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Effects of Stocking Larger-Sized Fish on Water Quality, Growth Performance, and the Economic Yield of Nile Tilapia (*Oreochromis niloticus* L.) in Floating Cages

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Abstract: Earlier research has mostly focused on the impacts of stocking density on fish growth, yield, and survival rate; however, knowledge of the effects of stocking larger-sized fish, particularly Nile Tilapia, is lacking. This type of research is critically important for increasing food security, achieving sustainable goals, and facing the challenges of climate change in the near future. Therefore, we investigated the effects of initial stocking body sizes of Nile Tilapia (*Oreochromis niloticus*) on water quality, growth performance, and economic yield in tropical riverine cages for 120 days in two culture cycles. Nile Tilapia of three different body sizes (34.06 ± 0.22 g, 10.98 ± 0.09 g, and 5.47 ± 0.04 for the first cycle and 33.85 ± 0.01 g, 11.07 ± 0.05 g, and 5.38 ± 0.06 g for the second cycle, indicated as T1, T2, and T3) were stocked in the culture treatments where unique stocking density and feed rations were maintained. The results revealed that water quality parameters did not differ significantly ($p > 0.5$) and were within a suitable range for Nile Tilapia culture. Treatments with larger-sized fish demonstrated a higher growth performance. The stocking fish size of 34.14–34.71 g was found to be the best among the three treatments regarding growth performance and economic return. As a result, except for T1 and T2 at a rural site and T1 at a semi-urban site, all of the treatments had negative allometry ($b < 3.0$), indicating that larger-sized fish and the rural site of the river are more suitable for cage culture. The rural site was found to be more suitable, possibly due to less variation of water parameters, more natural foods, and less pollution. The cages with larger-sized fish stocked had a higher net present value (NPV); internal rate of return (IRR); benefit–cost ratio (BCR); and rate on return (ROI), indicating that cage culture with larger-sized fish stocked is economically viable in the riverine system. Therefore, stocking the larger-sized fish (T1) and rural site are more suitable for cage culture.

Keywords: cage culture; relative condition factor; growth performance; stocking density; the survival rate

1. Introduction

Bangladesh, a self-sufficient fish-producing country, has the second-highest growth rate (9.1%) after Indonesia [1]. Its total fish production has expanded by around six-fold during the last three decades (0.754 million MT (Metric Ton) in 1983–1984 to 4.503 million

MT in 2019–2020). The inland culture fishery consists primarily of ponds; ox-bow lakes (*baor*); shrimp/prawn farms; seasonal cultured water bodies; pens; and cage culture, producing approximately 25.84 lakh metric tons in 2019–2020, accounting for approximately 57.38% of the total fish production [2]. The fisheries sector contributed about 3.52% to the Gross Domestic Production (GDP) and approximately 26.37% of the agricultural sector's total income. The inland fisheries accounted for 85.10% of the total catch (inland open water 27.72% and inland closed water 57.38%), and the remaining 14.90% came from the marine fisheries [2]. However, it is well documented that most capture fisheries have been over-exploited due to overfishing, habitat degradation, and pollution [3,4].

An improved or intensive aquaculture system has many negative impacts on the environment. Therefore, to reduce the environmental impacts or to continue the aquaculture practice over time with minimum environmental impacts, sustainable aquaculture is gaining popularity. It is also a way to reduce pressure on wild stock. However, sustainable aquaculture varies with species, geographical location, knowledge, and technology that is developed.

Furthermore, climate change is already having an impact on specific biological processes, altering freshwater food webs, and creating unforeseeable consequences for fish production, including increased risks of species invasions and the spread of vector-borne diseases. Freshwater aquatic species are experiencing changes in abundance, productivity, community composition, dispersion, and migration. Bangladesh's fisheries sector—especially inland fish culture—is sensitive to climate change as it influences the rainy season and causes flooding [5]. As sea levels rise, flooding of low-lying areas and the salinization of groundwater and soil will make many areas ideal for aquaculture, while also making them unsuitable for regular agriculture (MAB, 2009). Due to this and other flooding, it has been suggested that Bangladesh could transform from a "rice bowl" to a "fish pond". The high level of fishing pressure on natural water resources worldwide requires the implementation of innovative solid mitigation measures such as cage-culture farming [6].

Floating cage culture is an effective culture system that uses freshwater and marine habitats, such as rivers, lakes, floodplain areas, estuaries, seas, and reservoirs to produce quick fish production [7,8]. Since it can use communal water sources, this cage-culture approach offers an alternative aquaculture method, especially for landless people [9]. The close observation of fish behavior, easy disease detection, predator protection, easy relocation, relatively little capital investment, and the potential for improved prices are all advantages of cage culture [3,10]. Globally, comprehensive fish culture in cages has already been achieved with great success. In Bangladesh, aquaculture activities are still mostly focused on pond-based culture systems; however, fish production by cage aquaculture systems using various water resources was around 4590 MT in the fiscal year 2019–2020 [2].

Since the fish is resistant to harsh climatic fluctuations, has a low mortality rate, and has a faster growth rate, Nile Tilapia culture in cages has become popular. Nile Tilapia production in cages is especially advantageous because of disease resistance, hardiness, omnivory, ease of harvesting, adaptive capacity, and the ability to be grown with a high stocking density [11–13]. As a result, the cage culture of Nile Tilapia (*Oreochromis. niloticus* L.) has exploded in Bangladesh's Dakatia River, Kaptai Lake, and Titas River. In terms of generating money, animal protein intake, and improving the livelihood position of small-scale farmers, the Titas River may offer significant potential for floating-cage aquaculture. Titas River's annual fish production reached 1955 MT in 2018–2019 [2], which played a significant role in fulfilling the protein demand of Brahmanbaria.

Fish culture in net cages needs adherence to best practices, such as adopting an appropriate fish stocking density and fish size to enhance production efficiency. The identification of optimal-sized fish stockings is a critical aspect for the success of Nile Tilapia cage culture, as it has a direct impact on the fish's growth rate and survival, as well as their health and water quality, and, as a result, the farm's economics and profitability in 2018–2019 [2,14]. However, due to a lack of knowledge about the fish's appropriate stocking size, this business has frequently failed to reach full commercialization [15]. Moreover, the cage aquaculture of *O. niloticus*, considering the stocking density of different sized fish, growth, yield, and farm economics, has not been studied in detail in Bangladesh. Although stocking with different sized fish and management measures are practiced in Bangladesh by cage operators, these are not based on modern technical knowledge, resulting in the poor growth and survival rate of fingerlings, as well as low income. Therefore, the purpose of this study was to evaluate the effects of stocking with larger-sized fish on a growth performance, cost–benefit, and business feasibility analysis of Nile Tilapia (*O. niloticus* L.) in net-cage culture placed in a riverine system of Bangladesh. This is the first report of its kind and will help to improve the knowledge on cage-culture techniques in a riverine ecosystem, in order to achieve sustainable development goals and to expand climate-adaptive culture techniques.

2. Materials and Methods

2.1. Study Area and Experimental Design

The study was undertaken in twenty-seven nylon net cages that were installed on the Titas River of Bangladesh for two cycles, each lasting 120 days, from 16 March 2020 to 14 July 2020 (first cycle) and 20 July 2020 to 17 November 2020 (second cycle). Three sites on the Titas River with different geographic locations were chosen for conducting the study: Mojlishpur (Lat: 24°1′57.5688″ N; Lng: 91°8′41.6364″ E) as the site in the rural area; Shitanagar (Lat: 23°59′1.6908″ N; Lng: 91°6′53.0388″ E) as the semi-urban area; and Paikpara (Lat: 23°58′52.8348″ N; Lng: 91°30′49.122″ E) as the urban area (Figure 1). For the current study, twenty-seven newly constructed cages were used, where nine cages were triplicated with three treatments. The net cages hung with a cage frame were made of a knotless polyethylene net (mesh 1.0 cm). The cage's frame was made of a one-inch diameter GI (Galvanised Iron) pipe. Plastic drums were used as cage floats. A bamboo-made platform was set up over the cages, and all the cages were fixed to the platform's poles. Cages were installed on both sides of the platform for easy feed supply and intensive observation. In the present study, three different sizes of monosex Nile Tilapia with unique stocking density (500 fish/cage) were designed as T1, T2, and T3, respectively, with triplicates for each treatment group in three different cage sites. Moreover, the treatments were named with respecting cage sites as MT1, MT2, and MT3 for Mojlishpur; ST1, ST2, and ST3 for Shitanagar, and PT1, PT2, and PT3 for Paikpara. In brief, hormonally sex-reversed juvenile monosex male tilapia, *O. niloticus* L. averaging 34.06 ± 0.22 g for T1; 10.98 ± 0.09 g for T2; and 5.47 ± 0.04 g for T3 in the first cycle, and 33.85 ± 0.01 g for T1; 11.07 ± 0.05 g for T2; and 5.38 ± 0.06 g for T3 in the second cycle were transported to the experimental sites. The fish were kept in three net hapas for three hours for acclimation to the environment. The initial length of the fish in cm and weight in g were recorded individually with the help of a measuring scale and a digital electronic balance (OHAUS, Model CT 1200-S, Parsippany, NJ, USA). Finally, the cages (6.10 m × 3.05 m × 1.52 m or, 28.28 m^3 each) were randomly stocked with monosex Nile Tilapia, and the number of fish stocked in each cage was recorded simultaneously.

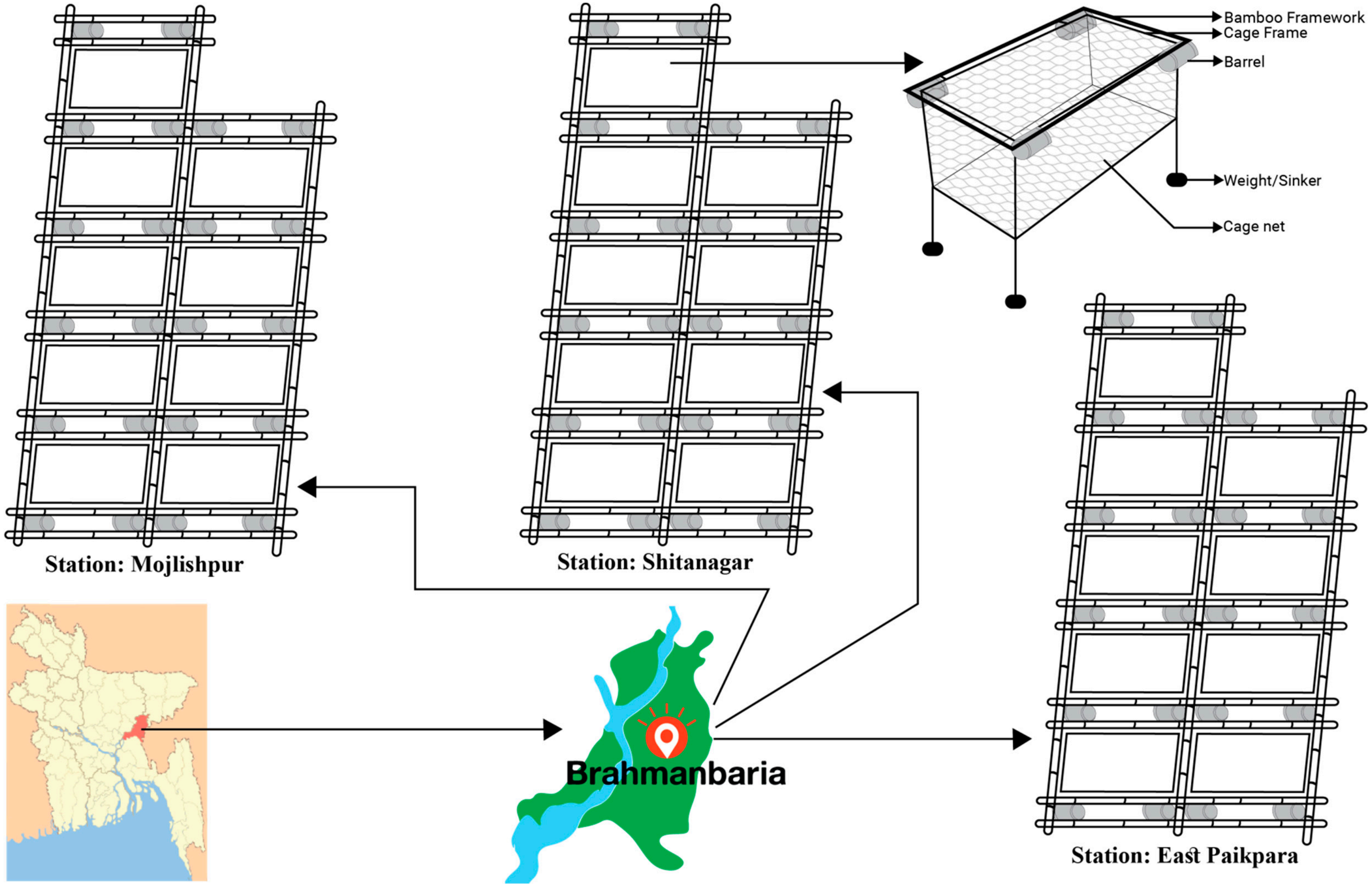

Figure 1. The study area of Nile Tilapia (*O. niloticus* L.) under cage-culture system in Titas River of Bangladesh.

2.2. Feeding and Management

The experimental fish were fed with commercial floating pelleted diets (Quality Feeds), and their nutritional compositions are listed in Table 1 (source: Quality Control Laboratory, Department of Fisheries, Savar, Dhaka, Bangladesh). The fish were hand-fed at 10% (MT3, ST3, and PT3), 8% (MT2, ST2, and PT2), and 6% (MT1, ST1, and PT1) of their body weight for the first two weeks; 7% (MT3, ST3, and PT3), 6% (MT2, ST2, and PT2), and 4% (MT1, ST1, and PT1) for the third and fourth weeks; 6% (MT3, ST3, and PT3), 5% (MT2, ST2, and PT2), and 3% (MT1, ST1, and PT1) for the fifth and sixth weeks; 5% (MT3, ST3, and PT3), 4% (MT2, ST2, and PT2), and 2% (MT1, ST1, and PT1) for the seventh to the tenth week; and 3% (MT3, ST3, and PT3), 2% (MT2, ST2, and PT2), and 1% (MT1, ST1, and PT1) for the rest of the two weeks. The daily ration was divided into two meals and supplied at 9:00 a.m. and 4:00 p.m. The ration was adjusted at an interval of every ten days, according to Phan et al. [16,17]. The health and behavioral conditions of Nile Tilapia were examined regularly, especially after feeding in the morning and evening. Every ten days, the fish were sampled to measure their length and weight, and sampling continued until the harvest was completed. A digital balance (CAMRY digital electrical balance Model EK 3052, Guangdong, China) was used to determine the body weight (g). On the other hand, temperature; dissolved oxygen (DO); pH; ammonia; total dissolved solids (TDS); depth; and water transparency were measured using a thermometer; portable DO meter (Lutron D5510, Shanghai, China); pH meter (Hanna 981017, Woonsocket, RI, USA); ammonia testing kit; TDS meter; meter ruler; and Secchi disk, respectively, on the ten-day interval from horizontal reference locations (50 m away along the river bank and 50 m away to the middle course from the cage sites).

Table 1. Feed types and their nutritional composition.

Test Parameter	Production Cycle					
	March–July			July–November		
	Feed (Nursery)	Feed (Starter)	Feed (Grower)	Feed (Nursery)	Feed (Starter)	Feed (Grower)
Crude protein (%)	38.20	29.22	24.76	37.58	29.58	25.33
Fat (%)	3.50	4.39	3.68	3.69	4.33	3.57
Crude fiber (%)	10.80	8.88	11.13	11.06	9.21	7.96
Crude ash (%)	14.20	9.09	13.16	14.82	12.63	12.34
Moisture (%)	9.50	11.06	11.28	9.65	8.60	10.38
Non-protein nitrogen (%)	0.00	1.85	1.00	0.00	0.00	0.00

2.3. Growth Performance

The growth performance, yield, and survivability of Nile Tilapia were evaluated using the following growth equations that were proposed by Pechsiri and Yakupitiyage [16].

$$\%\text{Length Gain} = \frac{\text{Final Length (cm)} - \text{Initial Length (cm)}}{\text{Initial Length (cm)}} \times 100 \tag{1}$$

$$\%\text{Weight Gain} = \frac{\text{Final Weight (g)} - \text{Initial Weight (g)}}{\text{Initial Length (g)}} \times 100 \tag{2}$$

$$\text{Mean Length Gain (cm/fish)} = \text{Mean Final Length (cm)} - \text{Mean Initaial Length (cm)} \tag{3}$$

$$\text{Mean Weight Gain (g/fish)} = \text{Mean Final Body Weight(g)} - \text{Mean Initaial Body Weight} \tag{4}$$

$$\text{Specific Growth Rate (SGR; \%/day)} = \frac{\ln \text{Final Body Weight} - \ln \text{Initaial Body weigh}}{\text{Duration of Experiment}} \times 100 \tag{5}$$

$$\text{Average Daily Growth Rate (ADGR; g/day)} = \frac{\text{Final Body weight (g)} - \text{Initial Body Weight(G)}}{\text{Duration Of Experiment}} \tag{6}$$

$$\text{Feed Conversion Ratio (FCR)} = \frac{\text{Feed intake(g)}}{\text{weight gain (g)}} \tag{7}$$

$$\text{Survival Rate (SR; \%)} = \frac{\text{Final Number of Live fish}}{\text{Initial Number of Live fish stocked}} \times 100 \tag{8}$$

where ln is the natural logarithm.

The relative condition factor (Kn = w/W) is the ratio of a fish's observed weight (w) to the expected weight (W) of a fish of the same length, as determined by the length–weight regression [18]. The total length was measured to the nearest 0.1 cm and weighed separately with an accuracy of 0.01 g to estimate the length–weight relationship (LWR). The LWR was calculated using the equation $W = aL^{b}$ where W represents the weight of the fish in grams, L represents the length of the fish in centimeters, and 'a' and 'b' represent the intercept and slope of the regression line, respectively [19]. Parameter 'a' and 'b' was calculated by using a linear regression analysis based on natural logarithm:

$$\log W = \log a + b \log L$$

The equation is similar to the regression equation y = a + bx. Furthermore, according to Froese [19] guidelines, outliers were eliminated from log-log plots before regression analysis.

2.4. Economic Yield

According to Asaduzzaman et al. [20], the following simple equation was used to estimate the net return and benefit–cost ratio. The fish were sold live on-site at the prevailing market price at the end of the culture period. Feed costs, fingerling costs, and total money gained from fish sales were all calculated.

$$R = I - (FC + VC + Ii).$$

where R = net return; I = income from monosex Nile Tilapia sale; FC = fixed costs (fixed costs include the setting cost of the cages); VC = variable costs (variable costs include the cost of fish feed; other operational costs vary in each cycle); and Ii = interest on inputs (the interest on the total cost for each cycle if the money is borrowed from a bank or any other financial organization).

$$\text{Benefit-cost ratio (BCR)} = \text{total net return/total input cost.}$$

Moreover, the economic viability was analyzed using profitability indicators such as rate of return (ROI) and the Break-even point (BEP) on total cost and net profit.

The rate on return (ROI) = NI/TC, where NI = net income and TC = total cost.

The break-even point (BEP) = TFC/(SUP-VCUP), where TFC= total fixed cost; VCUP = variable cost per unit production, and SUP = selling price per unit production.

2.5. Business Feasibility

According to Izmaniar et al. [21], the feasibility of business is analyzed using four investment criteria, namely the payback period (PBP); net present value (NPV); net benefit–cost ratio (Net BCR); and internal rate of return (IRR) with the flowing Formulas:

$$\text{Payback Period (PBP)} = \frac{\text{Total Capital Invested}}{\text{Annual Cash Flow}} \tag{9}$$

$$\text{Net present value (NPV)} = \sum_{t=1}^{n} \frac{B_t - C_t}{(1+i)^t} \tag{10}$$

$$\text{Net Benefit Cost Ratio (Net BCR)} = \frac{\sum_{t=1}^{n} NPV^{+}}{\sum_{t=1}^{n} NPV^{-}} \tag{11}$$

$$\text{Internal Rate of return (IRR; \%)} = \mathrm{i}_1 + \frac{\mathrm{NPV}^+}{\mathrm{NPV}^+ - \mathrm{NPV}^-}\,(\mathrm{i}_2 - \mathrm{i}_1) \tag{12}$$

where B_t is the benefit of year-t, C_t is the cost of year-t, i is the interest rate, and t is the investment time. NPV^+ is the positive net present value and NPV^- is the negative net present value. If NPV is positive, then i_1 is the interest rate, and when NPV is negative, i_2 is the interest rate. Moreover, it is assumed that if NPV ≤ 0; Net BCR ≤ 1; and IRR$\leq$9%, the business will make it unreasonable. On the other hand, if NPV > 0; net BCR > 1; and IRR > 9%, it will ensure that the business is reasonably developed.

2.6. Statistical Analysis

The mean values for growth parameters, survival, yield, production, and water quality for each treatment in each experimental site were tested using a two-way analysis of variance (ANOVA), after verifying the homogeneity of variance using "Hartley's test" [22,23]. Before analyzing the survival rate, the percentage data were arcsine transformed. All analyses were performed using R, version 2021.09.2 Build 382 and SPSS v.28. A linear regression analysis of the length–weight parameters and business feasibility indicators was visualized using the R, version 2021.09.2 Build 382, and the tidyverse and ggplot2 packages, respectively. All the statistical tests were considered at a 5% significance level.

3. Results and Discussions

3.1. Water Quality Parameters

The pH, dissolved oxygen, temperature, and total dissolved solids were not significantly varied across the treatments, cage sites, and horizontal reference locations (50 m along the riverbank and 50 m to the middle course from the cage site) (Table 2). However, the ammonia levels did not fluctuate much during the post-monsoon season but did fluctuate during the monsoon season. In addition, all of the environmental factors were found to be within the acceptable range for Nile Tilapia culture reported by Devi et al. [24] in the Poondi reservoir and Karnatak et al. [18] in the Maithon reservoir. Furthermore, more favorable ecological niches were observed in rural areas, compared to urban and semi-urban areas along rivers. The water quality at cage sites is influenced by small-scale farming, the river's size and its upwelling, the cage's location, flushing, feed management, the availability of natural foods, and sources of water pollution [19]. Secchi depth (transparency) showed temporal fluctuation throughout the experiment. According to Lianthuamluaia et al. [25], water transparency might vary seasonally. The existence of biotic parameters such as plankton abundance and the absence of *E. coli* and fecal streptococci in the cage-culture site led the authors to conclude that small-scale cage farming did not adversely affect water bodies. However, the urban cage site had a slightly lower water quality than the rural cage site because of the rapid development of the urban economy, human settlements, and industrialization, putting pressure on the inland surface water bodies in urban areas [26]. In Lake Victoria, Kashindye et al. [27] reported inconsistent environmental changes resulting from the cage culture, while Neto et al. [28] made similar observations in various reservoirs in Brazil. The water quality of different treatments did not differ significantly, indicating that cage culture had no adverse impact on the river environment and instead has enormous potential. However, for long-term river ecosystem management, an environmental-impact assessment of cage culture on rivers with a significant number of cages, and an estimation of the carrying capacity for different fish species would be required [29].

Table 2. The water-quality parameters during the experimental period of cage culture of Nile Tilapia (*O. niloticus* L.).

Parameters	Production Cycle	Mojlishpur				Shitanagar				Paikpara			
		Cage Site	50 m Away (Horizontal)	50 m Away (Vertical)	*p* Value	Cage Site	50 m Away (Horizontal)	50 m Away (Vertical)	*p* Value	Cage Site	50 m Away (Horizontal)	50 m Away (Vertical)	*p* Value
Depth (m)	First cycle	9.45 ± 0.06 ^{a}	9.47 ± 0.08 ^{a}	11.65 ± 0.07 ^{b}	0.00	9.77 ± 0.05 ^{a}	9.79 ± 0.06 ^{a}	11.97 ± 0.07 ^{b}	0.00	9.41 ± 0.07 ^{a}	9.40 ± 0.09 ^{a}	12.15 ± 0.07 ^{b}	0.00
	Second cycle	9.73 ± 0.02 ^{a}	9.74 ± 0.03 ^{a}	13.56 ± 0.03 ^{b}	0.00	10.05 ± 0.0 ^{a}	10.05 ± 0.03 ^{a}	13.87 ± 0.02 ^{b}	0.00	10.25 ± 0.03 ^{a}	10.26 ± 0.04 ^{a}	14.06 ± 0.03 ^{b}	0.00
Transparency (cm)	First cycle	31.72 ± 0.13 ^{a}	31.74 ± 0.16 ^{a}	32.94 ± 0.13 ^{b}	0.00	31.67 ± 0.13 ^{a}	31.69 ± 0.16 ^{a}	32.82 ± 0.13 ^{b}	0.00	31.62 ± 0.13 ^{a}	31.64 ± 0.16 ^{a}	32.75 ± 0.13 ^{b}	0.00
	Second cycle	32.38 ± 0.09 ^{a}	32.40 ± 0.09 ^{a}	33.47 ± 0.07 ^{b}	0.00	32.30 ± 0.07 ^{a}	32.30 ± 0.09 ^{a}	33.41 ± 0.07 ^{b}	0.00	32.25 ± 0.07 ^{a}	32.25 ± 0.09 ^{a}	33.35 ± 0.07 ^{b}	0.00
Water temperature (°C)	First cycle	29.43 ± 0.31	29.42 ± 0.39	29.41 ± 0.31	1.00	29.42 ± 0.32	29.42 ± 0.39	29.40 ± 0.32	1.00	29.47 ± 0.32	29.48 ± 0.39	29.47 ± 0.32	1.00
	Second cycle	27.87 ± 0.13	27.81 ± 0.16	27.80 ± 0.13	0.92	27.90 ± 0.13	27.95 ± 0.16	27.85 ± 0.13	0.94	27.94 ± 0.12	27.89 ± 0.15	27.89 ± 0.12	0.96
pH	First cycle	7.64 ± 0.02	7.66 ± 0.03	7.70 ± 0.02	0.20	7.59 ± 0.02	7.62 ± 0.02	7.64 ± 0.02	0.19	7.57 ± 0.02	7.59 ± 0.02	7.60 ± 0.02	0.27
	Second cycle	7.82 ± 0.03	7.83 ± 0.03	7.81 ± 0.03	0.88	7.81 ± 0.02	7.83 ± 0.04	7.86 ± 0.03	0.49	7.77 ± 0.03	7.80 ± 0.04	7.81 ± 0.03	0.70
Dissolved Oxygen (mg/L)	First cycle	5.97 ± 0.12	6.00 ± 0.15	6.03 ± 0.12	0.92	5.94 ± 0.12	5.97 ± 0.15	6.05 ± 0.12	0.81	5.88 ± 0.12	5.95 ± 0.15	6.01 ± 0.13	0.77
	Second cycle	6.48 ± 0.08	6.49 ± 0.10	6.51 ± 0.08	0.95	6.45 ± 0.08	6.46 ± 0.09	6.49 ± 0.08	0.93	6.43 ± 0.08	6.45 ± 0.09	6.48 ± 0.08	0.92
Total Dissolved Solids (mg/L)	First cycle	272.16 ± 6.52	270.41 ± 8.02	268.17 ± 6.75	0.91	275.60 ± 6.35	273.22 ± 7.79	270.88 ± 6.32	0.87	277.36 ± 6.25	275.51 ± 7.67	274.21 ± 6.18	0.93
	Second cycle	237.37 ± 3.77	235.76 ± 4.63	270.88 ± 6.32	0.88	240.15 ± 3.96	238.95 ± 4.88	238.12 ± 3.94	0.94	242.99 ± 3.94	241.27 ± 4.80	239.76 ± 3.91	0.84
Ammonia (mg/L)	First cycle	0.07 ± 0.004 ^{a}	0.06 ± 0.003 ^{a}	0.04 ± 0.002 ^{b}	0.00	0.08 ± 0.004 ^{a}	0.07 ± 0.003 ^{a}	0.04 ± 0.001 ^{b}	0.00	0.09 ± 0.003 ^{a}	0.07 ± 0.003 ^{a}	0.04 ± 0.002 ^{b}	0.00
	Second cycle	0.15 ± 0.010	0.15 ± 0.013	0.14 ± 0.011	0.81	0.17 ± 0.011	0.16 ± 0.014	0.16 ± 0.012	0.69	0.18 ± 0.012	0.17 ± 0.016	0.16 ± 0.013	0.51

Values are means ± SE. The *p* values indicate insignificant ($p > 0.05$) statistical difference at 95% confidence interval. Mean values in the same row different superscript letters differ significantly.

3.2. Growth Performance and Yield

The growth performance at both production cycles with respect to the mean length gain; % length gain; mean weight gain; ADGR (Average daily growth rate); FCR (feed conversion rato); survival rate; and production was significantly affected ($p < 0.05$) by the stocking of different fish sizes (Tables 3 and 4). However, the percent of weight gain and the specific growth rate in both cycles' other growth parameters are also affected by cage sites (Tables 3 and 4). The interaction between cage sites and fish size has a significant effect on the final fish length and weight gain. Moreover, the growth rate of Nile Tilapia with larger-sized stocks had a higher growth performance than those with smaller stocks. On the contrary, stocking smaller-sized fish increased the percentage of weight gain and the specific growth rate in all sites and culture cycles. However, fish production was significantly higher in the rural cage site (Mojlishpur) than the others and had a higher production rate in the first cycle than in the second cycle (Table 4). This might be due to the larger size of the fish and a higher survival rate. At the same time, the quality of water in rural areas was within the optimum range with minimal water-pollution sources. Moreover, the onset of winter was also observed in the second cycle, showing less productivity with the simultaneous interaction of cage sites and fish size. Nile Tilapia (*O. niloticus*) growth depends on stocking density, food quality, the diet's energy content, physiological status, reproductive state, and environmental factors [30]. Ahmed et al. [31] measured a daily weight gain of 1.45–1.98 g in cages feeding commercial pellet feed with probiotics on the Dakatia River, which is one-third of the current study with larger-sized fish. This was due to the stocking size and environmental conditions in the treatments. The SGR (Specific growth rate) values are inconsistent with those that were observed by Asase et al. [32]; Gibtan et al. [11]; and Ridha [33], who reported that SGR decreased with the increasing stocking density of Nile Tilapia. Ahmed et al. [31], with larger-sized fish stock in cage culture in Dakatia River, Chandpur, Bangladesh, found a slightly higher (95.76 to 97.54%) survival rate than the overall survival rate in different seasons and sites in the present study. As a result, the larger-sized fish that are stocked in the cage, the lower the mortality. The FCR of different stocking in the present study was lower than that of 1.046 to 1.25 and 1.81 to 2.05 for monosex Nile Tilapia in cage culture, respectively, as reported by Kunda et al. [34] and Moniruzzaman [35]. This may be due to comparatively better natural feed availability and optimum environmental inputs in the Titas River. The FCR of the present study agrees with those that were obtained by Ouattara et al. [36]; Liti et al. [37]; Bolivar et al. [38]; Ridha [33]; Gibtan et al. [11]; and Asase et al. [32], who reported that FCR increased with increasing stocking densities. This study's considerable variations in FCR for different sites and culture cycles might be due to variations in fish size and age, the availability of natural food quality, hygiene, and environmental conditions. Ahmed et al. [31] found a 9.93 to 11.63 kg m^{-3} yield with 33.66 ± 6.23 g weight and 50 fish/m^3 density in cages of Dakatia River, Bangladesh, which is lower than the yield of MT1, ST1, and PT1 of the present study. As a result, it is significantly crucial to stock larger-sized fish, and the fish yield depends on several factors, such as cage sizes, the initial weight of fry, the quality of fish fry, stocking density, feed availability and quality, seasonal variation, and the position of the cage site.

Table 3. Growth parameters of Nile Tilapia (*O. niloticus* L.) under cage-culture system in Titas River of Bangladesh with different stocking densities in the first cycle (March–July).

Cage Site	Fish Size	Mean Initial Length (cm)	Mean Final Length (cm)	Mean Length Gain (cm)	% Length Gain	Mean Initial Weight (gm)	Mean Final Weight (gm)	Mean Weight Gain (gm)	% Weight Gain	SGR % Day	Average Daily Growth Rate (ADGR)	FCR	Survival Rate (%)	The Relative Condition Factor	Production (kg/Cage/120 Days)
Mojlishpur	MT1	11.83 ± 0.05 ^{a}	29.92 ± 0.06 ^{b}	18.09 ± 0.10 ^{b}	152.86 ± 1.43 ^{c}	34.71 ± 0.29 ^{a}	689.00 ± 1.58 ^{a}	654.29 ± 1.85 ^{a}	1885.31 ± 21.06 ^{c}	2.49 ± 0.01c	5.45 ± 0.02 ^{a}	0.88 ± 0.00 ^{i}	97.00 ± 0.42 ^{a}	1.01 ± 0.01	334.17 ± 1.67 ^{a}
	MT2	8.39 ± 0.16 ^{b}	25.58 ± 0.08 ^{f}	17.18 ± 0.10 ^{h}	204.87 ± 4.98 ^{b}	11.11 ± 0.31 ^{b}	449.33 ± 2.80 ^{d}	438.22 ± 3.10 ^{d}	3951.98 ± 141.66b	3.08 ± 0.03 ^{b}	3.65 ± 0.03 ^{d}	0.93 ± 0.01 ^{g}	91.07 ± 0.29 ^{d}	1.01 ± 0.01	204.59 ± 0.64 ^{d}
	MT3	6.36 ± 0.06 ^{c}	23.13 ± 0.08 ^{i}	16.78 ± 0.14 ^{i}	264.08 ± 4.80 ^{a}	5.52 ± 0.09 ^{c}	299.67 ± 0.33 ^{g}	294.14 ± 0.42 ^{g}	5329.52 ± 91.95a	3.33 ± 0.01 ^{a}	2.45 ± 0.00 ^{g}	1.03 ± 0.01 ^{d}	86.20 ± 0.61 ^{g}	1.02 ± 0.02	129.16 ± 0.88 ^{g}
Shitanagar	ST1	11.61 ± 0.13 ^{a}	29.98 ± 0.03 ^{a}	18.38 ± 0.16 ^{a}	158.42 ± 3.12 ^{c}	34.21 ± 0.41 ^{a}	680.89 ± 1.06 ^{b}	646.68 ± 1.41 ^{b}	1890.88 ± 26.54c	2.49 ± 0.01 ^{c}	5.39 ± 0.01 ^{b}	0.91 ± 0.01 ^{h}	93.80 ± 0.69 ^{b}	1.01 ± 0.01	319.34 ± 2.63 ^{b}
	ST2	8.81 ± 0.09 ^{b}	26.22 ± 0.04 ^{e}	17.41 ± 0.05 ^{f}	197.65 ± 2.50 ^{b}	11.02 ± 0.16 ^{b}	441.33 ± 2.03 ^{e}	430.31 ± 1.93 ^{e}	3905.28 ± 45.92b	3.08 ± 0.01 ^{b}	3.59 ± 0.02 ^{e}	1.00 ± 0.01 ^{e}	89.07 ± 0.41 ^{e}	1.03 ± 0.02	196.54 ± 1.56 ^{e}
	ST3	6.47 ± 0.05 ^{c}	23.83 ± 0.10 ^{h}	17.36 ± 0.06 ^{g}	268.27 ± 2.00 ^{a}	5.48 ± 0.04 ^{c}	291.22 ± 3.36 ^{h}	285.74 ± 3.33 ^{h}	5216.22 ± 33.29a	3.31 ± 0.01 ^{a}	2.38 ± 0.03 ^{h}	1.07 ± 0.01 ^{c}	83.07 ± 0.37 ^{h}	1.03 ± 0.03	120.95 ± 1.29 ^{i}
Paikpara	PT1	11.47 ± 0.12 ^{a}	29.54 ± 0.07 ^{c}	18.08 ± 0.10 ^{c}	157.68 ± 2.52 ^{c}	34.37 ± 0.20 ^{a}	675.78 ± 3.07 ^{c}	641.41 ± 3.26 ^{c}	1866.61 ± 20.18c	2.48 ± 0.01 ^{c}	5.35 ± 0.03 ^{c}	0.93 ± 0.01 ^{f}	92.87 ± 1.04 ^{c}	1.01 ± 0.01	313.81 ± 4.58 ^{c}
	PT2	9.00 ± 0.05 ^{b}	26.83 ± 0.05 ^{d}	17.83 ± 0.10 ^{d}	198.17 ± 2.20 ^{b}	11.21 ± 0.11 ^{b}	429.22 ± 3.13 ^{f}	418.01 ± 3.24 ^{f}	3729.84 ± 65.15b	3.04 ± 0.01 ^{b}	3.48 ± 0.03 ^{f}	1.07 ± 0.01 ^{b}	86.80 ± 0.53 ^{f}	1.02 ± 0.02	186.30 ± 2.42 ^{f}
	PT3	6.36 ± 0.09 ^{c}	24.01 ± 0.05 ^{g}	17.66 ± 0.06 ^{e}	277.93 ± 4.82 ^{a}	5.39 ± 0.16 ^{c}	290.22 ± 2.15 ^{i}	284.83 ± 2.03 ^{i}	5292.78 ± 126.69a	3.32 ± 0.02 ^{a}	2.37 ± 0.02 ^{i}	1.11 ± 0.03 ^{a}	82.87 ± 1.27 ^{i}	1.03 ± 0.02	120.27 ± 2.70 ^{h}
Two-way ANOVA (*p* value)															
Site		0.482	0.000	0.000	0.34	0.405	0.000	0.000	0.360	0.262	0.000	0.000	0.000	0.854	0.000
Size		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.378	0.000
Site X Size		0.001	0.000	0.002	0.064	0.656	0.025	0.186	0.482	0.478	0.189	0.027	0.656	0.971	0.098

Note- SGR: Specific growth rate, FCR: Feed conversion ratio; a, b, c used in the table to show significant difference. Different letters indicates significant variation.

Table 4. Growth parameters of Nile Tilapia (*Oreochromis niloticus* L.) under cage-culture system in Titas River of Bangladesh with different stocking densities in the second cycle (July–November).

Cage Site	Fish Size	Mean Initial Length (cm)	Mean Final Length (cm)	Mean Length Gain (cm)	% Length Gain	Mean Initial Weight (gm)	Mean Final Weight (gm)	Mean Weight Gain (gm)	% Weight Gain	SGR % Day	Average Daily Growth Rate (ADGR)	FCR	Survival Rate (%)	The Relative Condition Factor	Production (kg/Cage/120 Days)
Mojlishpur	MT1	11.69 ± 0.07 ^{a}	29.84 ± 0.02 ^{a}	18.15 ± 0.08 ^{a}	155.29 ± 1.60 ^{g}	34.39 ± 0.10 ^{a}	690.00 ± 1.50 ^{a}	655.61 ± 1.49 ^{a}	1906.49 ± 6.52 ^{c}	2.50 ± 0.00 ^{c}	5.46 ± 0.01 ^{a}	0.89 ± 0.00 ^{i}	96.20 ± 0.23 ^{a}	1.01 ± 0.01	331.89 ± 0.35 ^{a}
	MT2	8.96 ± 0.02 ^{b}	24.76 ± 0.06 ^{f}	15.80 ± 0.05 ^{i}	176.43 ± 0.59 ^{f}	11.14 ± 0.06 ^{b}	447.56 ± 0.78 ^{d}	436.41 ± 0.79 ^{d}	3916.19 ± 23.64 ^{b}	3.08 ± 0.00 ^{b}	3.64 ± 0.01 ^{d}	0.98 ± 0.01 ^{f}	89.53 ± 0.48 ^{d}	1.01 ± 0.01	200.36 ± 1.41 ^{d}
	MT3	6.34 ± 0.02 ^{c}	23.01 ± 0.03 ^{i}	16.66 ± 0.04 ^{h}	262.62 ± 1.41 ^{c}	5.48 ± 0.09 ^{c}	297.33 ± 0.51 ^{g}	291.86 ± 0.48 ^{g}	5331.07 ± 89.07 ^{a}	3.33 ± 0.01 ^{a}	2.43 ± 0.00 ^{g}	1.02 ± 0.01 ^{e}	84.67 ± 0.52 ^{g}	1.03 ± 0.03	125.87 ± 0.86 ^{g}
Shitanagar	ST1	11.59 ± 0.14 ^{a}	29.26 ± 0.17 ^{b}	17.67 ± 0.21 ^{c}	152.61 ± 3.31 ^{h}	34.14 ± 0.44 ^{a}	674.33 ± 3.20 ^{b}	640.19 ± 3.63 ^{b}	1875.85 ± 35.12 ^{c}	2.49 ± 0.01 ^{c}	5.33 ± 0.03 ^{b}	0.92 ± 0.02 ^{h}	94.27 ± 0.75 ^{b}	1.03 ± 0.02	317.86 ± 4.00 ^{b}
	ST2	8.93 ± 0.07 ^{b}	26.07 ± 0.10 ^{e}	17.14 ± 0.16 ^{f}	192.02 ± 3.13 ^{e}	11.09 ± 0.09 ^{b}	434.44 ± 2.19 ^{e}	423.36 ± 2.27 ^{e}	3818.62 ± 50.32 ^{b}	3.06 ± 0.01 ^{b}	3.53 ± 0.02 ^{e}	1.04 ± 0.01 ^{d}	88.20 ± 0.83 ^{e}	1.04 ± 0.03	191.59 ± 2.03 ^{e}
	ST3	6.42 ± 0.05 ^{c}	23.38 ± 0.09 ^{h}	16.96 ± 0.10 ^{g}	264.14 ± 3.00 ^{b}	5.39 ± 0.08 ^{c}	286.22 ± 3.08 ^{i}	280.83 ± 3.08 ^{i}	5213.53 ± 94.37 ^{a}	3.31 ± 0.01 ^{a}	2.34 ± 0.03 ^{c}	1.08 ± 0.01 ^{c}	83.00 ± 0.83 ^{i}	1.04 ± 0.03	118.79 ± 1.94 ^{h}
Paikpara	PT1	11.55 ± 0.10 ^{a}	28.85 ± 0.10 ^{c}	17.30 ± 0.16 ^{e}	149.82 ± 2.51 ^{i}	34.24 ± 0.25 ^{a}	673.56 ± 3.04 ^{c}	639.31 ± 3.21 ^{c}	1867.19 ± 20.87 ^{c}	2.48 ± 0.01 ^{c}	5.33 ± 0.03 ^{i}	0.95 ± 0.01 ^{g}	90.73 ± 1.19 ^{c}	1.01 ± 0.02	305.61 ± 5.38 ^{c}
	PT2	8.95 ± 0.02 ^{b}	26.87 ± 0.07 ^{d}	17.92 ± 0.08 ^{b}	200.19 ± 1.18 ^{d}	11.17 ± 0.08 ^{b}	426.56 ± 2.23 ^{f}	415.38 ± 2.23 ^{f}	3718.40 ± 33.15 ^{b}	3.04 ± 0.01 ^{b}	3.46 ± 0.02 ^{f}	1.11 ± 0.01 ^{b}	83.67 ± 0.35 ^{h}	1.01 ± 0.02	178.45 ± 1.61 ^{f}
	PT3	6.39 ± 0.13 ^{c}	24.02 ± 0.09 ^{g}	17.63 ± 0.19 ^{d}	276.24 ± 8.24 ^{a}	5.41 ± 0.14 ^{c}	289.44 ± 3.89 ^{h}	284.03 ± 3.87 ^{h}	5255.31 ± 144.36 ^{a}	3.32 ± 0.02 ^{a}	2.37 ± 0.03 ^{h}	1.13 ± 0.02 ^{a}	80.87 ± 1.57 ^{b}	1.04 ± 0.03	117.01 ± 2.38 ^{i}
Two-way ANOVA (*p* value)															
Site		0.901	0.000	0.000	0.006	0.696	0.000	0.000	0.183	0.086	0.000	0.000	0.000	0.38	0.000
Size		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.438	0.000
Site X site		0.822	0.000	0.000	0.007	0.984	0.011	0.138	0.745	0.640	0.167	0.161	0.645	0.958	0.039

Note- SGR: Specific growth rate, FCR: Feed conversion ratio; a, b, c used in the table to show significant difference. Different letters indicates significant variation.

The relative condition factor of fish in this study had no significant difference ($p > 0.05$) due to the stocking of different fish sizes (Tables 3 and 4). The condition factor is a quantitative metric that determines how healthy a fish population is [39]. The mean relative condition factor (Kn) values of *O. niloticus* in this study were above the average condition of 1.0. This suggests that the fish were in good condition [40,41]. Feeding and food availability influence the fish's physiological differences because food reserves that are accumulated through feeding increase the fish condition factor [42]. The higher condition factor that was observed in the treatments could result from the fish utilizing their food for somatic growth, followed by their most significant weight gain. Except for MT1 (3.10 and 3.19) and MT2 (3.16 and 3.49 in the second cycle), and ST1 (3.17), all the treatments of the present study exhibited negative allometry ($b < 3.0$) (Figure 2). Moreover, the R^2 values in all the treatments exceeded 0.90, so the length–weight relationship revealed that Nile Tilapia in the cage followed the cube law. Furthermore, the weight increased at a rate of the cube of the length in the cage-culture system with larger-sized fish. However, the "b" values that were recorded for Nile Tilapia in the present study were in the range of 2.299 and 3.684 in the Atbara River and Khashm El-Girba reservoir, respectively [43]. It is presumed that the value may change depending on the fullness of the stomach, general appetite, maturity, seasons, stocking density, environmental factors, and even days [44,45]. Therefore, the stocking size and number, fish size, water quality, natural feed availability, and seasonal variation significantly varied the fish growth performance.

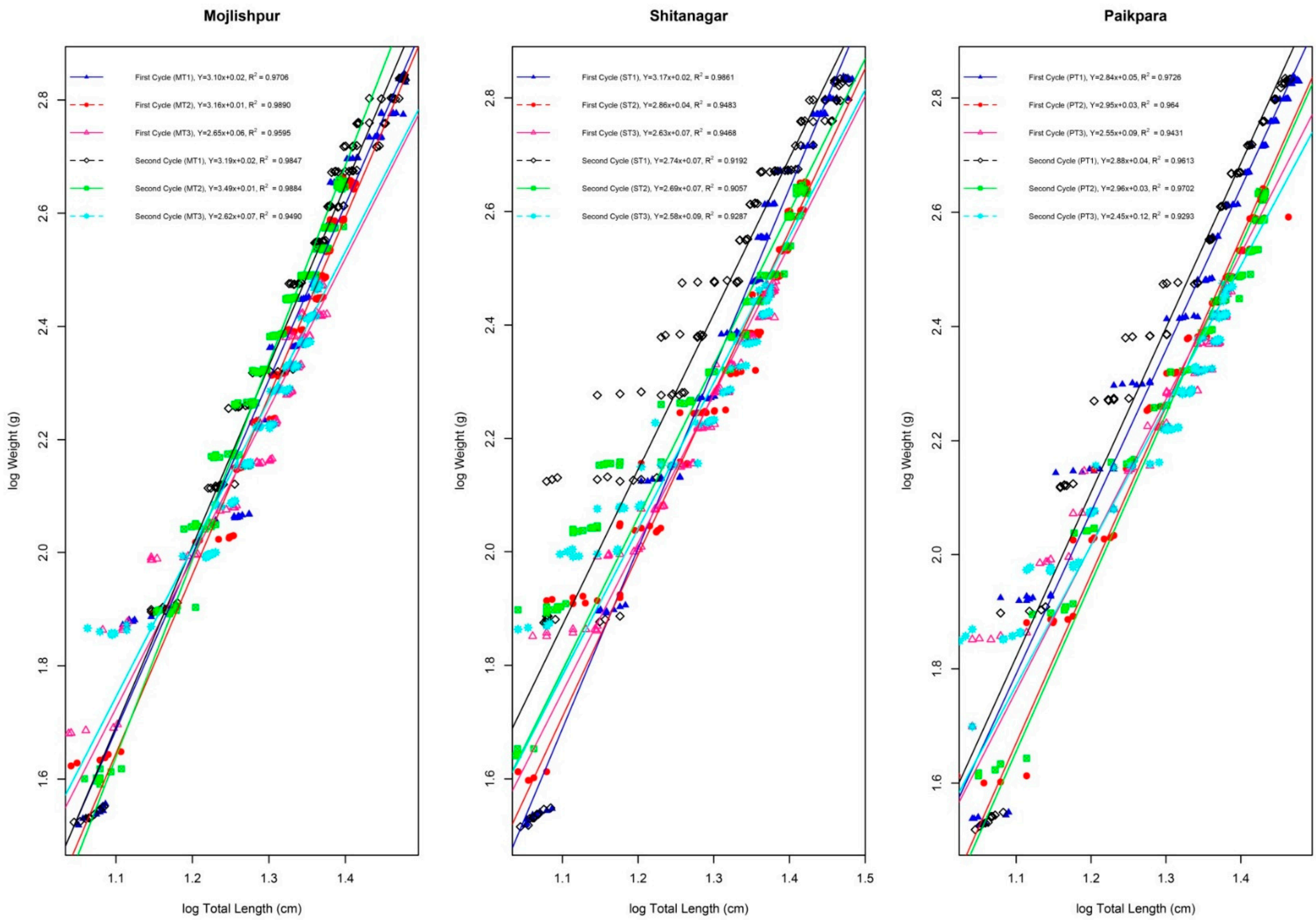

Figure 2. Linear regression analysis between data of various length–weight parameters of Nile Tilapia (*O. niloticus* L.) from cages culture.

3.3. Economic and Business Feasibility Analyses

Stocking larger sizes of Nile Tilapia and geographical location influenced production economics in the present study. Total variable cost, total cost, and gross return were significantly different among the treatments (Tables 5 and 6). The depreciation cost for each treatment was calculated as Bangladeshi Taka (BDT) 1619.52/cage. The net return (profit) in MT1 (BDT 13,191.97); ST1 (BDT 12,218.23); and PT1 (BDT 11,516.22) were significantly higher than all other treatments in the first cycle (Table 7). A similar net return (profit) pattern was observed in the second culture cycle. Although MT1, ST1, and PT1 had the highest total variable cost and total cost, the lowest payback period (PBP) value (less than 1) was obtained from MT1 in both production cycles (Table 7), demonstrating that the investment capital can be recovered after only one crop yield. After the second crop collection from the rural culture site (Mojlishpur) along the river, the business will receive income. On the other hand, ST1 and PT1 in the remaining cage sites must incur earnings after two crops. The rest of the treatments yielded negative payback periods, showing the economic loss of the culture of Nile Tilapia with small-sized fish stock. The production economics were mainly affected by the cost of feed and fingerlings, irrespective of the stocking densities, and accounted for about 70–80% of the total production cost. These prime factors affect profitability in cage farming [35] and the lowest stocking density with larger-sized fish, probably due to high survival and better growth rates [46].

Through an economic analysis, MT1, ST1, and PT1 in both culture cycles had the best NPV, IRR, BCR, and ROI values with the highest economic return due to preferred market size, low mortality, and maximum biomass production. In addition, the lowest financial return was found in T3, possibly due to inappropriate stocking size and the lowest selling price of monosex Nile Tilapia (Figure 3). The NPV values in Mojlishpur were investigated at 4% and 9% of the interest rates, which were BDT 12,0518.02 and BDT 10,5019.79, respectively (Figure 3), for MT1, followed by MT2 and MT3, indicating that the business was feasible with larger-sized fish stocking. The final evaluation revealed that the IRR value obtained for five years of investment in MT1 was above 100% for both 4% and 9% at the first culture cycle. This means that larger-sized fish stocks in cages provided 100% financial growth per crop yield. The rate of return (ROI) was significantly different ($p < 0.05$) and higher at the larger-sized fish stockings (MT1 for both 4% and 9% in both culture cycles) than at the lower stocking sizes (MT2, MT3). The urban and opposite-to-urban site cages followed a similar ROI to the rural site cages. The benefit–cost ratio (BCR) was 10.05, 1.44, and 1.69 in MT1, MT2, and MT3, respectively, in the first cycle. The second culture cycle provided almost similar results, and other sites followed the pattern of Mojlishpur. Similarly, for the result of the break-even point, in comparison to smaller-sized fish treatments, larger-sized fish showed significantly lower values, meaning that culture with larger-sized fish would earn a profit in the first crop after returning the investment (Table 7). Several factors affecting the feasibility of the fish culture business were production capacity, selling price, target species, feed-conversion ratio (FCR), fixed cost, and variable cost [47–49]. Additionally, Febrianty et al. [50] mentioned that business feasibility is also influenced by investment ability and management, while Sofia and Nurlianti [51] stated that it is affected by capital efficiency and operational costs. Furthermore, target species influence selling and price-related business feasibility [49]. However, it is not only the selling price, as target species are also related to the suitability of the culture area and market demand. With a larger size, Nile Tilapia had a massive demand in the market in the study area, showing that Nile Tilapia in cage culture in Titas River is feasible and has tremendous potential for sustainable aquaculture business.

Table 5. Investment cost (BDT) and fixed cost (BDT) of Nile Tilapia (*O. niloticus* L.) culture for 120 days under cage-culture system.

Cost Items	Unit	Price per unit	Total Price	Economic Life (year)	Depreciation Cost
Investment cost					
Cage net [(20 × 10 × 6) feet]	27	1800	48,600	5	9720
Plastic barrel (number)	60	1000	60,000	10	6000
Gi pipe for frame (1-inch diameter) (feet)	1944	55	106,920	10	10,692
Frame connecting angel (feet)	189	100	18,900	10	1890
Anchor (each 15 kg) (number)	15	1350	20,250	10	2025
Nylon rope (bundle)	3	4000	12,000	5	2400
Bamboo (number)	54	350	18,900	5	3780
Boat (number)	3	12,000	36,000	10	3600
Plastic bucket-cover 20 L	3	120	360	3	120
Scoop nets	3	1000	3000	3	1000
Testing kit	1	5000	5000	2	2500
Total investment cost			329,930		
The total investment cost for each treatment			109,976.667		
Fixed cost					
Total investment depreciation					43,727
Total investment depreciation for each treatment					14,575.66667

Table 6. Variable cost (BDT) of Nile Tilapia (*O. niloticus* L.) culture for 120 days under cage-culture system.

Cost Items	Production Cycle	Mojlishpur			Shitanagar			Paikpara Station		
		MT1	MT2	MT3	ST1	ST2	ST3	PT1	PT2	PT3
Fish seed (33.85–34.06 g)	First cycle	2500.00			2500.00			2500.00		
	Second cycle	2500.00			2500.00			2500.00		
Fish seed (10.91–10.98 g)	First cycle		1500.00			1500.00			1500.00	
	Second cycle		1500.00			1500.00			1500.00	
Fish seed (5.38–5.43 g)	First cycle			1000.00			1000.00			1000.00
	Second cycle			1000.00			1000.00			1000.00
Feed (nursery)	First cycle		796.61	745.21		803.84	757.09		810.33	719.33
	Second cycle		768.67	701.55		816.34	710.54		791.52	690.08
Feed (starter-1, 2, 3)	First cycle	8484.65	6391.96	6159.28	8227.80	6692.61	5953.02	8526.10	6782.40	6211.80
	Second cycle	8607.08	6754.41	5922.06	8177.40	6821.86	5959.10	8378.26	6728.16	6193.80
Feed (grower-1, 2)	First cycle	6546.11	2864.18		6603.30	2860.49		6367.83	2956.80	
	Second cycle	6462.35	2893.79		6753.60	2903.58		6483.87	2907.72	
Transportation	First cycle	3000.00	3000.00	3000.00	2500.00	2500.00	2500.00	2500.00	2500.00	2500.00
	Second cycle	3000.00	3000.00	3000.00	2500.00	2500.00	2500.00	2500.00	2500.00	2500.00
Total variable cost without labor wage	First cycle	20,530.77	14,552.75	10,904.49	19,831.10	14,356.95	10,210.11	19,893.93	14,549.53	10,431.13
	Second cycle	20,569.42	14,916.86	10,623.61	19,931.00	14,541.78	10,169.65	19,862.13	14,427.40	10,383.88
Labor wage (share profit system)	First cycle	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00
	Second cycle	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00
Total variable cost with labor wage	First cycle	22,530.77	16,552.75	12,904.49	21,831.10	16,356.95	12,210.11	21,893.93	16,549.53	12,431.13
	Second cycle	22,569.42	16,916.86	12,623.61	21,931.00	16,541.78	12,169.65	21,862.13	16,427.40	12,383.88

Table 7. Revenue return (BDT) and economic feasibility of Nile Tilapia (*O. niloticus* L.) culture for 120 days under cage-culture system.

Production Cycle	Stations	Treatments	Production (kg/cage)	Unit Price (BDT/kg)	Total Revenue (BDT)	Total Variable Cost (BDT)	Fixed Cost as Depreciation (BDT)	Total Cost (BDT)	Total Income as Profit (BDT)	Interest of Bank Loan as Investment (9%) (BDT)	Net Income (BDT)	Payback Period (PBP) (No Unit)	Break-Even Point (No Unit)
First cycle (March–July)	Mojlishpur	MT1	334.17	115.00	38,429.03	22,530.77	1619.52	24,150.29	14,278.74	1086.76	13,191.97	0.93	0.77
		MT2	204.59	95.00	19,435.90	16,552.75	1619.52	18,172.26	1263.64	817.75	445.89	27.41	4.24
		MT3	129.16	85.00	10,978.23	12,904.49	1619.52	14,524.01	−3545.78	653.58	−4199.36	−2.91	−6.34
	Shitanagar	ST1	319.34	115.00	36,724.13	21,831.10	1619.52	23,450.62	13,273.51	1055.28	12,218.23	1.00	0.82
		ST2	196.54	95.00	18,671.73	16,356.95	1619.52	17,976.46	695.27	808.94	−113.67	−107.50	5.28
		ST3	120.95	85.00	10,280.71	12,210.11	1619.52	13,829.63	−3548.92	622.33	−4171.25	−2.93	−6.33
	Paikpara	PT1	313.81	115.00	36,087.77	21,893.93	1619.52	23,513.45	12,574.32	1058.11	11,516.22	1.06	0.86
		PT2	186.30	95.00	17,698.25	16,549.53	1619.52	18,169.05	−470.81	817.61	−1288.41	−9.48	10.64
		PT3	120.27	85.00	10,223.37	12,431.13	1619.52	14,050.65	−3827.29	632.28	−4459.57	−2.74	−5.53
Second cycle (July–November)	Mojlishpur	MT1	331.89	110.00	36,507.56	22,569.42	1619.52	24,188.94	12,318.62	1088.50	11,230.11	1.09	0.88
		MT2	200.36	90.00	18,032.34	16,916.86	1619.52	18,536.38	−504.04	834.14	−1338.18	−9.13	10.95
		MT3	125.87	80.00	10,069.74	12,623.61	1619.52	14,243.13	−4173.38	640.94	−4814.33	−2.54	−4.78
	Shitanagar	ST1	317.86	110.00	34,964.44	21,931.00	1619.52	23,550.52	11,413.92	1059.77	10,354.15	1.18	0.94
		ST2	191.59	90.00	17,243.06	16,541.78	1619.52	18,161.30	−918.24	817.26	−1735.49	−7.04	17.42
		ST3	118.79	80.00	9503.08	12,169.65	1619.52	13,789.17	−4286.09	620.51	−4906.60	−2.49	−4.58
	Paikpara	PT1	305.61	110.00	33,616.64	21,862.13	1619.52	23,481.65	10,134.99	1056.67	9078.32	1.35	1.04
		PT2	178.45	90.00	16,060.39	16,427.40	1619.52	18,046.92	−1986.53	812.11	−2798.64	−4.37	−33.29
		PT3	117.01	80.00	9361.11	12,383.88	1619.52	14,003.40	−4642.29	630.15	−5272.44	−2.32	−4.04

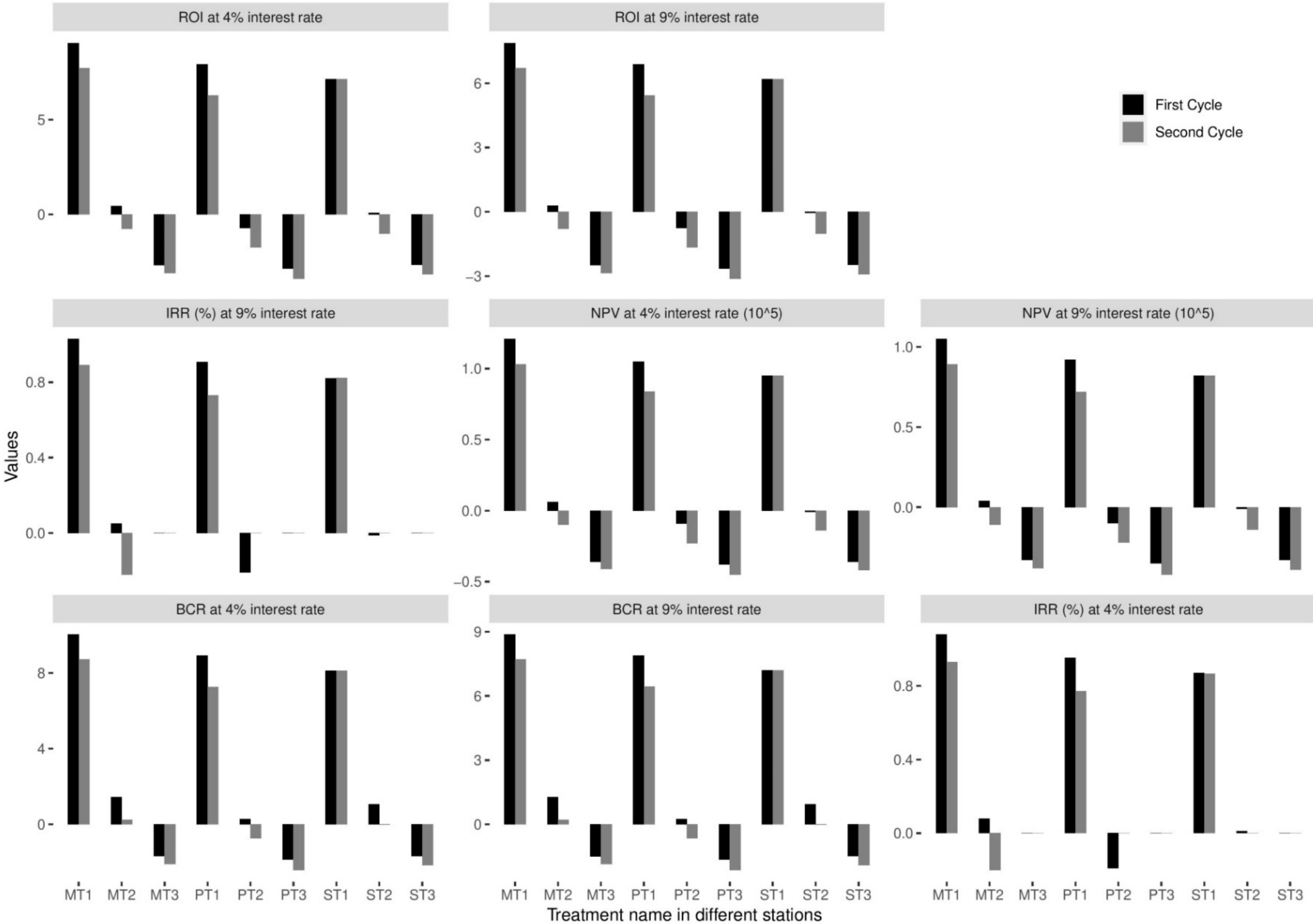

Figure 3. Net benefit–cost ratio (Net BCR); investment rate of return (IRR); net present value (NPV); and return on investments (ROI) after five-year run of cage-culture business of Nile Tilapia (*O. niloticus* L.) in Titas River.

4. Conclusions

The research shows that stocking cages with larger Nile Tilapia produces the optimum growth and survival rates. This shows that *O. niloticus* growth and survival in cages is size dependent. In terms of survival rate, growth, fish output, and economic return, a Nile Tilapia stocking size of 34.14–34.71 g is the best of the three treatments. Therefore, these stocking sizes of fish can be suggested to follow in Nile Tilapia cage farming in open water bodies, in order to increase fish production with a high economic return. The water-quality parameters in the farming area on the Titas River are still within permissible levels for the growth of *O. niloticus* in cages. The difficulty of achieving sustainability of small-scale aquaculture, especially cage culture due to climate change effects and shorter periods of culture, can be minimized, and sustainability significantly adopted by stocking larger-sized fish.

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