. The mean weight of fish in all stocking densities increased with time during the experiment, with slight variations in the mean weights during the first four months of culture. From the fifth month, fish stocked in cages at 200 fish/m^3 had a higher mean weight compared to the cages with 250 and 300 fish/m^3 stocking densities (Figure 2). The mean final weights of fish were 150.79±85.71 g, 127.82±68.43 g and 118.73±49.29 g in stocking densities

Table 1. Mean values ± SD of water quality parameters in cages for 6 months at Piida Bay-Lake Albert.

Parameter	Stocking density (fish/m^3)		
	200	250	300
Temperature (°C)	27.45±0.47	27.45±0.49	27.46±0.48
Dissolved Oxygen concentration (mgl^{-1})	3.63±0.67	3.45±0.65	3.44±0.80
pH	7.55±0.344	7.52±0.36	7.67±0.32

Table 2. Growth, condition and feed conversion ratio during the experimental period.

Parameter	Stocking densities(fish/m^3)		
	200	250	300
Mean Initial weight (g)	4.07±0.01^{a}	4.07±0.02^{a}	4.07±0.02^{a}
Mean Final weight (g)	150.79±85.7^{a}	127.82±68.43^{ab}	118.73±49.29^{b}
Mean Weight gain (g)	146.72±85.69	123.75±68.41	114.64±49.27
Mean Relative condition (Kn)	1.02±0.31^{a}	1.06±0.30^{a}	1.05±0.30^{a}
Feed conversion ratio (FCR)	3.16±0.01	3.55±1.28	3.68±0.07
Survival rate (%)	94.19	94.10	92.98

$^{a, b}$ Treatment means within the same row with different superscript letters are significantly different (P <0.05).

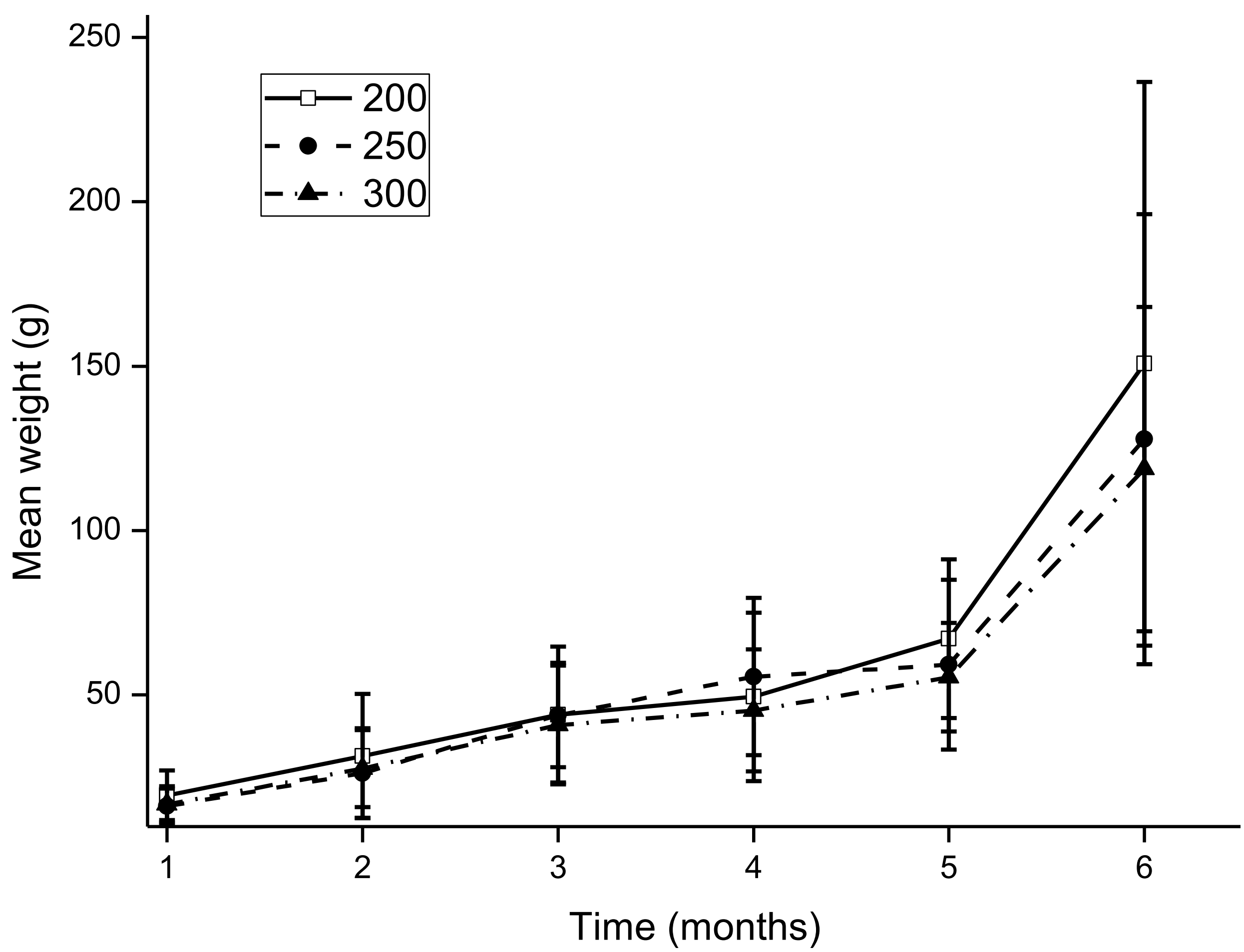

Figure 2. Variation in mean weight (±SD) of *O. niloticus* stocked in cages at three different densities.

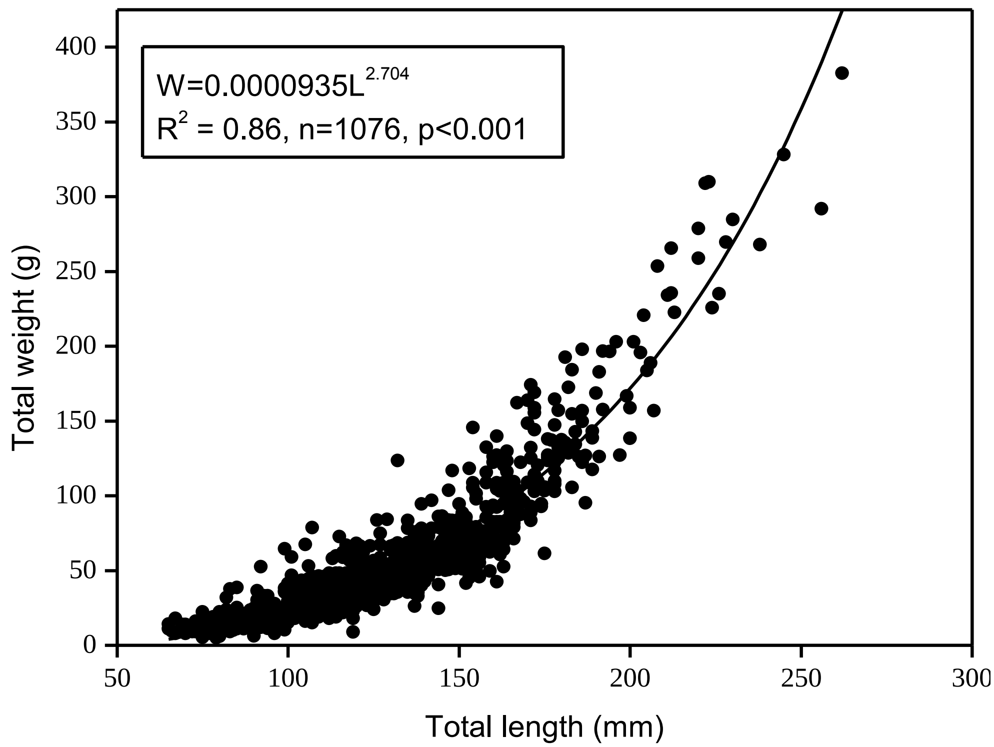

Figure 3. Relationships between Total length (mm) and Total weight (g) of *O. niloticus* stocked in cages at three different stocking densities.

of 200, 250 and 300 fish/m^3 respectively, from the initial mean weights of 4.07 g for all stocking densities (Figure 2). There was a significant difference (P<0.05) in mean final weights of the 200 and 300 fish/m^3 stocking densities though no significant disparity (P>0.05) was observed in mean final weights of the 200 and 250 fish/m^3 stocking densities.

Length-weight relationship and relative condition factor

The size of the *O. niloticus* ranged from 120-262 mm TL and 38.2-402.2 g TW. The relationship between length and weight derived by pooling data across all stocking densities (Figure 3) was highly significant (P<0.001). Similarly, the length and weight relationship for fish in each stocking density, obtained by the regression of length and weight of individuals across treatments was significant (P<0.001). For individual stocking densities, negative allometry was obtained with 'b' values deviating from the reference b value (b=3) (Table 3). The mean relative condition of *O. niloticus* differed among stocking densities ranging from 1.02-1.06. The fish exhibited a slightly higher condition than average in the 200 fish/m^3 cages compared to the 250 and 300 fish/m^3 cages (Figure 4). However, there were no significant differences in condition of fish among the stocking densities (P>0.05).

Survival

Overall, the survival rates across the different stocking densities had an inverse relationship with stocking density (Table 2). The survival rates (%) did not change significantly (P>0.05) amongst the three different stocking densities, and these ranged between 92.98 and 94.19. The mean survival rates (%) were 94.19, 94.10 and 92.98 for 200, 250 and 300 fish/m^3, respectively. The highest mean survival rate was observed in the 200 fish/m^3 stocking density, 250 fish/m^3 stocking density and lowest in the 300 fish/m^3 stocking density at the end of the culture period.

Feed conversion ratio

This study did not determine the amount of feed lost during feeding, and therefore the actual amount of feed consumed by the fish. Consequently, the study compared the FCR across the three stocking densities based on the total amount of feed given during the experiment for the different treatments. The FCR ranged from 3.16 to 3.68, and increased with increase in fish stocking density. A relatively low FCR was obtained in cages stocked with 200 fish/m^3, followed by 250 fish/m^3

Table 3. Length-weight regressions ($W=aL^b$) for Nile tilapia from cages across the 3 stocking densities, where b=slope of regression and log10a=intercept of regression.

Stocking density (fish/m^3)	n	R^2	b	p
200	356	0.85	2.71	<0.001
250	355	0.87	2.66	<0.001
300	357	0.86	2.77	<0.001

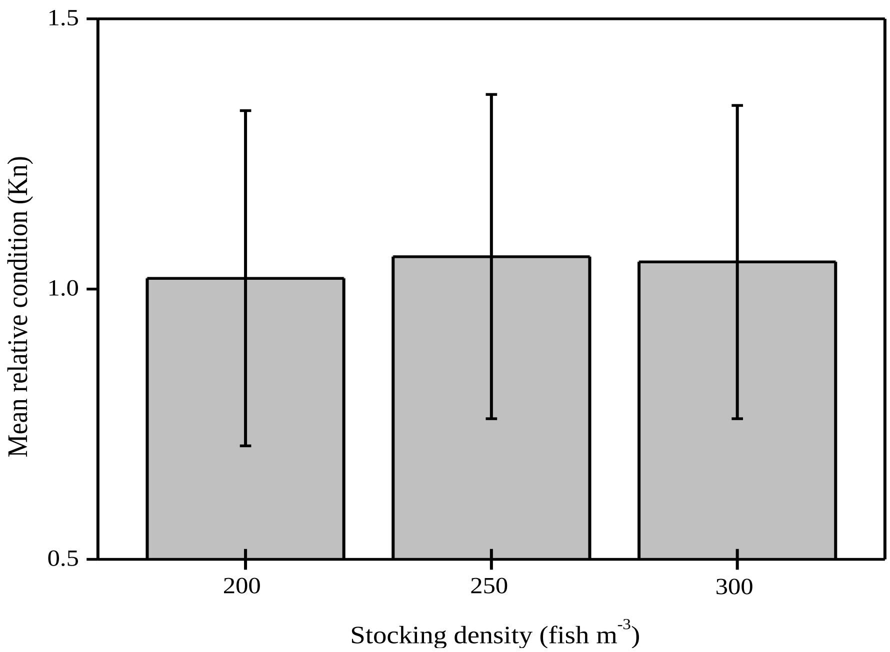

Figure 4. Mean relative condition factor (±SD) of *O. niloticus* stocked in cages at three different stocking densities.

and finally a higher FCR in 300 fish/m^3 of a cage (Table 2).

DISCUSSION

Water quality

Water quality greatly impacts the biology and physiology of the fish, and therefore affects the health and productivity of a fish culture system (Boyd, 2017). Consequently, maintenance of good water quality in cage aquaculture is critical for optimal growth of fish. In this study, suitable water quality parameters were maintained by regularly cleaning the cage netting to prevent fouling, which would otherwise limit appropriate water exchange within and outside the cages. Besides, the cages were installed in a site previously confirmed suitable for cage aquaculture through a site suitability study. The water parameters across all treatments ranged within accepted ranges, required optimal tilapia growth (Boyd, 2017; Popma and Masser, 2017), and thus did not have adverse effects on both growth and survival of the fish. Dissolved Oxygen (DO) concentration, pH and temperature results of this study conformed to those of Asmah et al. (2014) and Popma and Masser (2017), who recommended DO concentration and pH for Tilapia as >3 mg/L^{-1} and 6-9 respectively, and the optimal temperature between 27 and 32°C as recommended by Mengistu et al. (2020). However, the low DO levels within the experimental cages could have due to the high stocking densities, since fish utilize oxygen for respiration from the waters within and around cages (Kwikiriza et al., 2016). Further, the low DO levels could be as a result of inadequate exchange of water among cages since they were clustered in blocks (Mensah et al., 2018). Overall, the obtained water quality parameter values were within the favourable ranges required for tilapia growth. Therefore, the observed differences in fish growth may not be fully attributed to the characteristics of these water quality parameters.

Fish growth performance

The growth of Nile tilapia (*O. niloticus*) is impacted by stocking density, food quality and environmental factors such as such as Dissolved oxygen, temperature, and pH (Mensah et al., 2013; Mengistu et al., 2020). In the present study, stocking density affected the growth performance of Nile tilapia, with a negative correlation between stocking density and the growth performance of fish observed. Therefore, adopting growth performance alone, the resultant trend was that as stocking density increased, final weight gain decreased. Hence, growth performance attributed to the stocking densities showed superiority in the order 200 fish/m^3>250 fish/m^3>300 fish/m^3. This is in agreement with the results obtained by Asase (2013), Garcia et al. (2013) and Costa et al. (2017) that demonstrated an inverse relationship of stocking density and growth performance in tilapia cultured in net cages. Furthermore, the observed growth performance in the present study could be attributed to the differences in stocking density, since it influences fish behaviour, health, and feeding (Sanchez et al., 2010; Moniruzzaman et al., 2015; Enache et al., 2016). The observed no significant difference in the mean final weights of 200 and 250 fish/ m^3 stocking densities agrees with the results of a previous study by Garr et al. (2011). This study indicated that the effect of stocking density can sometimes be absent. The slow fish growth observed in the high stocked cages (300 fish/m^3) could be attributed to competition for limited space that resulted into the observed skin abrasions, which could have subsequently resulted into stress. This is in agreement with Roriz et al. (2017) who noted that skin abrasions and stress are observed in some fish individuals in highly stocked cages. Furthermore, M'balakaa et al. (2012) and Ronald et al. (2014) noted that although some fish species can tolerate extreme crowding, the competition for food limits their growth, resulting into poor weight gain. This was a similar scenario observed in highly stocked cages (300 fish/m^3), during this study. The competition for feed during fish feeding results into increased energy expenditure, and thus incurrence of greater metabolic costs. Additionally, there is increase in feed loss due to increased fish induced water turbulence in the highly stocked cages (Asase, 2013). In this study, this could have reduced the amount of food available for the fish and subsequently resulted into low growth rate in the highly stocked cages.

The length-weight relationship (LWR) is an important indicator of growth patterns and growth of fish (Silva et al., 2015). Length-weight relationships help to determine whether fish growth is isometric (b = 3) or allometric (negative allometric: b<3, or positive allometric: b>3), and also provide the condition of fish (Ricker, 1973). The fish across the stocking densities in the present study exhibited negative allometry, with the obtained "b" value lower than the reference value (b=3). This could be attributed to non-uniformity in sizes and very high variance among fish individuals. Notably, however, the values of "b" obtained in this study were in the recorded range (1.067 to 3.41) of "b" values of many fish species (Famoofo and Abdul, 2020). Similarly the "b" values in the present study were in the range of 2.299 and 3.684 recorded for Nile tilapia in the Atbara River and Khashm El-Girba reservoir, respectively (Ahmed et al., 2011). The mean Relative Condition (Kn) values of *O. niloticus* in this study were above the average condition of 1.0. This suggests that fish was in good condition (Ayode, 2011; Yosuva et al., 2018). Although Yilmaz et al. (2012) and Ali et al. (2016) noted that there may be differences in the condition factor due to sex, this was not applicable in this study since monosex male *O. niloticus* were applied in all the treatments.

Survival

Excessive stocking density in fish culture operations has a negative influence on fish survival (Garcia et al., 2013). In Nile tilapia culture, survival rate was reported to be density-dependent (Chakraborty and Banerjee, 2012). Therefore, an ideal stocking density for Nile tilapia culture in cages must take into account of its likely impact on fish survival, since it will affect the economic returns from the enterprise. In the present study, higher survival rates (above 90%) were obtained across the treatments, though inversely proportion to stocking density. These survival rates are in contrast with the previous study by Mensah et al. (2018), which reported 70-80% survival rates in a small scale tilapia cage culture, attributed to improper fish handling and water quality deterioration. The obtained higher survival rates in the present study could be attributed to the favourable environmental conditions throughout the experimental period. Indeed, Anusuya et al. (2017) indicated that higher survival rates in Nile tilapia aquaculture could be linked to favourable physio-chemical conditions of the water body where the fish is being cultured. The high survival rates, even in cages with high stocking densities, conforms with the results of Costa et al. (2017) that indicated survival rates above 90% for stocking densities of 250, 350 and 450 fish/m^3 in cages. Furthermore, Sorphea et al. (2010) and Khatune-Jannat et al. (2012) noted that, high stocking densities in fish culture may at times have no effect on mortality rates, and would consequently increase fish yield. In this study however, the overall growth performance and therefore fish yield, was lowest in higher stocking densities, even when stocking density had insignificant effect on mortality.

Feed conversion ratio

FCR expresses the ability of fish to effectively convert feed into body flesh and therefore feed use efficiency by fish. The lower values of FCR indicate that the fish has effectively converted the consumed feed into body flesh.

Therefore, the higher FCR values observed in this study, which increased with increasing stocking density, indicate poor food utilization efficiency. The FCRs in the present study deviated from the typical FCR values (1.4 to 2.5) for *O. niloticus* in African cage culture systems, as was reported by Ofori et al. (2010) and Mensah et al. (2018). However, the relatively low FCR obtained in low stocked cages (200 fish m^{-3}) suggests that, fish were somewhat able to extract more nutrients from the feed and subsequently converting it into flesh (Alhassan et al., 2018). The results of this study are also in agreement with Kapinga et al. (2014) and Asase et al. (2016), who indicated that feed conversion ratio increased with an increase in stocking density in tilapia culture. The observed higher values of FCR, in cages with higher fish density could be attributed to lower growth rate at higher stocking densities (Ronald et al., 2014). Additionally, this could be as a result of feed losses during fish feeding, which increases with increase in stocking density (Schmittou, 2006; Herrera, 2015). High stocking densities result in increased water turbulence during feeding, and hence increased feed losses.

Conclusion

The effects of stocking density were evident on the growth of Nile tilapia, in terms of weight gain and subsequently the final weight of fish. The best stocking density with regard to growth performance and feed conversion efficiency was 200 fish/m^3 of cage. However, the resultant final weight of the fish stocked at 200 fish/m^3 of cage was still low. This study, therefore, recommends further research, with low stocking densities, which would result into a higher final weight of the fish, and consequently higher yields from the cages.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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