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The Impact of Stocking Density on the Growth Performance, Survival, and Physiological Stress of Striped Eel Catfish (*Plotosus lineatus*) Cultivated in Floating Net Cages

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ABSTRACT

Plotosus lineatus is a species of marine catfish that has potential for aquaculture development. However, the influence of stocking density on its growth performance, survival, and physiological stress in floating net cage culture has not been fully explored yet. This study evaluated the effects of different stocking densities on the growth, survival, and blood glucose levels of *P. lineatus* cultured in floating net cages. The experiment was carried out for a period of 90 days in a completely randomized design with three different fish stocking densities (25, 38, and 50 fish/m²) and three replications each. The criteria measured were absolute length growth, absolute weight growth, specific growth rate, survival rate, and blood glucose level as a sign of physiological stress. The results indicated that up to 50 fish/m² stocking density had no significant effect on the growth performance and survival rate ($p > 0.05$). The absolute weight gain was 8.74 ± 1.56 to 9.53 ± 1.20 g. Blood glucose levels were increased significantly from 44.7 ± 2.09 mg/dL at 25 fish/m^2 to 60.3 ± 6.43 mg/dL at 50 fish/m ($p < 0.05$). Fish reared at 25 fish/m² exhibited relatively better growth performance, higher survival, and lower blood glucose levels compared with fish maintained at higher stocking densities. These results suggest that a stocking density of 25 fish/m² is the most appropriate rearing condition for *P. lineatus* in floating net cages, causing the least physiological stress and providing optimum growth and survival. Future studies would be interesting to study the combined effects of stocking density, feed quality, water management, dissolved oxygen dynamics, and culture duration on the sustainable production of *P. lineatus*.

1. INTRODUCTION

The aquaculture development potential of the marine catfish, *Plotosus lineatus*, is good due to its adaptability to the environment and nutritional value. The species has been reported from the tropical Indo-Pacific waters and has extended its distribution to the Mediterranean, indicating wide tolerance to environmental variation [1-3]. Marine catfish have morphological characteristics similar to freshwater catfish, such as an elongated eel-like tail, hard spines on the dorsal and pectoral fins, four pairs of barbels, an elongated body, and a brown color with two white stripes at the head [4]. Moreover, *P. lineatus* is rich in valuable nutritional components, such as protein and polyunsaturated fatty acids, which add to its potential as an alternative source of animal protein [5-7]. In response to increasing pressure on wild fishery resources, floating net cage culture has emerged as a promising approach for the aquaculture development of this species. However, successful production in floating net cages depends strongly on technical management, particularly stocking density, because density directly affects space availability, feed competition, social interaction, and fish physiological balance [8-10].

Stocking density is widely recognized as one of the most important factors influencing fish growth, survival, welfare, and physiological condition under aquaculture systems. Stocking density may alter growth performance, feed utilization, and survival in cultured fish because of intensified intraspecific competition and stress responses [8, 9, 11, 12]. The research on *P. lineatus* has mainly been on its population biology, habitat association, reproductive traits, morphometry, growth characteristics, domestication, and grow-out performance [3, 4, 8, 10, 12, 13]. In terms of physiological stress responses, blood glucose is a well-established and sensitive biomarker for activation of the hypothalamic-pituitary-adrenal axis in teleost fish under crowding conditions [11, 14]. Furthermore, recent studies have shown that increases in blood glucose and cortisol may precede measurable declines in growth or survival in high-density culture, emphasizing the importance of these indicators for early detection of sublethal stress [11, 14]. These results highlight the fact that conventional production parameters alone are unlikely to be sufficient for providing a complete assessment of the biological suitability of a specific stocking density.

However, the effect of stocking density on growth performance, survival, and physiological stress in *P. lineatus* cultured in floating net cages is not well known. Studies specifically integrating productive traits and physiological stress indicators in this species are rarely reported. In particular, limited data are available on how different stocking densities affect blood glucose responses in *P. lineatus* under floating net cage conditions. As a result, the threshold at which density begins to induce physiological stress, even when growth and survival appear unaffected, is presently unclear and remains a major challenge for the development of efficient and sustainable marine catfish culture.

Collectively, these limitations highlight the novelty of the present study in integrating conventional production indicators with a physiological stress marker to evaluate the suitability of stocking density for *P. lineatus* reared in floating net cages. The hypothesis of this study was that increasing stocking density would progressively elevate blood glucose levels as an indicator of physiological stress, while growth performance and survival would remain unaffected within the tested density range.

Based on this background, the present study aimed to evaluate the effects of different stocking densities on the growth performance, survival, and blood glucose levels of *P. lineatus* cultured in floating net cages. This study was expected to find a stocking density that could support favorable biological performance with a minimum of physiological stress. The results are expected to provide scientific evidence for the development of adaptive, efficient, and sustainable aquaculture management strategies for marine catfish culture.

2. MATERIAL AND METHOD

2.1 Materials

2.1.1 The equipment

The equipment used in this study included nine floating green mesh nets (1 m × 1 m × 1 m) (Figure 1), nylon rope (5 mm), a sewing machine for net construction, a ruler with 1 mm precision, a digital balance, a GlucoDr glucometer, a thermometer, a refractometer, a pH meter, and a dissolved oxygen meter.

Figure 1. Experimental design

2.1.2 The materials

The materials used in this study were wild-caught striped eel catfish (*Plotosus lineatus*) collected from Tapulaga Village, Soropia District, Konawe Regency, Southeast Sulawesi Province, Indonesia, and shrimp heads obtained from fish-processing waste as feed.

2.1.3 Ethical approval

The study was conducted on live fish under regular aquaculture-raising conditions. Formal ethical approval was not required under institutional laws for this type of aquaculture research. However, all handling procedures were performed in accordance with the standard animal welfare principles to minimize stress during the acclimatization, sampling, and measuring. The experiment was performed using humane handling procedures at all stages.

2.2 Methods

2.2.1 Experimental design

This study employed a completely randomized design with three stocking density treatments and three replications, resulting in nine experimental units. The treatments were 25 fish/m², 38 fish/m², and 50 fish/m².

2.2.2 Rearing containers and test animals

The rearing units consisted of nine floating green mesh nets measuring 1 m × 1 m × 1 m each. The nets were constructed using nylon rope and installed in floating net cages, with sinkers attached at the bottom to maintain stability. A total of 339 fish were used in the experiment, distributed as follows: 25 fish/m² × 3 replicates = 75 fish, 38 fish/m² × 3 replicates = 114 fish, and 50 fish/m² × 3 replicates = 150 fish. The average initial total length was 7.1 ± 0.6 cm. Before stocking, the fish were acclimatized for seven days to allow adaptation to the rearing environment and to reduce handling stress [15].

2.2.3 Maintenance and feeding

The fish were reared for 90 days and fed shrimp heads at a feeding rate of 10% of total biomass per day. Feeding was carried out manually twice daily at 08:00 and 16:00 WITA. Net cleaning was performed once a week to minimize biofouling, maintain water circulation, and preserve suitable rearing conditions.

2.2.4 Growth measurement

Total length and body weight were measured at the beginning and end of the experiment. Total length was measured using a ruler with 1 mm precision, while body weight was measured using a digital balance.

2.2.5 Blood glucose measurement

Blood glucose levels were measured at the beginning and end of the experiment using a GlucoDr glucometer. One fish from each replicate was sampled for blood glucose analysis, resulting in n = 3 per treatment. This sampling approach was adopted because blood sampling in small fish is inherently destructive; removing more than one fish per replicate would have materially reduced stocking density and confounded the experimental design. However, the relatively small sample size (n = 3 per treatment) should be considered a limitation and interpreted cautiously when evaluating statistical significance. Blood was collected from the caudal base, and one drop of blood was placed on the test strip for direct reading on the glucometer display. The measurement procedure followed the method described by the research [16].

2.2.6 Water quality measurement

Water quality parameters, including temperature, salinity, pH, and dissolved oxygen, were measured every two weeks using a thermometer, refractometer, pH meter, and dissolved oxygen meter, respectively (Table 1).

Table 1. Water quality parameters

No.	Parameters	Tools	Measurement Time
1	Temperature (°C)	Thermometer	Once every two weeks
2	Salinity (ppt)	Refractometer	Once every two weeks
3	pH	pH meter	Once every two weeks
4	Dissolved Oxygen (mg/L)	DO meter	Once every two weeks

2.3 Data analysis

The observed data were used to calculate absolute length growth, absolute weight growth [17], specific growth rate [8, 18], and survival rate [9, 18, 19]. Absolute length growth was calculated using Eq. (1):

$$H = L_t - L_0 \tag{1}$$

where, H: Absolute length growth (cm); L_t: The average total length at the end of the study (cm); L_0: The average total length of the initial study (cm).

$$W = W_t - W_0 \tag{2}$$

where, W: Absolute weight growth (g); W_t: The average total weight at the end of the study (g); W_0: The average total weight of the initial study (g).

$$SGR = \frac{\text{In}W_t - \text{In}W_0}{t} \times 100 \tag{3}$$

where, SGR: Specific growth rate (%); W_t: Final body weight (g); W_0: Initial body weight (g); t: Rearing time (days).

$$SR = \frac{N_t}{N_0} \times 100 \tag{4}$$

where, SR: Survival rate (%); N_t: Final total amount of fish (individual); N_0: Initial total amount of fish (individual).

3. RESULTS AND DISCUSSION

3.1 Growth performance

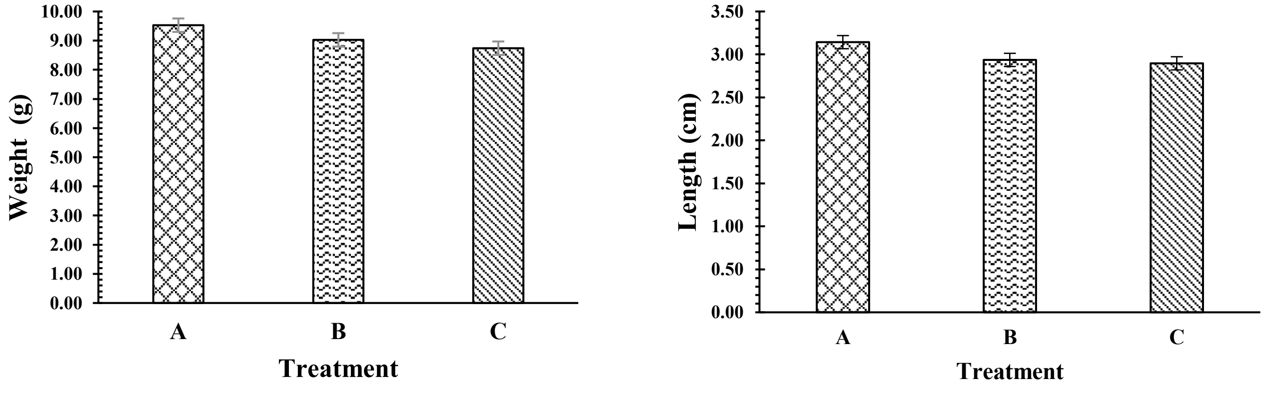
Marine catfish reared in floating net cages for 90 days exhibited measurable growth in both length and weight under all stocking density treatments. Absolute weight growth showed a declining trend with increasing stocking density. Fish stocked at 25 fish/m² had the highest absolute weight gain (9.53 ± 1.20 g), followed by those stocked at 38 fish/m² (9.03 ± 1.25 g) and 50 fish/m² (8.74 ± 1.56 g) (Figure 2(a)). Statistical analysis showed that stocking density did not significantly affect absolute weight growth ($p > 0.05$).

A similar pattern was observed for absolute length growth. Fish reared at 25 fish/m² showed the highest absolute length growth (3.14 ± 0.52 cm), followed by fish at 38 fish/m² (2.94 ± 0.32 cm) and 50 fish/m² (2.90 ± 0.23 cm) (Figure 2(b)). However, the differences among treatments were not statistically significant ($p > 0.05$).

The specific growth rate ranged from 1.71 and 1.77% day^{-1}. The highest value was recorded at 25 fish/m² (1.77 ± 0.08% day^{-1}), followed by 38 fish/m² (1.75 ± 0.05% day^{-1}) and 50 fish/m² (1.71 ± 0.18% day^{-1}) (Figure 3). Stocking density did not significantly affect specific growth rate ($p > 0.05$), although a slight decline was observed as stocking density increased.

3.2 Survival rate

The survival rate of *P. lineatus* remained relatively high during the rearing period, ranging from 68.0 to 76.7%. The highest survival rate was recorded at 25 fish/m² (76.7 ± 4.2%), followed by 50 fish/m² (74.0 ± 8.5%) and the lowest at 38 fish/m² (68.0 ± 6.1%) (Figure 4). Interestingly, survival at 38 fish/m² was lower than at 50 fish/m², which appears inconsistent with expectations based on density-stress relationships. This pattern is most likely due to natural variation among replicates due to the relatively small sample size (n = 3), rather than a direct biological effect of stocking density. The relatively large standard deviation at 50 fish/m² (± 8.5%) also suggests considerable variability within treatments, which may have masked density-related trends. High variability among replicates may also have contributed to the absence of significant differences among treatments. Statistical analysis indicated that stocking density had no significant effect on survival rate ($p > 0.05$).



(a) (b)

Figure 2. Growth of *P. lineatus* during the rearing period (a) fish weight, (b) fish length

Notes: A: stocking density 25 individuals/m^2, B: stocking density 38 individuals/m^2, and C: stocking density 50 individuals/m^2

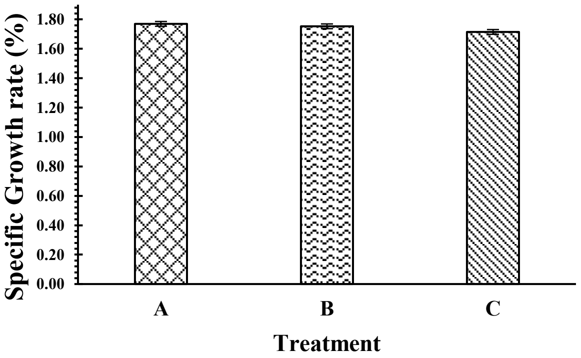


Figure 3. Specific growth rate of *P. lineatus* fish
Notes: A: stocking density 25 individuals/m^2, B: stocking density 38 individuals/m^2), and C: stocking density 50 individuals/m^2)

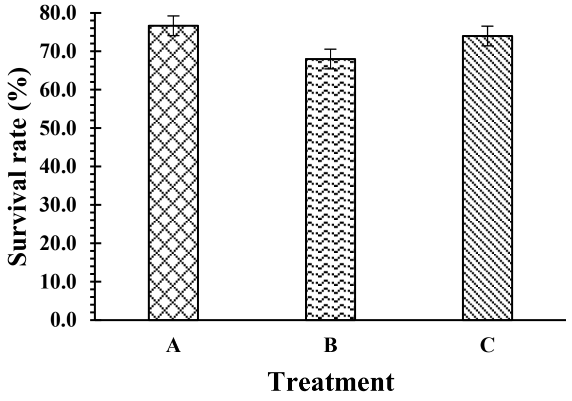


Figure 4. Survival rate of *P. lineatus* fish
Notes: A: stocking density 25 individuals/m^2, B: stocking density 38 individuals/m^2, and C: stocking density 50 individuals/m^2

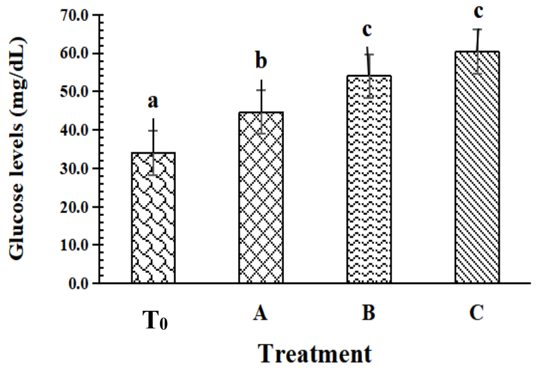


Figure 5. Glucose levels of *P. lineatus* fish under different stocking densities
Notes: T$_0$: Initial treatment time, A: stocking density 25 individuals/m^2, B: stocking density 38 individuals/m^2, and C: stocking density 50 individuals/m^2

3.3 Blood glucose levels

Blood glucose levels showed a clear response to stocking density. The blood glucose levels at the beginning of the experiment were similar between treatments, with an average of about 34 mg/dL. After 90 days of rearing, the blood glucose levels increased with the increase in the stocking density. The highest blood glucose level was recorded in the stocking density of 50 fish/m² (60.3 ± 6.43 mg/dL), followed by 38 fish/m² (54.0 ± 6.56 mg/dL), and the lowest value was in the stocking density of 25 fish/m² (44.7 ± 2.09 mg/dL) (Figure 5). Statistical analysis demonstrated that stocking density significantly affected blood glucose levels ($p < 0.05$). Given the small sample size (n = 3 per treatment), this result should be interpreted with appropriate caution; importantly, the observed directional trend across treatments remained biologically consistent.

3.4 Water quality

Water quality parameters remained relatively stable throughout the study period and were within acceptable ranges for marine catfish culture. The average water temperature was 29.6 °C, salinity was 33 ppt, pH was 7.08, and dissolved oxygen was 5.6 mg/L. These values indicate that the rearing environment was suitable for fish maintenance during the experimental period.

4. DISCUSSION

4.1 Effect of stocking density on growth performance

The present study showed that absolute weight growth, absolute length growth, and specific growth rate tended to decline with increasing stocking density, although the differences were not statistically significant. This pattern suggests that higher stocking density affects energy allocation in fish, but the effect was not strong enough to markedly reduce overall growth performance within the 90-day culture period.

Better growth at the lower stocking density may be explained by reduced competition for space and feed [20, 21], allowing more dietary energy to be allocated to somatic growth rather than maintenance and social interaction. This interpretation is in agreement with the theory of fish bioenergetics, which states that growth is dependent upon the balance between energy intake and metabolic expenditure [22, 23]. This is in agreement with the study [24], which reported that fish reared at lower densities generally exhibit higher growth rates due to reduced physiological and social stress.

The decrease in growth at 38 and 50 fish/m^2 was not significant, but the decreasing trend shows that intraspecific competition increases with the degree of crowding. Such competition may decrease feeding efficiency and increase metabolic costs for adaptation and maintenance. This pattern is in line with the concept of density-dependent growth, in which higher stocking densities reduce individual growth performance even when total biomass may increase [25-27].

4.2 Effect of stocking density on survival

Survival remained relatively high in all treatments, indicating that *P. lineatus* can tolerate the tested stocking densities under floating net cage conditions. However, the highest survival at 25 fish/m² suggests that lower stocking density provides a more favorable environment for maintaining fish stability and reducing negative interactions among individuals.

The absence of significant differences in survival may indicate that the density range tested in this study had not exceeded the species' tolerance threshold in terms of mortality. Notably, the lower survival at 38 fish/m² compared with 50 fish/m² requires specific consideration, as this pattern is counterintuitive from a density-stress perspective. The most plausible explanation is stochastic variation among replicates compounded by the small sample size (n = 3 per treatment), which reduces statistical robustness and increases sensitivity to random mortality events in individual nets. Similar within-treatment variability attributable to small sample size has been reported in comparable aquaculture studies [28]. Future studies should have at least five replicates per treatment to boost statistical power and effectively detect density-dependent variations in survival. Generally, the decreased survival values at intermediate and high density may indicate the early stages of crowding stress, competition, and reduced individual comfort, in accordance with earlier findings that increasing stocking density may impact fish survival by intensifying stress and competition [28].

4.3 Physiological stress response to stocking density

Unlike growth and survival, blood glucose responded significantly to increasing stocking density, indicating that physiological stress occurred before major changes in productive performance became evident. Blood glucose is widely recognized as a sensitive indicator of stress in fish because stress-induced hormonal responses stimulate the mobilization of energy reserves to maintain homeostasis.

The progressive increase in blood glucose with increasing stocking density suggests that fish experienced greater physiological stress under crowded conditions. This result supports the idea that increased stocking density may lead to increased social interaction, competition, and behavioral pressure, which in turn may trigger endocrine stress responses. The increase in glucose observed in this study is similar to that reported by studies [11, 14], which found that blood glucose may increase under stressful culture conditions before reductions in growth or survival are observed.

These results suggest that physiological indicators may be more sensitive than traditional growth variables in detecting sublethal stress. Collectively, these findings suggest that blood glucose level appears to be a useful complementary parameter for evaluating the suitability of stocking density in *P. lineatus* culture. The non-significant growth and survival responses, in contrast with the significant blood glucose response in this study, illustrate an important physiological decoupling: fish can maintain acceptable productive performance under crowded conditions while at the same time suffering measurable endocrine stress. This has been documented in other teleost species, where hyperglycaemia occurs as part of the immediate stress response mediated by catecholamines and cortisol, mobilizing hepatic glycogen to support locomotor and metabolic demands associated with crowding [11, 23].

The interactive relationship between glucose, growth, and survival in the present study suggests a trajectory consistent with the bioenergetics stress model: elevated glucose indicates energy reallocation from anabolic processes toward stress compensation, which, if sustained or intensified, would ultimately manifest as reduced growth and survival at higher densities or longer culture durations [22, 23]. Regarding water quality, the stable temperature, salinity, pH, and dissolved oxygen values recorded throughout the experiment (Table 2) indicate that the differences in blood glucose response among treatments were driven primarily by biological and social pressures from crowding rather than by environmental deterioration. This is an important control consideration, as dissolved oxygen decline at high biomass is a common confound in density studies; its stability here strengthens the interpretation that elevated glucose was density-driven. Future studies should monitor additional water quality parameters, such as total ammonia nitrogen and nitrite, to further validate this interpretation.

Table 2. Water quality results during the fish-raising phase

No.	Parameters	Measurement Result	Optimum Range	Ref.
1	Temperature (°C)	29.6	28-31	[4]
2	Salinity (ppt)	33	32.3-34.1	[4]
3	pH	7.08	7.02-7.20	[4]
4	Dissolved Oxygen (mg/L)	5.6	5.6-5.8	[4]

4.4 Implications for floating net cage culture

The stable water quality observed throughout the study indicates that the differences in fish response were primarily related to stocking density rather than environmental deterioration, as discussed in the previous section. From the perspective of practical aquaculture management, the present findings strongly support a clear recommendation to farmers who raise *P. lineatus* in floating net cages to use a stocking density of 25 fish/m^2 for minimizing physiological stress and maintaining acceptable growth performance and survival. This density appears to represent a biologically optimal balance point within the range tested. Regarding commercial scalability, however, several important caveats must be acknowledged. A lower stocking density will generally reduce production yield per unit area, which may affect economic viability at scale unless compensated by better individual growth performance and reduced mortality. Farmers operating under high-input or high-density systems should monitor blood glucose or other stress indicators periodically, particularly during periods of low dissolved oxygen, feed restriction, or elevated water temperature, to detect sublethal stress before it translates into production losses. In addition, the present study was limited to blood glucose as a physiological stress indicator. Future research should include cortisol assays, hematological parameters, and indices of immune function to provide a more complete picture of the welfare status of *P. lineatus* in response to different stocking densities. Multi-indicator frameworks would greatly enhance the robustness and practical applicability of density recommendations for commercial marine catfish culture.

Overall, the results suggest that physiological stress responses, as indicated by blood glucose level, may arise prior to visual changes in growth and survival. This study provides novel evidence that the addition of physiological indicators to traditional production metrics offers a more sensitive and comprehensive approach for determining optimal stocking density in *Plotosus lineatus* aquaculture systems. Stocking density management in floating net cage systems should consider not only production parameters but also physiological indicators of fish welfare. Based on the present findings, 25 fish/m² provides the most favorable balance between growth, survival, and stress minimization for *P. lineatus* culture, and we recommend this density as a practical management guideline for floating net cage systems under comparable environmental conditions.

5. CONCLUSIONS

The present investigation revealed that a stocking density of 25 fish/m² provides the most favorable balance between growth performance, survival, and physiological welfare of *P. lineatus* cultured in floating net cages. Growth and survival were not significantly affected by increasing stocking density up to 50 fish/m² ($p > 0.05$), although blood glucose levels increased progressively with increasing crowding, indicating elevated physiological stress under high-density conditions. Based on these results, a stocking density of 25 fish/m^2 in floating net cage culture systems is recommended to minimize physiological stress while maintaining acceptable production performance. This recommendation was consistent with the overall biological responses observed in the treatments. Overall, these findings emphasize the practical relevance of including physiological stress indicators in addition to conventional production parameters in aquaculture management.

Further assessment of possible trade-offs between production yield per unit area and individual fish welfare under conditions of commercial farming should be performed before broader application. Future research should also investigate the interplay between stocking density and other culture management factors, such as feed quality and composition, water management strategies, and extended rearing periods, to improve stocking density recommendations for large-scale marine catfish production. Future investigations should also be encouraged to include other indicators of physiological stress, such as plasma cortisol, hematological parameters, and immune-related biomarkers, to further validate and extend the physiological observations made in the current study.

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