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# PRODUCTION PERFORMANCE AND FINANCIAL ANALYSIS OF GLASS EEL (*Anguilla bicolor*) NURSERY AT DIFFERENT STOCKING DENSITIES USING RAS

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ABSTRACT

*Eel aquaculture remains dependent on wild-caught glass eels, whose supply fluctuates seasonally and peaks during the rainy season. Improving nursery efficiency through optimized stocking density is therefore essential. This study evaluated the effects of three stocking densities (1, 2, and 3 g $L^{-1}$) on the production performance and financial feasibility of glass eel (Anguilla spp.) nursery operations in recirculating aquaculture systems (RAS). Stocking density significantly affected survival, biomass yield, and profitability ($p < 0.05$). The highest density (3 g $L^{-1}$) resulted in the lowest survival rate (35.69 ± 3.70%), which was significantly lower than both 1 g $L^{-1}$ and 2 g $L^{-1}$, yet produced the greatest biomass (11.42 ± 0.57 g $L^{-1}$). Financial analysis showed that all treatments were viable, with 3 g $L^{-1}$ yielding the highest profit (IDR 378,035,622 ± 45,089,672). Despite reduced survival, profitability remained relatively stable across treatments, indicating that biomass gain compensated for mortality-related losses. These findings demonstrate that a stocking density of 3 g $L^{-1}$ provides the most advantageous balance between production output and economic return for glass eel nursery operations in RAS.*

KEYWORDS: glass eel nursery; stocking density optimization; recirculating aquaculture system (RAS); aquaculture economics; production performance

## INTRODUCTION

Eel farming represents one of the important sectors in Indonesia's aquaculture industry, offering substantial potential for economic growth and export value (Osmaleli *et al*., 2023). However, the sustainability of eel aquaculture is currently constrained by the unreliable supply of glass eel seeds. Artificial breeding technologies for eel (*Anguilla bicolor*) have not yet achieved consistent success, resulting in continued dependence on wild-caught fry. The availability of these wild seeds is highly seasonal glass eel abundance increases during the rainy season and drops significantly in the dry season (Wahju *et al*., 2020). Consequently, inconsistent seed supply often disrupts production cycles and may cause financial losses in large-scale operations.

Stocking density serves as a key management parameter that directly influences both biological performance and economic efficiency in eel farming. Increasing stocking density is a practical strategy to maximize fry utilization during periods of high seed availability, enabling farmers to improve biomass yield without additional capital investment (Ghozlan et al., 2018). Previous studies have examined glass eel culture only at relatively low stocking densities ranging from 0.5 to 2 g $L^{-1}$ (Iskandar *et al*., 2021; Sukardi *et al*., 2018), and there is currently no available data evaluating performance at densities above 2 g $L^{-1}$. This lack of information limits understanding of how higher stocking densities might influence both biological performance and economic outcomes in nursery operations. Despite these limitations, higher densities are already being practiced in the field, emphasizing the need for comprehensive evaluation to determine density levels that ensure optimal productivity and profitability.

Stable and optimal water quality is essential when stocking density increases. The development of recirculating aquaculture systems (RAS) provides controlled rearing conditions that ensure water stability, efficient land use, and reduced disease risk (Lindholm Lehto, 2023; Meisch & Stark, 2019). Therefore, this study aims to evaluate the production performance and financial feasibility of glass eel (*Anguilla bicolor*) nurseries at different stocking densities (1 g $L^{-1}$, 2 g $L^{-1}$, and 3 g $L^{-1}$) under RAS conditions. The findings are expected to identify density levels that optimize both biological performance and economic return, contributing to the development of sustainable and profitable eel aquaculture practices.

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## MATERIALS AND METHODS

### Fish Origin and Husbandry

The research was conducted from November 2023 to January 2024 at the Laboratory for the Development of Industrial Technology for Agriculture and Biomedic (LAPTIAB), National Research and Innovation Agency (BRIN), Kompleks Sains dan Teknologi (KST) BJ Habibie. The eels used in this study were at the glass eel stage, weighing approximately 0.16 ± 0.01 g, and were sourced from the Cimandiri River estuary, Palabuhanratu, Sukabumi, West Java, Indonesia. The glass eels were acclimated for two days before being stocked in the prepared rearing media, followed by a 60-day cultivation period.

The containers used in this study consisted of 15 fiber round tanks with a diameter of 60 cm, each filled with 100 liters of water. Each tank was equipped with aeration using a circular uniring with a diameter of 15 cm. We installed a gutter-type filter above each tank. The filter media consisted of synthetic cotton (dacron), biomate, zeolite, coral fragments, and bioballs. Water quality parameters, including temperature, pH, and dissolved oxygen (DO), were measured using a Horiba water quality checker® to assess daily fluctuations. In addition, ammonia, nitrite, nitrate, alkalinity, and hardness were analyzed biweekly with titration methode.

At the beginning of the rearing period (days 0–5), we fed the eels with *Artemia* nauplii ad libitum. They were fed Tubifex worms restrictedly at a feeding rate (FR) of 20% during days 6–15. During days 15–20 , feed adaptation was introduced by offering *Tubifex* worms with an FR of 10% and feed paste with an FR of 3%. From days 20–60, the eels were fed a powdered feed formed into a paste with an FR of 5%. The feed used was a commercial eel feed containing 46.59% protein. The artificial feed was supplemented with a commercial probiotic containing *Lactobacillus casei* and *Saccharomyces cerevisiae* to improve feed digestibility (Siddik *et al.*, 2021).

### Research Design

This study employed a completely randomized design with three treatments and five replicates. The treatments consisted of stocking densities of 1 g $L^{-1}$, 2 g $L^{-1}$ , and 3 g $L^{-1}$. Fish sampling was conducted every 15 days. A total of 30 fish per tank were sampled to measure body length using a ruler with an accuracy of 0.1 cm, and their weight was recorded using a scale with an accuracy of 0.01 g. Stress response was monitored by measuring blood glucose levels every 15 days, with three fish per tank sampled. We measured blood glucose by collecting blood from the glass eels and applying it to a glucometer (Accu-Chek Active®). We measured water quality parameters, including temperature, pH, and dissolved oxygen (DO), in the morning and afternoon using a Horiba water quality checker® to assess their daily fluctuations.

### Observed Research Parameters

The research data were analyzed based on production performance and financial outcomes. The culture performance parameters consisted of survival rate (SR, %), biomass (g $L^{-1}$), absolute growth rate (AGR, g $day^{-1}$), specific growth rate (SGR, % $day^{-1}$), absolute length rate (ALR, cm $day^{-1}$), specific length rate (SLR, % $day^{-1}$), feed conversion ratio (FCR), and coefficient of weight variation (CWV, %). The financial analysis consists of profitability analyses, investment criteria, and sensitivity analyses. All parameters were computed using MS Excel and analyzed for variance at a 95% confidence interval. If significant differences were observed between treatments, Duncan's Multiple Range Test was conducted using SPSS 25. Water quality and blood glucose data were analyzed descriptively and presented in tables and graphs.

The financial feasibility analysis of glass eel farming encompassed investment costs (I), fixed costs (FC), variable costs (VC), total costs (TC), total revenue (TR), profit ($TR - TC$), and the revenue–cost ratio (R/C = TR/TC). A cost–benefit analysis (CBA) was applied, incorporating Net Present Value (NPV), Benefit–Cost Ratio (BCR), Internal Rate of Return (IRR), and sensitivity analysis. The assessment covered a 15-year production cycle, corresponding to the lifespan of tarpaulin ponds, with a micro-scale loan interest rate of 8.25%.

#### Net Present Value (NPV)

NPV represents the present value of the net benefit stream, calculated as:

$$\text{NPV} = \sum_{t=1}^{n} \frac{\text{Bt}-\text{Ct}}{(1+i)^t}$$

Where: Bt = benefit in years, Ct = cost in years, n = length of culture in years, r = discount rate.

#### Benefit–Cost Ratio (BCR)

BCR is the ratio of the total present value of positive net benefits to the total present value of negative net benefits:

$$\text{B/C} = \frac{\sum_{t}^{n} \frac{\text{Bt}-\text{Ct}}{(1+i)^t}}{\sum_{t}^{n} \frac{\text{Bt}-\text{Ct}}{(1+i)^t}} \text{untuk } \frac{(\text{Bt}-\text{Ct})>0}{(\text{Bt}-\text{Ct})<0}$$

 

Where: Bt = Benefit in year t, Ct = Cost in year t (IDR), n = Project lifespan, i = Annual interest rate (% per year)

Internal Rate of Return (IRR)

IRR is the discount rate at which the present value of total revenues equals that of total costs. A project is considered viable when IRR exceeds the opportunity cost of capital:

$$\text{IRR} = i^1 + \frac{NPV^1}{NPV^1 - NPV^2}(i^2 - i^1)$$

where: $i^1$ = discount rate resulted from NPV positive, $i^2$ = discount rate resulted from NPV negative, $NPV^1$ = NPV in interest level $i^1$, $NPV^2$ = NPV in interest level $i^1$

## RESULTS AND DISCUSSION

### Production Performance

The production performance obtained from the research is shown in Table (1). The stocking density treatments affected the production performance of glass eels, with variations observed in each parameter and treatment tested.

The survival rate (SR) in the 1 g $L^{-1}$ stocking density treatment showed the best results ($p < 0.05$). Biomass at the 3 g $L^{-1}$ stocking density showed the highest value ($p < 0.05$). The values of AGR and SGR among treatments did not differ significantly ($p > 0.05$). ALR and SLR at the 3 g $L^{-1}$ stocking density were lower compared to the 1 g $L^{-1}$ and 2 g $L^{-1}$ treatments. The FCR at the 3 g $L^{-1}$ stocking density showed the lowest value. The CWV between treatments did not show significant differences ($p > 0.05$).

The survival rate of glass eels decreased progressively across all treatments (Figure 1). The 1 g $L^{-1}$ treatment maintained the highest and most stable survival, whereas 2 g $L^{-1}$ showed a moderate decline and 3 g $L^{-1}$ exhibited the greatest reduction, particularly after day 30. Overall, the final survival rate was highest at 1 g $L^{-1}$, followed by 2 g $L^{-1}$ and 3 g $L^{-1}$.

Table 1. Production performance of glass eel (*A. bicolor*) nursery with different stocking densities during 60 days of culture in a recirculating aquaculture system

| Parameters | Densities (g $L^{-1}$) | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| Survival rate (%) | $83.954 \pm 4.578^{b}$ | $74.910 \pm 4.321^{ab}$ | $67.067 \pm 4.260^{a}$ |
| Absolute biomass (g $L^{-1}$) | $5.25 \pm 0.74^{a}$ | $9.05 \pm 1.18^{b}$ | $11.42 \pm 0.57^{c}$ |
| Absolute growth rate (g $day^{-1}$) | $0.0116 \pm 0.000^{a}$ | $0.0115 \pm 0.002^{a}$ | $0.0104 \pm 0.001^{a}$ |
| Specific growth rate (% $day^{-1}$) | $3.239 \pm 0.080^{a}$ | $3.118 \pm 0.063^{a}$ | $3.121 \pm 0.042^{a}$ |
| Absolute length rate (cm $day^{-1}$) | $0.061 \pm 0.001^{b}$ | $0.062 \pm 0.003^{b}$ | $0.056 \pm 0.002^{a}$ |
| Specific length rate (% $day^{-1}$) | $0.873 \pm 0.015^{b}$ | $0.891 \pm 0.023^{b}$ | $0.817 \pm 0.025^{a}$ |
| Feed conversion ratio | $1.58 \pm 0.055^{ab}$ | $1.41 \pm 0.149^{a}$ | $1.71 \pm 0.127^{b}$ |
| Coefficient variation of weight (%) | $17.77 \pm 3.260^{a}$ | $18.26 \pm 3.150^{a}$ | $14.36 \pm 1.700^{a}$ |

Values in the form of numbers followed by different superscript letters on the same row show significantly different results at the 95% test level (Duncan test).

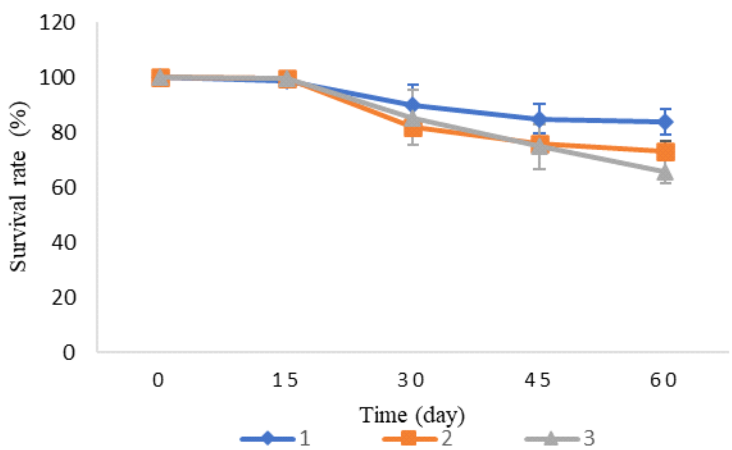


Figure 1. Survival rate of glass eel (*A. bicolor*) nursery with different stocking densities during 60 days of culture in a recirculating aquaculture system.

The average body weight of glass eels increased steadily across all stocking densities (Figure 2). The 1 g $L^{-1}$ treatment showed the highest growth, particularly after day 45, followed closely by the 3 g $L^{-1}$ treatment. Meanwhile, the 2 g $L^{-1}$ treatment exhibited slightly lower growth during the same period. At the end of the culture, glass eels in the 1 g $L^{-1}$ treatment achieved the highest average weight, followed by those in the 3 g $L^{-1}$ and 2 g $L^{-1}$ treatments.

The average body length of glass eels increased under all stocking density treatments (Figure 3). During the early phase (days 0–30), growth patterns were relatively similar across treatments. After day 45, the 3 g $L^{-1}$ treatment showed slightly higher length gain compared to the 1 g $L^{-1}$ and 2 g $L^{-1}$ treatments. By the end of the culture period, the 3 g $L^{-1}$ treatment exhibited the lowest average body length.

The feed conversion ratio (FCR) of glass eels varied among stocking density treatments (Figure 4). The lowest FCR was recorded in the 2 g $L^{-1}$ treatment, indicating the most efficient feed utilization. In contrast, the 3 g $L^{-1}$ treatment showed the highest FCR, followed by the 1 g $L^{-1}$ treatment. These results suggest that increasing stocking density tends to reduce feed efficiency.

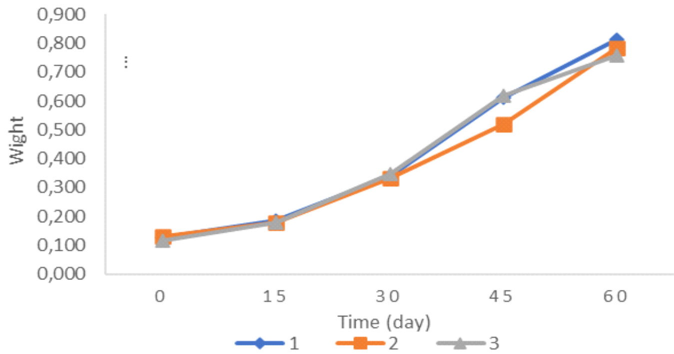


Figure 2. Average body weight of glass eel (*A. bicolor*) nursery with different stocking densities during 60 days of culture in a recirculating aquaculture system.

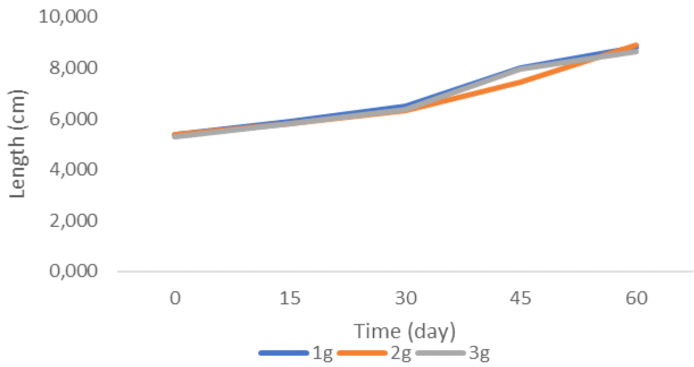


Figure 3. Average body length of glass eel (*A. bicolor*) nursery with different stocking densities during 60 days of culture in a recirculating aquaculture system.

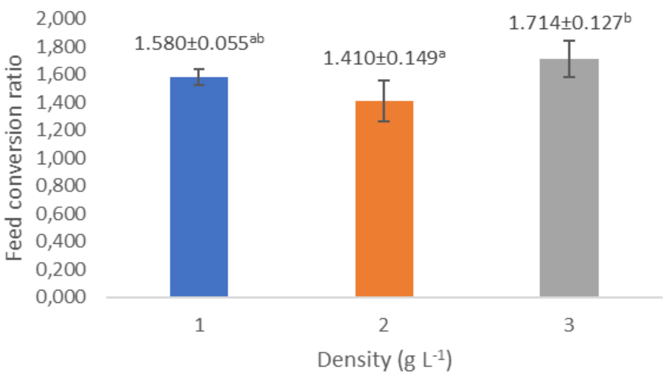


Figure 4. Feed convertion ratio of glass eel (*A. bicolor*) nursery with different stocking densities during 60 days of culture in a recirculating aquaculture system.

Increasing stocking density in RAS can enhance overall production and economic performance, but it requires careful management of water quality and fish health to mitigate the negative impacts on growth and stress. The achievement of production efficiency and fish welfare depends on the system's carrying capacity, which determines the optimal stocking density. Carrying capacity involves spatial planning and the physical limits of the environment to support aquaculture structures (Duarte *et al*., 2003). Production carrying capacity refers to the maximum biomass that can be produced without negatively impacting growth rates (Smaal & van Duren, 2018).

Absolute biomass in fish cultivation is influenced by several key factors: individual weight, number of individuals, and survival rate. These factors interact in complex ways to determine the overall productivity and efficiency of aquaculture systems. In this study, it was found that the highest stocking density, 3 g $L^{-1}$, produced the greatest harvest biomass compared to the stocking densities of 1 and 2 g $L^{-1}$. This result is consistent with the findings of (Budiardi *et al*., 2023), which indicated that higher stocking densities can yield greater biomass. This suggests that a stocking density of 3 g $L^{-1}$ is still within the environmental carrying capacity of the system. The environmental conditions in this study were supported by the use of a recirculating aquaculture system (RAS). RAS offers controlled culture conditions that optimize. Moreover, this system is efficient in nutrient management and water recycling, both of which contribute to increased biomass production (Zhang *et al*., 2023).

Higher stocking densities can increase total biomass, they often lead to decreased survival rates due to stress, aggression, and competition (Peña-Herrejón *et al*., 2019). In this study, the highest stocking density of 3 g $L^{-1}$ exhibited the lowest survival rate. This may have occurred due to increased stress levels and competition during feeding. High stocking densities often lead to increased stress and aggressive interactions among individuals, which can result in physical injuries and higher mortality rates (Zheng *et al*., 2023). Increased competition for food and space at higher densities can lead to malnutrition and weakened immune responses, further decreasing survival rates (Ezhilmathi *et al*., 2022). The high mortality rate began on days 15 to 30. Mortality during the glass eel stage was suspected to be caused by the adaptation process from natural feed to commercial paste feed. Glass eels transitioning fro transitioningm natural to artificial diets often struggle to adapt. Farm-sourced eels, which are accustomed to artificial diets, require a longer period to switch to natural prey and adapt to new foraging strategies, leading to lower survival rates initially (Simon *et al*., 2013). Careful management and adherence to optimal densities are essential for maintaining high survival rates in aquaculture.

Growth performance, represented by absolute growth rate (AGR) and specific growth rate (SGR), showed no significant differences among treatments ($p > 0.05$). This indicates that variations in stocking density between 1–3 g $L^{-1}$ did not have a significant effect on individual growth performance. The relatively consistent SGR values suggest that the recirculating aquaculture system (RAS) provided stable environmental conditions that supported uniform growth. A slight decrease in AGR and SGR at the highest stocking density (3 g $L^{-1}$) may reflect increased competition for feed and space, leading to mild stress and reduced feeding efficiency. Similar trends have been reported in other aquaculture species, where high stocking densities suppressed growth performance due to crowding stress and limited resource availability (Banerjee & Ray, 2017; Ndashe *et al*., 2023). Therefore, although growth parameters were not significantly different among treatments, stocking densities above 2 g $L^{-1}$ may begin to exert physiological stress on glass eels.

Feed conversion ratio (FCR) and survival rate also exhibited different responses to variations in stocking density. The lowest FCR value was recorded at a stocking density of 2 g $L^{-1}$, indicating better feed utilization efficiency compared to the 1 g $L^{-1}$ treatment. Fish maintained at moderate densities are less likely to experience aggressive competition for food, which promotes more uniform feeding behavior and reduces feed wastage. Consistent with this finding, Le Boucher *et al.* (2024) reported that moderate stocking densities resulted in improved feed conversion ratios and minimized feed losses, highlighting the importance of maintaining optimal density levels to enhance feeding efficiency and overall culture performance.

In aquaculture, the CWV is a useful indicator for assessing the uniformity of eel sizes, where a lower CV reflects more consistent growth and is advantageous for marketability and processing efficiency (Liu *et al*., 2023; Niwitpong, 2015). A higher CV indicates greater variability within the population, while values below 20% denote uniform growth (Baras *et al*., 2011). In this study, the CV ranged from 14.36% to 18.26% with no significant differences among treatments ($p > 0.05$), suggesting uniform growth performance across stocking densities.

Overall, increasing stocking density in RAS can enhance biomass production and economic output as long as it remains within the system's carrying capacity. In this study, a density of 3 g $L^{-1}$ yielded the highest harvest biomass, indicating that it was still supported by the environmental capacity of the system, despite reducing survival due to stress and competition. Growth performance remained statistically similar across treatments, suggesting that the controlled conditions of the RAS promoted uniform growth, although the highest density showed early signs of physiological stress. Feed efficiency was optimal at the moderate density of 2 g $L^{-1}$, and low CV values across treatments indicated consistent size uniformity. Collectively, these results demonstrate that higher densities can improve overall production, but only when carefully managed within ecological and physiological limits to avoid declines in survival and culture efficiency.

Stress parameter

The fluctuation pattern of glucose levels across treatments showed a similar trend, ranging from 21.6 to 47.6 mg $dL^{-1}$ (Figure 5). The glucose levels at the end of the rearing period were 37.46±5.84 mg $dL^{-1}$ for the 1 g $L^{-1}$ stocking density, 32.56±4.95 mg $dL^{-1}$ for the 2 g $L^{-1}$ stocking density, and 34.87±3.82 mg $dL^{-1}$ for the 3 g $L^{-1}$ stocking density.

Stocking density exerts a significant influence on both the physiological responses and economic performance of glass eels. Elevated densities trigger stress, evidenced by increased blood glucose concentrations resulting from cortisol-mediated endocrine activation to maintain energy homeostasis. While mild stress can be tolerated, chronic exposure at higher densities impairs metabolic efficiency, suppresses growth, and shifts energy allocation from tissue synthesis to maintenance. In this study, blood glucose fluctuations followed a similar pattern across treatments, indicating a uniform physiological response; however, greater variations were observed at higher densities (Nawir *et al.*, 2023). At 3 g $L^{-1}$, glucose levels exceeded the optimal range of 15.4–38.0 mg $dL^{-1}$ (Fekri *et al.*, 2015; Harianto *et al.*, 2020) yet remained within the tolerance threshold of 53 mg $dL^{-1}$ (Budiardi *et al.*, 2023). Although the eels survived and continued to grow, both feed conversion efficiency and growth performance were lower than those observed at 1 and 2 g $L^{-1}$. These results align with findings in *Anguilla bicolor bicolor* (Lukas *et al.*, 2017) and other species such as *Oreochromis niloticus* and *Clarias gariepinus*, where crowding stress elevated glucose levels and reduced growth efficiency (Ahmed & Turchini, 2021).

Prolonged stress under high stocking densities also reduces feed efficiency and survival rate (SR), thereby diminishing harvestable biomass and total production. Economically, this reduction translates into lower NPV, IRR, and BCR values due to decreased output without corresponding reductions in fixed costs (Syliver *et al.*, 2025).

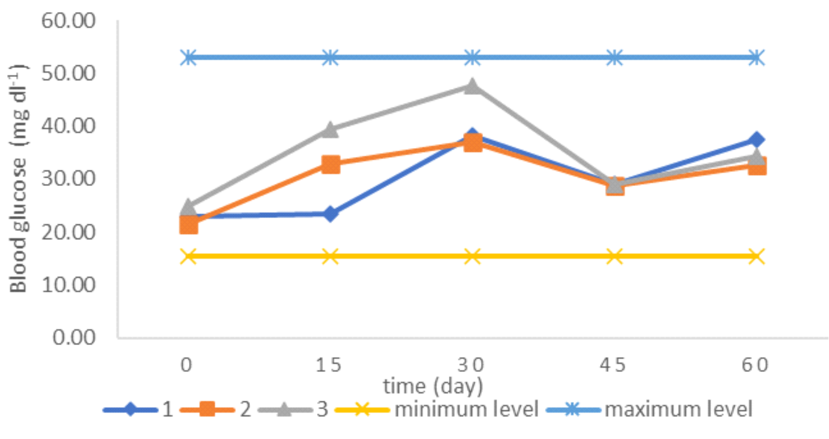


Figure 5. Blood glucose levels of glass eel (*A. bicolor*) nursery with different stocking densities during 60 days of culture in a recirculating aquaculture system.

Water Quality

The water quality during the rearing period in this study met the acceptable standards outlined for fish culture (Table 2). Research on glass eel aquaculture highlights the importance of water quality management for achieving optimal survival and growth (Setiadi *et al.*, 2021). Optimal water temperature can stimulate appetite, leading to accelerated growth rates (Harianto *et al.*, 2020). Higher levels of dissolved oxygen are associated with improved growth performance (Waldrop *et al.*, 2020). Changes in pH can affect the chemical balance within fish. In this study, pH values ranged from 6.5 to 9.0, which falls within the optimal range (Boyd, 2025). pH levels outside the optimal range can disrupt osmoregulation, impair respiration, and lead to harmful effects on metabolism (Menon *et al.*, 2023). The water quality across the three treatments remained within the optimal range for eel growth, indicating that variations in SR and growth were influenced by stocking density. Higher stocking densities increased competition for space (Muchlisin *et al.*, 2021).

### Profitability analysis

The business model was designed based on an annual operational scale. The initial price of glass eels was set at IDR (Indonesian Rupiah) 1,000,000 utilizing ten fiberglass tanks, each with a capacity of 500 L. Each production cycle lasts for 2 months, with a total of 5 cycles per year. The selling price is IDR 1,900,000 kg$^{-1}$, and feed cost was IDR 65,000. The estimated annual harvest biomass at stocking densities of 1, 2, and 3 g L$^{-1}$ reached 135.45 kg, 233.7 kg, and 332.45 kg, respectively.

Based on the profitability assessment, the best rearing performance for glass eel farming was observed at a stocking density of 3 g L$^{-1}$ (Table 3). Although higher stocking density increased total production costs, it also generated significantly higher revenues, resulting in superior profit margins. The break-even point (BEP) analysis showed that the density of 1 g L$^{-1}$ had a higher BEP compared to 2 and 3 g L$^{-1}$, indicating lower economic efficiency at lower densities. In this context, a lower BEP value is considered more desirable, confirming that the 2 and 3 g L$^{-1}$ densities were more economically advantageous. Furthermore, the highest average cost efficiency and revenue cost ratio (R/C ratio) were obtained at a stocking density of 3 g L$^{-1}$.

Comparable findings were reported in large-scale glass eel rearing operations in Sukabumi, where variable costs reached IDR 2 trillion, yielding a BEP of 27,835 kg, a production cost (HPP) of IDR 1,283,884, an R/C ratio of 1.17, and a payback period (PP) of 0.2 years (Iskandar *et al.*, 2021). Similarly, for glass eel stocking sizes ranging from 0.35–1.04 g, an R/C ratio of 1.78–1.97, a payback period of 0.36–0.44 years, a BEP of IDR 179,461,241–190,315,883, and a production cost of IDR 966,842–1,065,574 were reported (Budiardi *et al.*, 2023).

Table 2. Water quality of glass eel (*A. bicolor*) nursery with different stocking densities during 60 days of culture in a recirculating aquaculture system

| Parameter | Density (g L$^{-1}$) | | | Optimum Range*) |
|---|---|---|---|---|
| | 1 | 2 | 3 | |
| Temperature (°C) | 27.7 – 31.7 | 27.9 – 31.2 | 28.1 – 32.2 | 28.0-33.0[a] |
| pH | 6.2 – 8.1 | 6.1 – 8.0 | 6.0 – 8.1 | 6.5-9.0[b] |
| Dissolved oxygen (mg L$^{-1}$) | 5.0 – 8.1 | 4.8 – 7.9 | 5.2 – 7.8 | >5[b] |
| Ammonia (mg L$^{-1}$) | 0.003 – 0.067 | 0.005 – 0.057 | 0.003 – 0.085 | <0.05[b] |
| Nitrite (mg L$^{-1}$) | 0.009 – 0.171 | 0.024 – 0.133 | 0.030 – 0.181 | <0.66[b] |
| Nitrate (mg L$^{-1}$) | 1.304 – 2.895 | 1.255 – 3.147 | 1.075 – 2.780 | 0.1–4.5[c] |
| Alkalinity (mg L$^{-1}$) | 24 - 56 | 28 - 61 | 28 - 52 | 25-75[b] |
| Hardness (mg L$^{-1}$) | 64.1 – 136.1 | 68.1 – 88.1 | 48.0 – 108.1 | 75-150[c] |

*) [a](Luo *et al.*, 2013) b(Boyd, 2025) [c](Lukas *et al.*, 2017) [d](Bhatnagar & Devi, 2013)

Table 3. Profitability analysis of glass eel (*A. bicolor*) nursery with different stocking densities during 60 days of culture in a recirculating aquaculture system

| Parameter | Density (g L$^{-1}$) | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| Total investment (IDR) | 365,923,000 | 365,923,000 | 365,923,000 |
| Fixed cost (IDR) | 107,882,708 | 107,882,708 | 107,882,708 |
| Variable cost (IDR) | 73,425,913 ± 1,321,233[a] | 109,603,585 ± 2,133,505[b] | 149,329,303 ± 3,456,118[c] |
| Total cost (IDR) | 181,308,621 ± 1,321,233[a] | 217,486,293 ± 3,113,505[b] | 257,212,011 ± 3,456,118[c] |
| Total revenue (IDR) | 264,246,195 ± 19,650,312[a] | 458,252,809 ± 45,198,502[b] | 621,573,746 ± 53,218,252[c] |
| Profit (IDR) | 88,741,351 ± 17,836,746[a] | 249,149,560 ± 29,127,867[b] | 378,035,622 ± 45,089,672[c] |
| *Break event point* (kg) | 78.97 ± 2.09[a] | 75.76 ± 1.93[b] | 75.08 ± 1.86[b] |
| *Break event point* (IDR) | 150,035,998 ± 3,978,503[a] | 143,951,153 ± 3,670,356[b] | 142,648,695 ± 3,540,980[b] |
| Average cost (IDR kg$^{-1}$) | 1,313,050 ± 100,440[a] | 926,183 ± 72,082[b] | 794,110 ± 63,615[c] |
| *Payback Period* (year) | 4.54 ± 0.86[a] | 1.53 ± 0.20[b] | 1.01 ± 0.14[b] |
| *Revenue-Cost Ratio* | 1.45 ± 0.11[a] | 2.06 ± 0.16[b] | 2.33 ± 0.16[c] |

Values in the form of numbers followed by different superscript letters on the same row show significantly different results at the 95% test level (Duncan test).

In this study, survival declined slightly at 3 g $L^{-1}$, indicating that beyond a certain threshold, higher density may compromise individual health even if total yield increases. Nevertheless, the 3 g $L^{-1}$ treatment demonstrated superior economic performance, primarily due to the substantially greater total biomass yield. This suggests that in recirculating aquaculture systems (RAS), increased productivity per unit volume can offset biological losses, thereby enhancing overall profitability. From an industry standpoint, these findings carry important implications for optimizing the use of limited glass eel resources, which are both seasonal and costly. High-density culture allows producers to maximize production output during periods of seed abundance, supporting production continuity and economic resilience. Similar patterns have been documented in other aquaculture species, including seabass and tilapia, where increased stocking densities under well-managed RAS conditions enhanced both production efficiency and economic returns (Martins *et al.*, 2010; Zhaoqun *et al.*, 2015). Hence, implementing high stocking densities should be supported by rigorous environmental monitoring and robust filtration systems to sustain water quality and fish welfare. Overall, these results emphasize the necessity of integrating biological and economic evaluations to inform effective stocking strategies for commercial eel farming.

### Financial Feasibility Analysis

The financial feasibility analysis in this study was conducted based on several key assumptions. The investment evaluation assumed a business lifespan of 15 years, with a retail credit interest rate of 8.25% obtained from Bank Rakyat Indonesia (BRI) for the year 2024. In addition, an income tax rate of 0.5% of annual revenue was applied in accordance with the Government Regulation of the Republic of Indonesia No. 23 of 2018.

The results of the financial analysis indicate that all three stocking density treatments are financially viable (Table 4). Based on the Net Present Value (NPV), all treatments produced positive values (P > 0), confirming economic feasibility. The Net Benefit-Cost Ratio (BCR) for each treatment was greater than or equal to 1, signifying that the benefits outweigh the costs. Furthermore, the Internal Rate of Return (IRR) values for all densities exceeded the prevailing interest rate, reinforcing the profitability of the investment. The Payback Period (PP) for all treatments was also shorter than the projected business lifespan, which indicates a relatively quick recovery of the initial capital investment.

The analysis clearly demonstrates that different stocking densities have a substantial impact on the profitability of *A. bicolor* nursery operations. Among the treatments, the stocking density of 3 g $L^{-1}$ produced the highest NPV (IDR 2,042,324,727), IRR (94.39%), and BCR (7.55), indicating superior financial performance compared to the lower densities. These findings suggest that increasing stocking density enhances production output, thereby boosting revenue and improving overall investment efficiency.

From an economic standpoint, the positive NPV and high BCR values reflect the capacity of glass eel nursery operations to generate returns exceeding both investment and operational costs. The markedly higher NPV at 3 g $L^{-1}$ demonstrated that the additional biomass yield effectively compensated for the increased operational costs, resulting in enhanced profitability (Bergamo *et al.*, 2021). Additionally, the BCR for different fish farming systems in Taiwan showed values around 2.6, indicating good profitability (Huang *et al.*, 2016).

Meanwhile, the exceptionally high IRR and short payback period achieved at 3 g $L^{-1}$ indicate strong financial resilience and rapid capital recovery, making this density the most advantageous for commercial implementation. Hernández-Llamas *et al.* (2025) similarly emphasized that high IRR values reflect efficient capital utilization and robust investment per-

Table 4. Financial feasibility analysis of glass eel (*A. bicolor*) nursery with different stocking densities during 60 days of culture in a recirculating aquaculture system

| Parameter | Feasibility criteria | Density (g $L^{-1}$) | | |
|---|---|---|---|---|
| | | 1 | 2 | 3 |
| NPV (IDR) | > 0 | 330,407,867 ± 124,395,646$^{a}$ | 1,560,405,252 ± 233,494,540$^{b}$ | 2,042,824,727 ± 5,900,705$^{c}$ |
| BCR | ≥ 1 | 1.86 ± 0.53$^{a}$ | 5.39 ± 1.05$^{b}$ | 7.55 ± 0.74$^{c}$ |
| IRR (%) | > discount rate | 20.87 ± 6.34$^{a}$ | 86.63 ± 56.34$^{b}$ | 94.39 ± 13.59$^{c}$ |
| PP (year) | ≤ business lifespan | 6.18 ± 1.54$^{a}$ | 1.71 ± 0.25$^{b}$ | 1.12 ± 0.19$^{b}$ |

*Values in the same row followed by different superscript letters indicate significant differences at the 95% confidence level (Duncan test). NPV = Net Present Value, BCR = Benefit-Cost Ratio, IRR = Internal Rate of Return, PP = Payback Period.*

formance, while the inclusion of the Payback Period (PP) provides a more realistic assessment of risk-adjusted recovery time (Gwóźdź, 2015). Therefore, the faster recovery observed at 3 g $L^{-1}$ signifies a financially attractive and relatively low-risk investment profile compared to the other treatments.

Overall, these findings imply that optimizing stocking density can serve as a strategic approach to maximizing financial performance in eel nursery systems, particularly under recirculating aquaculture system (RAS) conditions that promote efficient water and space utilization. Practically, adopting a stocking density of 3 g $L^{-1}$ offers an optimal balance between biological productivity and financial return, supporting the development of sustainable and commercially viable aquaculture enterprises. Integrating these financial insights with biological performance indicators will be crucial for formulating comprehensive models aimed at improving profitability and sustainability in eel aquaculture within Indonesia.

Sensitivity Analysis

Sensitivity analysis was conducted to evaluate the impact of key biological parameters on the financial viability of *A. bicolor* nursery operations. This approach evaluates how changes in a single variable while all other factors are held constant influence key profitability indicators, thereby providing insight into the degree of risk exposure associated with each parameter (Arbonés *et al*., 2014; Gu *et al*., 2022). Projects showing substantial shifts in financial indicators with minor assumption changes are considered more vulnerable, whereas stable indicators under varying conditions indicate stronger economic resilience. Such analysis provides valuable insights for decision-makers to assess investment robustness and make well-informed operational adjustments.

In this study, the survival rate (SR) was selected as the primary variable for sensitivity testing, as the glass eel stage represents the most fragile phase in the culture cycle, where mortality risk is high and directly linked to economic outcomes. Survival rate substantially influences production volume, sales, and profit margins, making it a critical determinant of overall feasibility. The results of the sensitivity analysis for different stocking densities are presented in Table 5.

The analysis revealed that at a stocking density of 1 g $L^{-1}$, the operation remains financially viable at a minimum SR threshold of 69.17%, representing a 14.78% decrease from the observed rate. At 2 g $L^{-1}$ and 3 g $L^{-1}$, viability thresholds were 43.86% and 35.69%, corresponding to reductions of 31.05% and 31.38%, respectively. These results suggest that higher stocking densities exhibit greater tolerance to declines in survival rate, implying stronger resilience and economic stability under fluctuating biological conditions.

Table 5. Sensitivity analysis of glass eel (*A. bicolor*) nursery with different stocking densities during 60 days of culture in a recirculating aquaculture system

| Parameter | Density (g $L^{-1}$) | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| Survival rate (%) | $69.17 \pm 2.29^{b}$ | $43.86 \pm 4.05^{b}$ | $35.69 \pm 3.70^{a}$ |

Values in the same row followed by different superscript letters indicate significant differences at the 95% confidence level (Duncan test).

Sensitivity to SR is particularly crucial in glass eel culture, as survival variability not only reflects biological performance but also influences profitability through seed cost fluctuations and biomass yield (Sukardi *et al*., 2018). A comprehensive understanding of these sensitive variables enables aquaculture managers to implement targeted management strategies aimed at improving fish health, reducing mortality rates, and ultimately enhancing the long-term sustainability of production systems. The findings align with the principle outlined by (Hernández-Llamas *et al*., 2025), which emphasizes that identifying the most influential variables allows producers to mitigate risks through precise and adaptive management. In practice, aquaculture operators can use such sensitivity assessments to simulate alternative scenarios adjusting stocking density, strengthening biosecurity protocols, or refining feeding and harvest strategies to maintain profitability under varying biological and market conditions.

Overall, the sensitivity analysis underscores that survival rate is a pivotal factor determining both biological success and financial resilience in eel nursery systems. Maintaining optimal SR through improved culture management can significantly enhance investment stability and ensure long-term sustainability in recirculating aquaculture operations.

Collectively, these studies indicate that sustainable profitability in glass eel farming depends on a balanced approach that harmonizes biological and financial parameters. An economically viable culture system is not solely defined by high output but by its capacity to maintain profitability amid biological variability and price fluctuations. Thus, integrating performance optimization, financial feasibility evaluation, and sensitivity-based risk management forms the foundation of a resilient production model for *A. bicolor* nurseries in RAS environments. Such integrative assessment frameworks are essential for guiding evidence-based decision-making, particularly in the context of emerging aquaculture industries seeking to expand sustainably while minimizing economic uncertainty.

## CONCLUSION

This study shows that a stocking density of 3 g $L^{-1}$, despite lowering survival, yields the highest biomass and significantly greater profits compared to 1 and 2 g $L^{-1}$. These findings suggest that higher densities can enhance economic returns in eel nurseries, but they also underscore the need to balance production efficiency with sustainability. Beyond short-term profitability, stocking density influences resource use, environmental load, and the scalability of eel farming for domestic and global markets. The results indicate that higher densities may be viable when supported by improved farm management practices such as water quality control, targeted feeding, and health monitoring to mitigate survival losses. Future research should therefore explore the integration of these practices under diverse environmental and market conditions, enabling farmers to optimize stocking strategies that strengthen both long-term profitability and environmental stewardship in the global aquaculture industry.

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