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Research article

Optimization of stocking density for mono-sex Nile tilapia (*Oreochromis niloticus*) production in riverine cage culture in Bangladesh

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ABSTRACT

Determining a suitable stocking density of fish for an ambient condition is very important for economic benefit in cage aquaculture, which is not yet tested for many species in Sylhet district of Bangladesh. Therefore, current research was conducted in order to explore the effect of various stocking densities on growth and production performances of mono-sex Nile tilapia cage aquaculture in an open running water body, the Gurukchi River. Considering maximizing economic benefit, it is the first instance of such research in the Sylhet district of Bangladesh. In the three treatments (T_1, T_2, and T_3), fingerlings were stocked at 40, 60 and 80 fish/m^3, respectively with initial weights of 39.51 ± 0.91, 39.61 ± 0.71 and 38.54 ± 0.57g, respectively. Fish were fed with commercial floating pellet feed at 8-4% of their body weight. The results showed that growth performance of Nile tilapia significantly decreased with increasing stocking density. The mean total yields were 13.25 ± 0.48, 18.43 ± 0.88 and 22.76 ± 0.63 kg/m^3 in T_1, T_2 and T_3, respectively, which showed significant variations ($p < 0.05$) among treatments. The benefit-cost ratio analysis revealed that T_1 (1.512 ± 0.022) and T_2 (1.499 ± 0.063) were significantly ($p < 0.05$) higher than T_3 (1.191 ± 0.071), with no significant differences observed between T_1 and T_2. Notably, a significantly higher ($p < 0.05$) net profit was observed in T_2 than in T_1 and T_3. Overall, 60 fish/m^3 stocking density was the best stocking density for commercial cage aquaculture of tilapia in a riverine environment of the north-eastern Bangladesh.

1. Introduction

Cage aquaculture is very popular throughout the world, and a lot of research has been conducted in several countries [1]. In Bangladesh, cage culture started in the 1980s in Kaptai Lake [2]. Later on, a number of non-government organizations (NGOs) along with the respective government departments attempted for decades to introduce cage aquaculture. However, in that period, the spread of this technology was very slow in the country [3]. Afterwards, in the last decade, cage culture gained popularity among farmers in some regions of Bangladesh as a result of continuous efforts, though some areas like the Greater Sylhet region still need to be focused on the extension of this technology. Therefore, till date the Department of Fisheries in collaboration with other government organizations and NGOs has continued to promote cage aquaculture, and according to DoF (2018), in 2017–18 tilapia was the only species cultured in cage aquaculture and total production resulted in 3,523 MT [3].

Tilapia, commonly called aquatic chicken, exists in a number of waterbodies and has been effectively cultured in a wide variety of environmental settings and is recognized as one of the important groups of cultured fish fauna in different parts of the world, mainly in developing countries [4, 5, 6]. There were several attempts to introduce tilapia to the farmers' level of Bangladesh from 1954 to the next few decades [7]. Finally, a synthetic strain of Nile tilapia, Genetically Improved Farmed Tilapia (GIFT), was introduced from the Philippines in 1994 [7] which gained much popularity among farmers due to its excellent growth and survival performance. Due to availability of fries, after 1998, there has been remarkable progress in the farming of GIFT in Bangladesh. Currently, Bangladesh ranks in 3rd place in Asia and 4th in tilapia production around the world [3].

The Sylhet division of Bangladesh is blessed with a huge number of special types of waterbodies, *haors* [8], which include several types of seasonal and perennial waterbodies. However, total production from both the capture and culture fisheries of the Sylhet division was low (2, 70,627 MT) compared to the other divisions of the country [3]. Similarly, cage culture production from this division is also very poor (112 MT) [3]. However, it is a good sign that commercial cage culture of tilapia has

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recently been started in three districts of Sylhet division (Habiganj, Moulvibazar and Sunamganj) except the Sylhet district [3]. Hence, these *haors* can be used for cage culture activities which are supposed to add more production and could be a significant option for alternate income generation of poor fishers [8]. Thus, it was necessary to initiate a research work on cage farming of tilapia in the *haor* region of Sylhet. Successful culture was supposed to be a good motivation for spreading this technology throughout the Sylhet district.

The growth of tilapia generally depends on some factors which include the stocking density, physiological status of fish, reproductive status of fish, food quality, energy content of the diet, and environmental drivers like dissolved oxygen, pH, temperature, etc. [9, 10]. Among these factors, stocking density of fish plays a significant role in profitable aquaculture. In the case of cage aquaculture of tilapia in Bangladesh, many farmers are reluctant to follow the recommended stocking densities and operation procedures, which in turn result in less economic profit from poor growth and survival rates [11]. Proper stocking density also reduces input and maintenance costs. As a result, both under-stocking and overstocking are commercially less viable in commercial culture systems [12]. Cage aquaculture by local poor fishers in Bangladesh demands a higher stocking density to maximize production and profit [13]. Therefore, it is necessary to find out its economically profitable stocking density for tilapia. However, little work has yet been done on the optimization of stocking densities of mono-sex Nile tilapia in cages in the vast *haor* region of Bangladesh [11]. Most importantly, riverine cage culture of tilapia considering stocking density's impacts on growth, production, and economics has not yet been studied in the north-eastern *haor* region of Bangladesh. Moreover, cage culture in the *haor* regions would have great potentiality as 2–3 crops can be cultured per year in the same cage setup depending on the water availability in the wetlands. Therefore, the objective of the current study was set to find out an optimal stocking density of mono-sex Nile tilapia in net cages at riverine condition with profitability analysis under three different stocking densities.

2. Materials and methods

2.1. Ethical approval

The Ethics Committee of the Department of Aquatic Resource Management, Sylhet Agricultural University, Sylhet, Bangladesh, approved the specific experimental design.

2.2. Study period and area

The current experiment was conducted for a period of 92 days from 10 August to 10 November 2019 in nine galvanized iron (GI) pipe framed net cages which were set-up in the Gurukchi River near the Gurukchi village under Lengura union (Figure 1). The Gurukchi River is a tributary of the Shari-Goyain River located in the Gowainghat upazila of the Sylhet

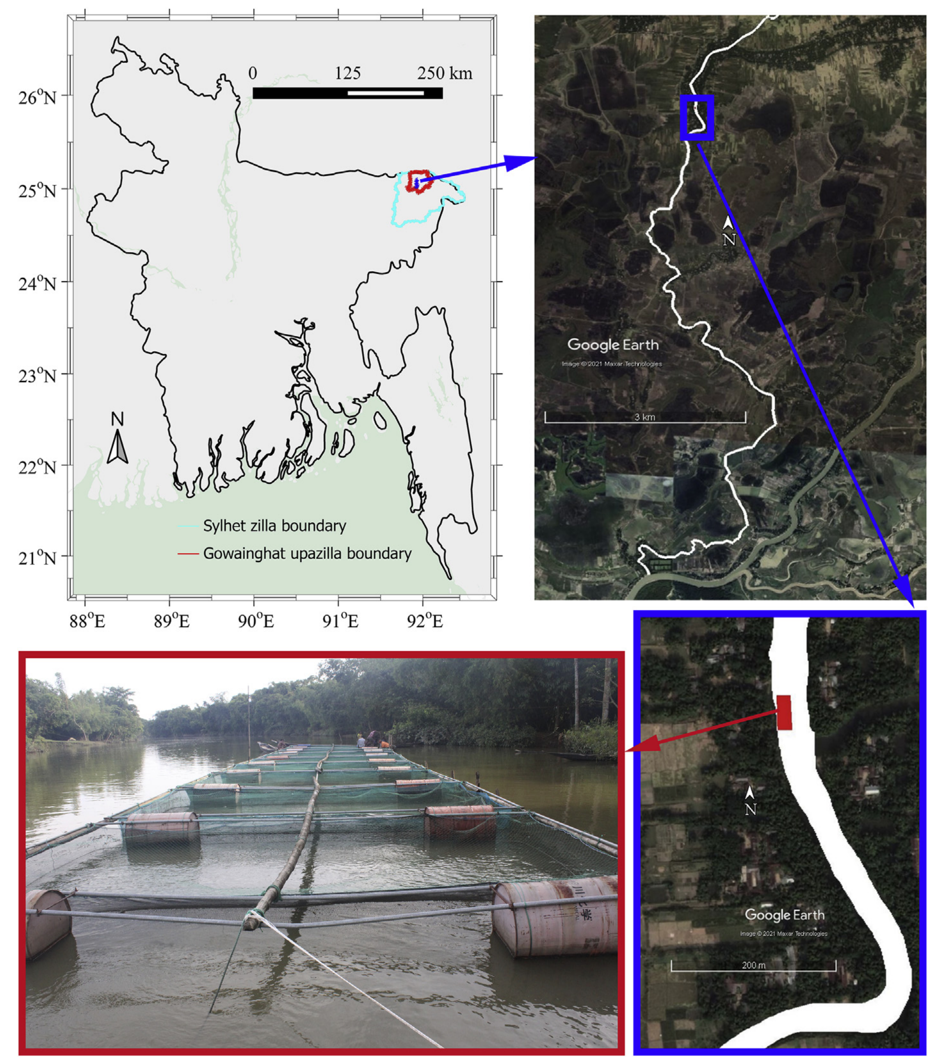

Figure 1. Floating cages in the Gurukchi River.

district of Bangladesh. This river is almost 10 km long and its average water depth varies between 1 and 12 m. It is navigable by large boats during the wet season, and it flows directly into the Shari-Goyain River from the upstream catchment areas of Gurukchi and adjacent villages. The lower portion of the river is called the Mohali Canal, which is joined with the Shari-Goyain River at Shiyala Point near the Ratargul Swamp Forest [14]. The Shari-Goyain River is a transboundary river of Bangladesh which comes from the Meghalaya district of India [15, 16]. In the dry months (November to March), the upper and lower portions of the river dry up, and thus become closed without having any water flow. Moreover, the water depth of this river heavily drops from February to April due to the use of its water for irrigation purposes.

2.3. Cage preparation and set-up

For this study, 36 m^3 (6 m × 3 m × 2 m) size cages were used. The cages were constructed by using knotless black nylon net hanging from a quadrangular cage frame (6 m × 3 m) made of GI pipes (1 inch in diameter) placed horizontally above the water level. However, the water volume in each cage was maintained at 30 m^3 (6 m × 3 m × 1.67 m) by hanging it with floating large metallic drums. The mesh size of the net was kept as low as 3.00 cm in order to prevent the escape of experimental fish fries. However, this mesh size was wide enough to easily pass a large amount of water through the cages. Each cage frame was joined together with iron plate where the total structure was floated above water with closed iron drums which were placed between every two cages along with two ends of the cage series. A platform made of bamboos was set up with the cage frame for human movement for supplying feeds, sampling, and harvesting of fish [11]. Local fishers actively engaged themselves in the whole activities during the culture period.

2.4. Study design

Three treatments for three different stocking densities were used, each with 3 replications for finding out the appropriate stocking density. Fishes were stocked at 40, 60 and 80 fish/m^3 in treatment-1 (T_1), treatment-2 (T_2) and treatment-3 (T_3), respectively. Artificial aeration was not supplied to the cages as the cages were set up in flowing water of a river where dissolved oxygen content was sufficient for fish growth. After 92 days of the experiment, growth, production, and economic analysis were carried out.

2.5. Stocking of tilapia

Healthy and uniform-sized tilapia fingerlings were collected from a reputed commercial private hatchery, Delta Agro Fisheries. That farm is located at the neighbouring upazila, Bishwanath in the same district. Therefore, fingerlings were transported by a pick-up van in large plastic drums. As the farm is not very far, fishes were transported in water filled plastic containers and gently agitated by hand to add oxygen from the air rather than using oxygenated bags. Before stocking, the length and weight of 25 fingerlings from each cage were recorded at random. The mean initial weights were 39.51 ± 0.91, 39.61 ± 0.71 and 38.54 ± 0.57 g and mean initial lengths were 12.86 ± 0.25, 12.86 ± 0.43 and 12.83 ± 0.18 cm for T_1, T_2 and T_3, respectively. After transportation, the fingerlings were first acclimatized in a rectangular *hapa* (inverted mosquito net) for 2 h and dead fish were removed accordingly. Then the fingerlings were released into the cages early in the morning.

2.6. Feed and feeding management

In this study, commercially available floating starter feed (approximately 29% crude protein) was used in the early stages of tilapia, and later on when they grew up, grow-out pelleted floating feed (approximately 26% crude protein) was used. In general, the small-scale fish farmers in the *haor* regions of Sylhet are not rich enough to continuously supply high priced, high protein content feed to the fish. As the target of this study is to find out the suitable stocking density for the small-scale fish farmers, the mentioned fish feeds were used rather than using a higher percentage of protein-contained feed. Feeding was initiated at 8% of the body weight of the fish at the first month and gradually reduced to 4% of body weight from the second month, and then continued until the end of the study period. Feeds were manually spread by hand in the cages through the upper opening of the *hapas*. The total feed for a day was divided into two equal halves and supplied in the morning between 8.00 and 9.00 am and in the evening at 4.00–5.00 pm. Feeding status was monitored regularly after broadcasting of feeds. Feeding rates were adjusted fortnightly depending on the mean body weight and stage of their growth which were determined through random sampling of 25 fishes per cage [17]. Nets of the cages were cleaned up once a week in order to maintain the passage of an adequate amount of river water through the cages. The conditions of the cages were also checked simultaneously to inspect whether they were damaged or not.

2.7. Sampling of tilapia

Sampling of the fishes was done monthly by using a large scoop net in order to check the overall growth and health conditions of fishes. During each sampling, length and weight of randomly selected 25 individuals were measured and recorded from each of the cages. Length of fish was measured by a stainless steel scale attached with a wooden frame and weight of fish was measured by a two digit precision digital balance (Model: EK600i, Origin: Japan). At the end of the study, all fishes were harvested, counted, and the bulk weight was also estimated separately for each cage.

2.8. Estimation of growth, yield and survival of tilapia

During harvesting, length and weight of 25 individuals from each cage were measured. Then, the bulk weight of tilapia was measured separately for each of the cages and recorded accordingly.

The following formulae were used to evaluate the different parameters of fish production [18, 19, 20]:

$$\text{Weight gain (g)} = \text{Final weight (g) - initial weight (g)} \quad (1)$$

$$\text{Survival rate (\%)} = \frac{\text{Number of fish harvested}}{\text{Initial number of fish stocked}} \times 100 \quad (2)$$

Yield of fish:

$$\text{i. Gross yield} = \text{Number of fish caught} \times \text{average final weight} \quad (3)$$

$$\text{ii. Net yield} = \text{Number of fish caught} \times \text{average weight gain} \quad (4)$$

Specific growth rate (SGR) was calculated by using the following formula:

$$\text{SGR (\% per day)} = \frac{\log_e W_2 - \log_e W_1}{T} \times 100 \quad (5)$$

where,

W_1 = the initial live body weight (g)
W_2 = the final live body weight (g)
T = duration of fish rearing (days)

The feed conversion ratio (FCR) was determined for each of the three treatments by using the following formula:

$$\text{FCR} = \frac{\text{Feed fed (dry weight)}}{\text{Live weight gain}} \quad (6)$$

2.9. Water quality monitoring

Hydro-chemical variables *viz*. pH, conductivity, total dissolved solids (TDS), dissolved oxygen, water transparency and temperature of water inside the cages were measured on monthly basis by using a digital multi-sensor (YSI Multi-Sensor, model: Professional Plus, Brand: YSI, Origin: USA). Water transparency was measured by using a Secchi disc. The water quality parameters are shown in Table 1. Mean values of water temperature, dissolved oxygen, conductivity, TDS, pH and transparency were found within the suitable limits for fish culture.

2.10. Benefit-cost analysis

Benefit-cost ratio (BCR) for different treatments was calculated on the basis of the prices of cage making materials, fish seed (including transportation cost), feed, and the revenue from the sale of tilapia. At the end of the study, all fish were sold to the local consumers in the local markets. The analysis was based on market prices of fish and all other items expressed in Bangladeshi Taka (BDT) considering the contemporary gross exchange rate of 85 BDT as equivalent to 1 USD. The net benefit and BCR were calculated using the following formulae:

$$\text{Net benefit} = \textit{Gross return} - \textit{Total cost} \quad (7)$$

$$\text{BCR} = \frac{\textit{Gross return}}{\textit{Total cost}} \quad (8)$$

2.11. Statistical analysis

Statistical analysis of all collected data was performed using One Way Analysis of Variance (ANOVA), where the mean values were compared to Duncan's Multiple Range Test (DMRT). The software Statistical Package for the Social Sciences (SPSS) version 20.0 was used for all the analysis. Probabilities of $p < 0.05$ were considered to test the significance level.

3. Results

3.1. Growth and production performances

The growth and production related parameters of tilapia (Table 2) showed that stocking density had a significant effect ($p < 0.05$) on growth and production performances, where a decreasing trend of individual fish growth was observed with the increasing stocking densities but an increasing trend of total production was found with increasing stocking densities. Mean final weights of tilapia were 337.39 ± 11.40 g, 312.06 ± 14.50 g and 265.69 ± 13.37 g, respectively, in T_1, T_2 and T_3, indicating significantly higher mean final weights in T_1 and T_2 than in T_3. However, no significant differences were observed in mean final weights between T_1 and T_2. The highest final length (24.08 ± 0.35 cm) of Nile tilapia was achieved at a density of 40 fish/m^3, followed by 60 fish/m^3 and 80 fish/m^3. Monthly data showed no significant variations in weight and length of tilapia across three treatments during the first two months, but significantly higher mean weight and length were found in T_1 and T_2 than in T_3 during final harvesting (Table 2; Figures 2 and 3). On the other hand, total yield and net yield showed increasing trends with increasing stocking densities (Table 1). However, the survival rate was unaffected by stocking density that ranged between 96.83 ± 1.22% and 98.17 ± 0.63%. Fish mortality was observed immediately after fish stocking in the cages, which have been caused due to transportation stress.

The specific growth rate (%/day) was significantly higher in T_1 (2.295 ± 0.06) and T_2 (2.219 ± 0.069) than T_3 (2.075 ± 0.052), but no significant difference was observed between T_1 and T_2. Significantly lower FCR was found in T_1 (1.046 ± 0.020) and T_2 (1.074 ± 0.055) than T_3 (1.248 ± 0.084) that indicated stocking densities of 40 fish/m^3 and 60 fish/m^3 have no significant difference in FCR, but stocking density of 80 fish/m^3 showed significantly higher amount of feed requirement compared to final production.

Table 1. Water quality parameters of cages during the culture period.

Parameters	Values (mean ± SD)
Water temperature (°C)	27.40 ± 3.43
Dissolved oxygen (mg/l)	5.46 ± 1.48
Conductivity (μS)	43.65 ± 3.49
TDS (ppm)	21.30 ± 1.95
pH	6.58 ± 0.36
Transparency (cm)	30.88 ± 7.77
Depth (m)	4.17 ± 2.73

Table 2. Growth and production performances of tilapia in different treatments (mean ± SD).

Parameters	Treatments		
	Treatment-1	Treatment-2	Treatment-3
Initial weight (g)	39.51 ± 0.91	39.61 ± 0.71	38.54 ± 0.57
Initial length (cm)	12.86 ± 0.25	12.86 ± 0.43	12.83 ± 0.18
Final weight (g)	337.39 ± 11.40^a	312.06 ± 14.50^a	265.69 ± 13.37^b
Final length (cm)	24.08 ± 0.35^a	23.62 ± 0.35^a	22.39 ± 0.14^b
Total yield (kg/cage)	397.47 ± 14.49^c	546.39 ± 21.11^b	617.65 ± 36.76^a
Net yield (kg/cage)	349.58 ± 15.57^b	475.10 ± 22.38^a	525.15 ± 36.55^a
Total yield (kg/m^3)	13.25 ± 0.48^c	18.21 ± 0.70^b	20.59 ± 1.23^a
Net yield (kg/m^3)	11.68 ± 0.51^b	15.90 ± 0.76^a	17.60 ± 1.19^a
SGR (%/day)	2.295 ± 0.060^a	2.219 ± 0.069^a	2.075 ± 0.052^b
Survival	98.17 ± 0.63	97.30 ± 0.94	96.83 ± 1.22
FCR	1.046 ± 0.020^b	1.074 ± 0.055^b	1.248 ± 0.084^a

In each row, the values with different superscripts denote significant differences ($P < 0.05$) and the values with same or no superscript indicate no significant difference ($P < 0.05$).

3.2. Economic return

Total expenditure was significantly diverse ($p < 0.05$) across the treatments, but significantly higher ($p < 0.05$) total revenue was shown in T_2 (BDT 54,639 ± 2,111) and T_3 (BDT 55,588 ± 3,309) than in T_1 (BDT 39,747 ± 1,449) (Table 3). Significantly higher ($p < 0.05$) net revenue was observed in T_2 (BDT 18,168 ± 2,159) than T_1 (BDT 13,464 ± 730) and T_3 (BDT 8,926 ± 3,250). According to benefit-cost analysis, significantly higher ($p < 0.05$) BCR was found in T_1 (1.512 ± 0.022) and T_2 (1.499 ± 0.063) than in T_3 (1.191 ± 0.071), but there were no significant differences between T_1 and T_2. Therefore, considering the above facts, the economic analysis suggests that both 40 fish/m^3 and 60 fish/m^3 stocking densities in floating cages in the Gurukchi River would be profitable, but considering the net revenue, 60 fish/m^3 is the best among the three densities.

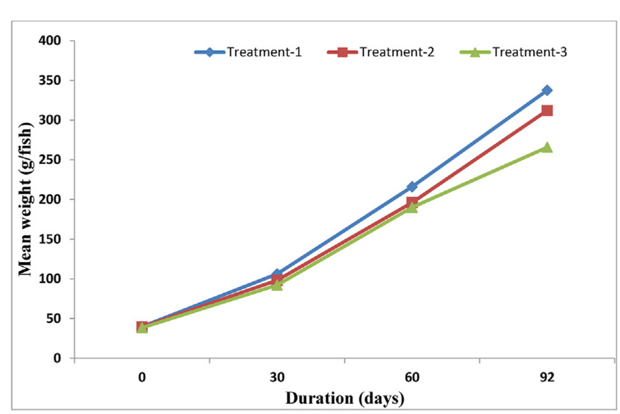

Figure 2. Monthly weight variation of tilapia in different treatments.

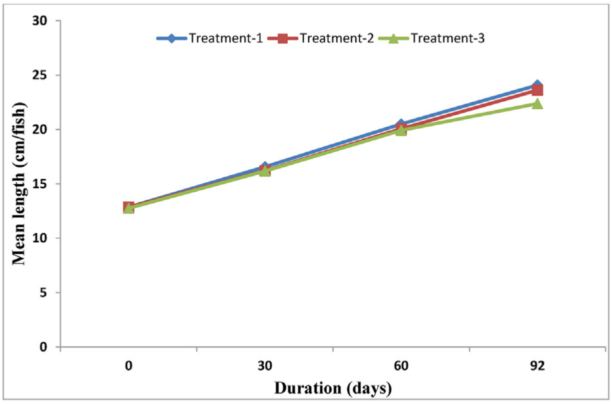

Figure 3. Monthly length variation of tilapia in different treatments.

Table 3. Economic analysis of different treatments.

Parameters	Treatments (mean ± SD)		
	Treatment-1	Treatment-2	Treatment-3
Fry cost (BDT)	6,000	9,000	12,000
Feed cost (BDT)	$18,283 \pm 893^{c}$	$25,471 \pm 756^{b}$	$32,663 \pm 994^{a}$
Cage cost (BDT)	2,000	2,000	2,000
Total expenditure (BDT/cage)	$26,283 \pm 893^{c}$	$36,471 \pm 756^{b}$	$46,663 \pm 994^{a}$
Total revenue (BDT/cage)	$39,747 \pm 1449^{b}$	$54,639 \pm 2,111^{a}$	$55,588 \pm 3,309^{a}$
Net revenue (BDT/cage)	$13,464 \pm 730^{b}$	$18,168 \pm 2,159^{a}$	$8,926 \pm 3,250^{b}$
BCR	1.512 ± 0.022^{a}	1.499 ± 0.063^{a}	1.191 ± 0.071^{b}

In each row, the values with different superscripts denote significant differences ($P < 0.05$) and the values with same or no superscript indicate no significant difference ($P < 0.05$).

4. Discussion

The goal of this study was to determine the optimal stocking density for mono-sex Nile tilapia in a riverine cage culture system in order to determine the most suitable stocking density for a profitable cage aquaculture that would eventually improve the livelihoods of rural fishers as an alternative source of income. Increased tilapia stocking densities resulted in a downward trend in fish growth. Significantly higher mean final weight, mean final length, and SGR (%/day) were attained at the stocking density of 40 fish/m^3 and 60 fish/m^3 than at 80 fish/m^3. FCR was also found to be significantly lower at densities of 40 and 60 fish/m^3 than at densities of 80 fish/m^3. The possible reason may be that fish get more space for easy movement in the lower stocking densities and feed efficiency is positively correlated with living space in the cages [21, 22]. Furthermore, many scientists have found that lower stocking densities result in less stress in cultured fish [23, 24]. Higher feed efficiency and a lower level of stress in the fish body ensured significantly higher final weight gain, which was previously reported by several researchers [12, 25]. Stocking densities have no significant and direct effect on the survival rate of tilapia, which was similar to several other research studies with different types of fish species under different culture conditions and environments [22, 23, 26]. In very high stocking densities in cage culture tilapia or other fishes might be prone to infectious diseases spreading [27] as seen in the cage culture of Nile tilapia in the Dakatia River during the last decade [28]. However, in this study, their density was much lower than that of all treatments, suggesting that they had no effect on infectious disease conditions during the study period. Notably, Nile tilapia can live in a wide range of aquatic environmental parameters, which allows this species to be cultured at high stocking densities in cage aquaculture without any significant impact on fish mortality. However, stocking density and production performance obtained in this study are found stable with many other researches on this species with various environments [10, 11, 29, 30]. As it was running water with less pollution, all physico-chemical parameters of the river water were found within the acceptable limits for aquaculture in tropical waters [31].

Marma et al. [11] studied Nile tilapia with 35, 40 and 45 fish/m^3 stocking densities in the Dekar *Haor* of Sunamganj district and found the highest mean final weight was 175.07 ± 17.52 g in the treatment with 35 fish/m^3 densities, which is significantly ($p < 0.05$) higher than those of the 40 stocking densities (169.3 ± 15.19 g) and the 45 fish/m^3 densities (143.00 ± 14.92 g). The authors also documented that the daily weight gain of tilapia was reduced with stocking density. In the present study, gross production increased with increasing stocking density. However, as density increased, so did the cost of fingerlings and feed. Feed costs comprise about 69.56%–70.00% of the total cost for each treatment. Cage infrastructural costs remained the same in all treatments and were calculated based on depreciation costs. The higher fry cost and feed requirement for higher stocking density were found in a lower BCR with low economic sustainability.

The design of the present research was prepared to support local fishers by involving them as an alternate livelihood option to cope with the situation during the fishing ban period as well as find out the suitable stocking density of tilapia in cage aquaculture in the riverine condition. Higher stocking density has been shown to enhance gross production, however the cost of production rises with increased stocking density, making it unaffordable for local poor fish farmers. On the other hand, very lower stocking density provides less net profit, which could not be economically viable considering the labour for maintenance. Furthermore, the *haor* region is prone to flash floods on a regular basis, and poor and middle-class fish farmers are vulnerable to these hydro-meteorological hazards and threats [32]. Therefore, efficient management of cages with higher stocking densities is difficult, and relocating the cages to a relatively safer zone becomes impossible during such kinds of sudden disasters, which may cause total loss to the cage aquaculture system [13]. However, current study recorded higher fish production at the higher stocking density (80 fish/m^3) but the mean growth parameter and economic profit were lower than others. The stocking density of T_2 (60 fish/m^3) exhibited significantly higher production, growth performance and a commercial economic profit. Though BCR did not show any significant differences between the densities 40 fish/m^3 and 60 fish/m^3 but net profit was higher in 60 fish/m^3. Therefore, the overall results of the present study indicated that the 60 fish/m^3 stocking density of tilapia is the best among three treatments in respect to growth, survival rate, production, and economic return. Therefore, the farmers could be suggested to rear tilapia with this stocking density (60 fish/m^3) in the cages to get sustainable production and higher economic return in a short period of time. Moreover, with significantly less cost required in the T_1, this 40 fish/m^3 density could be the second option for successful cage aquaculture with low investment.

5. Conclusions

The current study was successfully conducted to explain the effect of three different stocking densities on the growth, production, and economic profit of tilapia in a riverine cage aquaculture system. In conclusion, it can be validated that 60 fish/m^3 showed the highest performance among all three densities. As a result, this stocking density could be recommended for the effective cage culture of mono-sex Nile tilapia, which has implications for sustainable and cost-effective commercial cage aquaculture practices in the riverine environment. The output of the study could be an important tool to accelerate the commercial production of tilapia in riverine cages in the *haor* region of Bangladesh.

Declarations

Author contribution statement

Mrityunjoy Kunda; Debasish Pandit: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Ahmed Harun-Al-Rashid: Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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