



## PRODUCTION OF JUVENILE FAT SNOOK (*Centropomus parallelus*) IN FISH PENS INTEGRATED WITH WHITELEG SHRIMP (*Penaeus vannamei*) FARMING

### PRODUÇÃO DE JUVENIS DE ROBALO-PEVA (*Centropomus parallelus*) EM TANQUES- REDE INTEGRADOS AO CULTIVO DE CAMARÃO-BRANCO-DO-PACÍFICO (*Penaeus vannamei*)

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### Resumo

Este estudo teve como objetivo avaliar o crescimento e a sobrevivência de juvenis de robalo-peba (*Centropomus parallelus*) em diferentes densidades de estocagem, utilizando tanques-rede instalados em um viveiro (~1,1 ha) de cultivo de camarão marinho na Fazenda Experimental Yakult UFSC, em Barra do Sul, SC. Doze estruturas circulares de tela plástica, cada uma com área de 26,4 m<sup>2</sup>, foram utilizadas em quatro densidades de estocagem (30, 60, 90 e 120 peixes/tanque), com três repetições por tratamento. Os peixes (22,3 ± 8,0 g e 13,1 ± 1,5 cm) foram estocados em novembro e amostrados cinco vezes até maio do ano seguinte. Eles foram alimentados com uma ração comercial para salmonídeos contendo 46% de proteína bruta (PB). A temperatura foi de 25,9 ± 3,2 °C, a concentração de oxigênio dissolvido foi de 5,8 ± 3,0 mg/L e a salinidade variou de 5 a 20. O peso final do robalo-peba variou de 113,0 ± 12,5 g (densidade 120) a 129,8 ± 22,6 g (densidade 30). As taxas de sobrevivência variaram de 27,5% (densidade 60) a 53,3% (densidade 30). Este estudo demonstrou a viabilidade técnica da pré-engorda de juvenis de robalo-peba em viveiros de cultivo de camarão.

Palavras-chaves: Engorda; Piscicultura; Robalo-peba; Tanque-rede; Viveiro de camarão.

## Abstract

This study aimed to evaluate the growth and survival of juvenile fat snook (*Centropomus parallelus*) at different stocking densities in fish pens installed in a pond (~1.1 ha) used for marine shrimp farming at the Experimental Farm Yakult UFSC, Barra do Sul, SC. Twelve circular enclosures made of plastic mesh, each with an area of 26.4 m<sup>2</sup>, were established at four stocking densities (30, 60, 90, and 120 fish/pen), with three replicates per treatment. Fish (22.3 ± 8.0 g and 13.1 ± 1.5 cm) were stocked in November and sampled five times until May of the following year. They were fed a commercial salmonid diet containing 46% crude protein (CP). The temperature was 25.9 ± 3.2 °C, dissolved oxygen concentration was 5.8 ± 3.0 mg/L, and salinity ranged from 5 to 20. The final weight of fat snook ranged from 113.0 ± 12.5 g (density 120) to 129.8 ± 22.6 g (density 30). Survival rates ranged from 27.5% (density 60) to 53.3% (density 30). This study demonstrated the technical feasibility of pre-fattening juvenile fat snook in shrimp-farming ponds.

**Keywords:** Fish culture; Grow out; Net pen; Robalo-peva; Shrimp pond.



## Introduction

Marine fish farming has emerged as an increasingly relevant activity for diversifying Brazilian aquaculture production, particularly given the wide availability of coastal environments and the potential to produce food of high nutritional and economic value (Nascimento et al., 2022). Despite this potential, the activity remains at an early stage of development in Brazil, and its contribution to national aquaculture production is currently negligible, reflecting challenges related to technological development, the availability of juveniles, nutrition, and production systems (Valenti et al., 2021). In this context, the identification and development of native species with favourable characteristics for aquaculture are essential for consolidating marine fish farming in Brazil. The fat snook (*Centropomus parallelus*) stands out as a promising candidate due to its zootechnical potential and ecological and commercial importance in Brazilian coastal ecosystems and fisheries (Barni et al., 2013; Cerqueira et al., 2020).

Snook, or camorim, are estuarine fish of significant commercial importance along the entire Brazilian coast and throughout much of the American continent, particularly in the USA and Mexico, where numerous studies have been conducted (Contreras-García et al., 2025). The two most common and commercially important species in Brazil are the fat snook and the common snook (*C. undecimalis*) (Cerqueira et al., 2020). Snook species possess intrinsic biological characteristics, such as euryhalinity, disease resistance, and high market value, that make them suitable for rearing in the same infrastructure used for marine shrimp farming (Cerqueira; Tsuzuki, 2009). Shrimp farms are typically located in coastal and estuarine environments characterised by considerable variations in water quality, including salinity, temperature, and dissolved oxygen. Although shrimp farming is a well-developed aquaculture sector across the American continent, there is still a need to develop alternative production activities, such as marine fish farming.

Whiteleg shrimp (*Penaeus vannamei*) aquaculture worldwide, including in Brazil, has been repeatedly affected by viral diseases such as white spot syndrome virus (WSSV, or “mancha branca” in Brazil), which emerged in Asia around 1993 and caused catastrophic losses, including 70,000 metric tonnes in Thailand alone in 1996, followed by subsequent declines in production across the region (Flegel; Alday-Sanz, 1998). In Brazil, particularly in Santa Catarina, WSSV outbreaks after 2004 led to a widespread crisis, forcing farms to be abandoned and highlighting the vulnerability of intensive shrimp production (Goularti Filho; Ronçani, 2018; Neves; Martins, 2021).

In Asia and Australia, these disused ponds, termed “brownfields” (Monwar et al., 2013), offer untapped potential for diversification into marine fish farming using the same coastal infrastructure (Saraswathy et al., 2016). Species such as tilapia (*Oreochromis niloticus*) and Asian sea bass, or barramundi (*Lates calcarifer*), which is morpho-ecologically similar to snook, have been successfully cultured commercially in coastal and estuarine environments (Venkatachalam et al., 2018; Singh, 2000).

Shrimp-farming ponds are normally shallow areas (Blacio et al., 2026), making fish pens an appropriate type of aquaculture enclosure for this environment. A fish



pen is a fixed aquaculture enclosure used in coastal waters, lakes, or rivers, consisting of netting or screened walls secured to stakes driven into the bottom and using the natural seabed or lakebed as its base. Unlike fully floating cages, fish pens are stationary structures that allow fish to be reared in their natural environment while permitting water exchange, preventing escape, and providing protection against predators (Kutty; Campbell, 1987). Fish pens could be used to emulate the rearing of snook in earthen ponds with fewer individuals than would be used in commercial production. However, stocking density is one of the first parameters to be defined in this system.

Stocking densities for barramundi grow-out in earthen ponds vary according to the production phase and intensity. Nursery hapas within ponds use densities of 400–475 fish m<sup>-3</sup> for juveniles (0.1–1 g), followed by 20–50 fish m<sup>-3</sup> during the pre-fattening phase, until the fish reach 150–200 g, and lower densities of 10–30 fish m<sup>-3</sup> during the final grow-out phase (Singh, 2000; Solanki et al., 2023). In integrated shrimp-pond or coastal systems, stocking densities of approximately 1 fish m<sup>-2</sup> have been reported, as have ratios of 1:4–6 when barramundi are stocked with tilapia (Monwar et al., 2013; Singh, 2000).

Studies on the grow-out of fat snook juveniles in floating net cages have tested stocking densities ranging from 20 to 40 fish m<sup>-3</sup>, showing that lower densities promote higher individual growth rates, specific growth rates, and weight gain, whereas higher densities result in greater final biomass due to the direct relationship between stocking density and production (Ostini et al., 2007). Similarly, in freshwater net pens, fat snook juveniles stocked at 12.5, 25.0, and 37.5 fish m<sup>-3</sup> achieved biomass increments proportional to stocking density, with survival rates of approximately 90% and no significant effect of stocking density on specific growth rate among treatments (Liebl et al., 2016). For common snook, cage-culture trials in subtropical waters evaluated densities of 10, 20, and 40 fish m<sup>-3</sup> across different growth phases, identifying an optimal density of approximately 24 fish m<sup>-3</sup> for juveniles transitioning to market size, above which growth declined while survival remained stable (Silva et al., 2021). These findings underscore the need for site-specific optimisation in fish pens, balancing growth, survival, and productivity.

In addition to the lack of information regarding the adaptation of snook to the proposed environment and structure, the most appropriate stocking density remains unknown. Therefore, initial research on this topic should adopt a conservative approach to stocking density. This study aimed to evaluate the growth and survival of juvenile fat snook (*Centropomus parallelus*) at different stocking densities in fish pens installed in a pond (~1.1 ha) used for marine shrimp farming at the Experimental Farm Yakult UFSC, Barra do Sul, SC. To this end, an experiment was conducted using juvenile fish stocked in pens at different densities (30, 60, 90, and 120 fish per pen) to collect data on growth metrics, including weight and length gain, survival rates, and production performance. The analysis also included estimates of biomass production and economic yield per hectare.



## **Material and Methods**

### ***Fish origin and acclimation***

The individuals, obtained through captive reproduction, were sourced from an experimental hatchery (LAPMAR-UFSC, Florianópolis, SC) specialising in fat snook production (Cerqueira; Tsuzuki, 2008). All procedures were approved by the Institutional Committee for Animal Ethics and Experimentation (CEUA/PROPESQ/UFSC, protocol PP00231/2009). The fish were transported to the experimental site (Fazenda Experimental Yakult UFSC, Barra do Sul, SC) in appropriate 300-L transport boxes (Trevisan Equipamentos Agroindustriais Ltda., Palotina, PR) equipped with aeration and oxygen supply systems. Transport was conducted over three trips (21 October and 27 October, and 4 November), at one-week intervals, with three batches of fish ( $n = 1,000$ ).

Initially, six floating cages of  $1.0 \text{ m}^3$  ( $1 \times 1 \times 1 \text{ m}$ ) were used. The cages were constructed with PVC frames (50 mm pipes) and 3 mm mesh netting (Engepesca Ltda., Itajaí, SC) and installed in a water supply canal. During the acclimation period (21 October to 4 November), the fat snook received a commercial diet (Nicoluzzi Rações Ltda., Penha, SC) with a 2 mm pellet size and 56% crude protein. Following transfer to the experimental units (4 November), the supplemented diet was continued for an additional week. The fish received the same management during their acclimation period (8–16 December).

### ***Experimental units and design***

In a shrimp-farming pond measuring  $244 \text{ m} \times 67 \text{ m}$  ( $\sim 1 \text{ m}$  depth and  $11,450 \text{ m}^2$  total area), twelve circular fish pens were installed, each with an area of  $26.4 \text{ m}^2$ , a diameter of 5.8 m, and a height of 1.8 m. The pens were constructed from knotless multifilament netting with a 4 mm mesh. Each unit was supported by bamboo stakes spaced 1 m apart and buried 20 cm into the sediment, as was the netting, to prevent fish from escaping (Figure 1 A and 1B).





**Figure 1.** (A) Side view of the shrimp pond with fish pens during the water-filling process. (B) Front view of the shrimp pond with the fish pens partially filled.

The initial weight and length of the fat snook were  $22.3 \pm 8.0$  g and  $13.1 \pm 1.5$  cm, respectively. Four stocking densities were tested, with three replicates per treatment: 30 fish per pen ( $1.14$  fish/m<sup>2</sup>;  $25.3$  g/m<sup>2</sup>), 60 fish per pen ( $2.27$  fish/m<sup>2</sup>;  $50.6$  g/m<sup>2</sup>), 90 fish per pen ( $3.41$  fish/m<sup>2</sup>;  $76.0$  g/m<sup>2</sup>), and 120 fish per pen ( $4.54$  fish/m<sup>2</sup>;  $101.3$



g/m<sup>2</sup>). The fish were stocked on 4 November and sampled on 6 December, 20 January, 20 March, 26 April, and 24 May.

For sampling, the fish were fasted for one day before and one day after biometric measurements to minimise feed waste resulting from stress and loss of appetite. Each sample consisted of 30% of the total expected number of fish in each pen or the maximum number of fish captured. Total length was measured using an ichthyometer (cm), and body weight was measured using a digital scale (g; capacity up to 5 kg).

#### ***Feeding and water quality***

Fish were fed from Monday to Saturday, twice daily until apparent satiation, using a commercial salmonid diet (Nicoluzzi Rações Ltda., Penha, SC) with a 5 mm pellet size and 46% crude protein. The specific quantity of feed offered was not recorded.

Water quality parameters were measured daily at 16:00 h at a location near the pond gate. A digital multiparameter meter (YSI Professional Plus, Yellow Springs, OH, USA) was used to measure bottom-water temperature and dissolved oxygen. Salinity was measured once a week using a digital refractometer. The pond was equipped with a 2 HP paddlewheel aerator.

The Yakult Farm sources water from the Barra do Itapocu Lagoon, which is strongly influenced by rainfall patterns, primarily affecting salinity and alkalinity (Ferreira, 2009). Consequently, water renewal in the pond was interrupted during certain periods in summer, for up to 15 days, resulting in low water levels, salinity, and dissolved oxygen concentrations inside the pens, where the nets became fouled. This led to sudden decreases in dissolved oxygen, which fell below 2 mg/L inside the pens while remaining above 4 mg/L in the surrounding pond. Fish were observed gasping at the surface in some pens. To mitigate these conditions, an additional 2 HP paddlewheel aerator was installed, and the frequency of cleaning fouled nets was increased to improve water exchange. Mean temperature was  $25.9 \pm 3.2$  °C (range: 22–27 °C), mean dissolved oxygen concentration was  $5.8 \pm 3.0$  mg/L (range: 2–8 mg/L), and salinity ranged from 5‰ to 20‰.

#### ***Production performance data and statistical analysis***

The following parameters were calculated for each experimental unit:

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

$$\text{Specific growth rate (\%/day)} = \left[ \frac{\ln(\text{final weight}) - \ln(\text{initial weight})}{(\text{cultivation days})} \right] \times 100 \quad (2)$$

$$\text{Length gain (cm)} = \text{Length gain (cm)} \quad (3)$$



$$\text{Fulton's Condition Factor (K)} = \left[ \frac{(\text{final weight})}{(\text{final length}^3)} \right] \times 100 \quad (4)$$

$$\text{Biomass (g)} = \text{number of fish} \times \text{weight} \quad (5)$$

$$\text{Survival Rate (\%)} = \left[ \frac{(\text{final number of fish})}{(\text{initial number of fish})} \right] \times 100 \quad (6)$$

Means and standard deviations ( $\pm$  SD) of these parameters were calculated for each individual sample ( $n \geq 15$ ) and for each stocking density ( $n = 3$  or  $2$ ). Regression analysis was used to evaluate the influence of stocking density (independent variable) on growth (dependent variable) in fat snook, whereas one-way ANOVA was applied to common snook. The coefficient of variation (standard deviation/mean  $\times 100$ ) was used to assess the dispersion of weight gain.

## Results

### *Growth performance and seasonal trends*

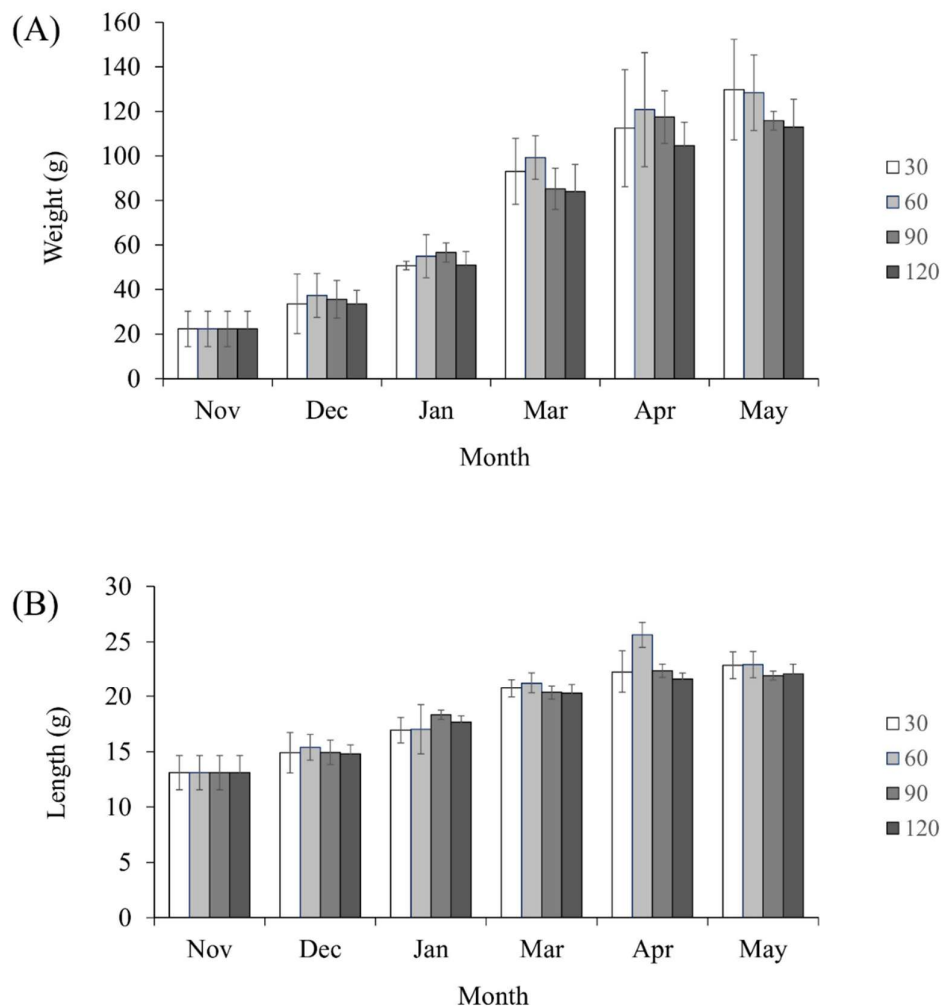
Growth in weight and total length was significant during the first months of the study (December to April). However, a clear seasonal trend was observed, with growth in fat snook virtually stagnating during the autumn months (April to May) (Figures 2 and 3).

Stocking density had a significant influence on final individual performance. Final weights ranged from  $113.0 \pm 12.5$  g (density 120) to  $129.8 \pm 22.6$  g (density 30). Regression analysis confirmed that increased stocking density negatively affected final weight ( $p \approx 0.036$ ; Figure 4A). Specific growth rate (SGR) followed a similar trend, being higher in the lower-density treatments (Table 1). Fulton's condition factor (K), however, showed no significant variation among treatments. The weight-length relationship analysis (Figure 4B) further illustrated the distinct dispersion patterns and supported the higher condition factor (K) values (1.04–1.10) observed in the fish.



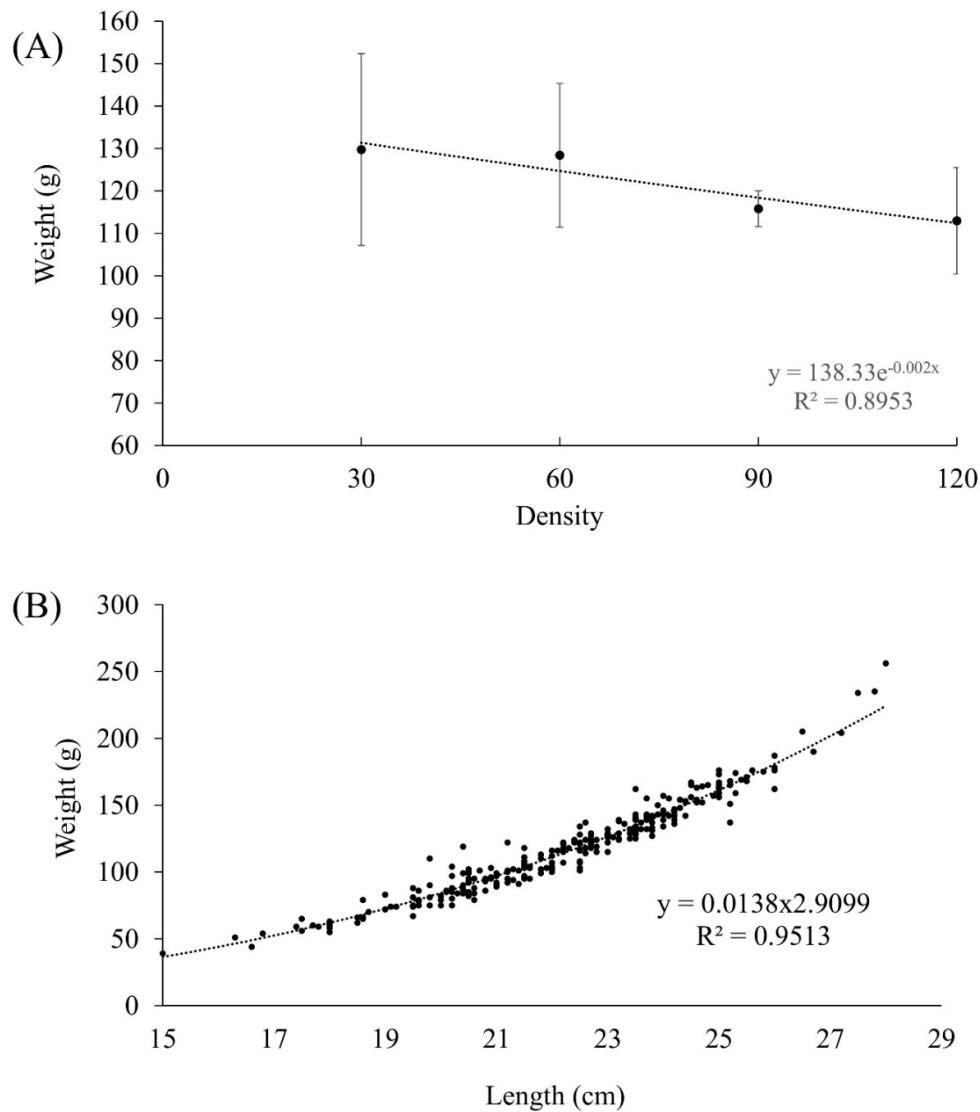


**Figure 2.** Juvenile fat snook (*Centropomus parallelus*) farmed at different densities (30, 60, 90, and 120 fish/pen) in fish pens integrated with marine shrimp farming after 202 days of culture from November to May.



**Figure 3.** Growth in weight (g) and total length (cm) of performance of juvenile fat snook (*Centropomus parallelus*) farmed at different densities (30, 60, 90, and 120 fish/pen) in fish pens integrated with marine shrimp farming after 202 days of culture from November to May.





**Figure 4.** (A) Final weight of performance of juvenile fat snook (*Centropomus parallelus*) farmed at different densities (30, 60, 90, and 120 fish/pen) in fish pens integrated with marine shrimp farming after 202 days of culture from November to May. (B) Final length-weight relationship. A: n=266, B: n= 74.

**Table 1.** Production performance of juvenile fat snook (*Centropomus parallelus*) farmed at different densities (30, 60, 90, and 120 fish/pen) in fish pens integrated with marine shrimp farming after 202 days of culture. Initial coefficient of variation (CVi), final coefficient of variation (CVf), specific growth rate (SGR %/day), Fulton's condition factor (K).

| Growth parameters   | Treatments (fish/pen) |              |             |              |
|---------------------|-----------------------|--------------|-------------|--------------|
|                     | 30                    | 60           | 90          | 120          |
| Initial weight (g)  | 22.3 ± 8.0            | 22.3 ± 8.0   | 22.3 ± 8.0  | 22.3 ± 8.0   |
| CVi (%)             | 35.7                  | 35.7         | 35.7        | 35.7         |
| Final weight (g)    | 129.8 ± 22.6          | 128.4 ± 16.9 | 115.8 ± 4.2 | 113.0 ± 12.5 |
| CVf (%)             | 31.7                  | 23.9         | 29.5        | 25.5         |
| Initial length (cm) | 13.1 ± 1.5            | 13.1 ± 1.5   | 13.1 ± 1.5  | 13.1 ± 1.5   |
| Final length (cm)   | 22.9 ± 1.2            | 22.9 ± 1.2   | 22.0 ± 0.5  | 22.1 ± 0.9   |
| Weight gain (g)     | 107.4 ± 22.6          | 106.1 ± 16.9 | 93.5 ± 4.2  | 90.6 ± 12.5  |
| Length gain (cm)    | 9.8 ± 1.2             | 9.8 ± 1.2    | 8.8 ± 0.4   | 9.0 ± 0.9    |

|                                   |                |               |                 |                |
|-----------------------------------|----------------|---------------|-----------------|----------------|
| SGR (%/day)                       | 0.87 ± 0.08    | 0.86 ± 0.07   | 0.81 ± 0.02     | 0.80 ± 0.05    |
| Fulton's condition                | 1.08 ± 0.01    | 1.06 ± 0.02   | 1.10 ± 0.03     | 1.04 ± 0.01    |
| Biomass gain (g)                  | 1327.0 ± 431.6 | 774.5 ± 188.8 | 2865.4 ± 1255.6 | 1959.0 ± 752.3 |
| Final density (g/m <sup>2</sup> ) | 75.5 ± 16.3    | 80.0 ± 7.1    | 184.4 ± 47.5    | 175.4 ± 28.5   |

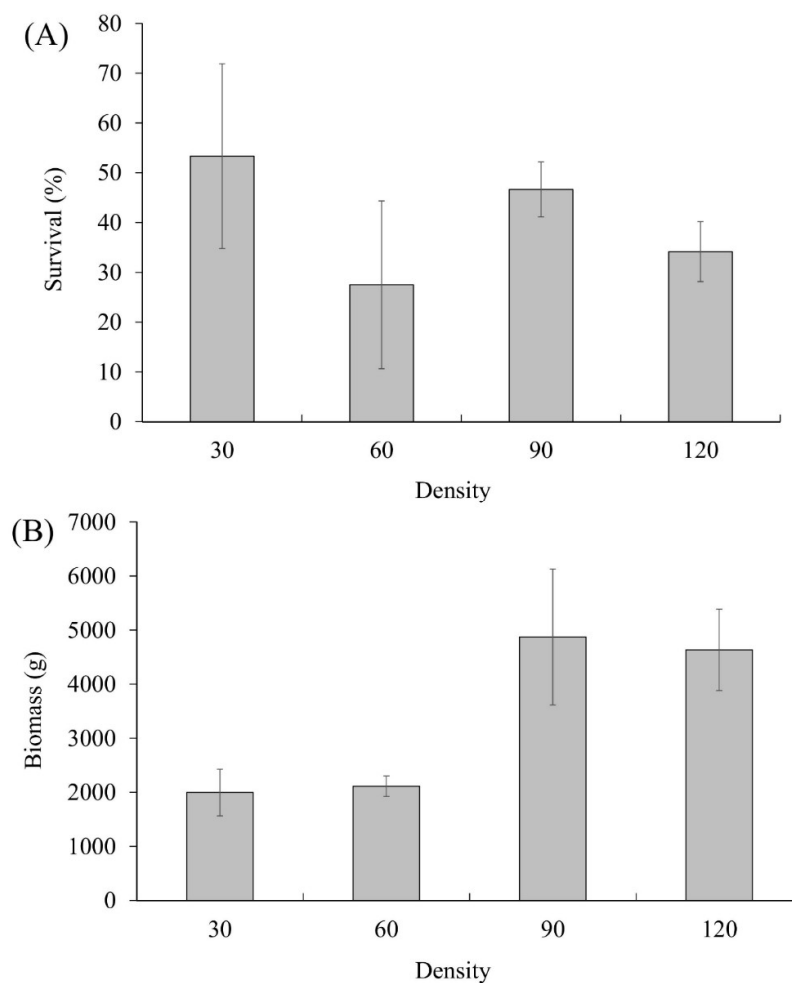
Note: Densities 30, 90, and 120: n=3; Density 60: n=2.

### Water quality and survival challenges

Survival of fat snook (Figure 5A) ranged from 27.5% to 53.3%, with no clear correlation with stocking density. Mortality occurred in intense, sporadic events that affected treatments at random (e.g., 40 deaths in a single pen in one day). The primary causes were identified as hypoxia and avian predation. Before the March sampling, fish escaped from one pen in the 60-fish treatment, resulting in only two replicates for this treatment.

### Biomass production

Final biomass was strongly influenced by survival rates (Figure 5B). Densities 90 and 120 achieved significantly higher final biomass (1,841.1 g and 1,752.9 g, respectively) compared to densities 30 and 60.



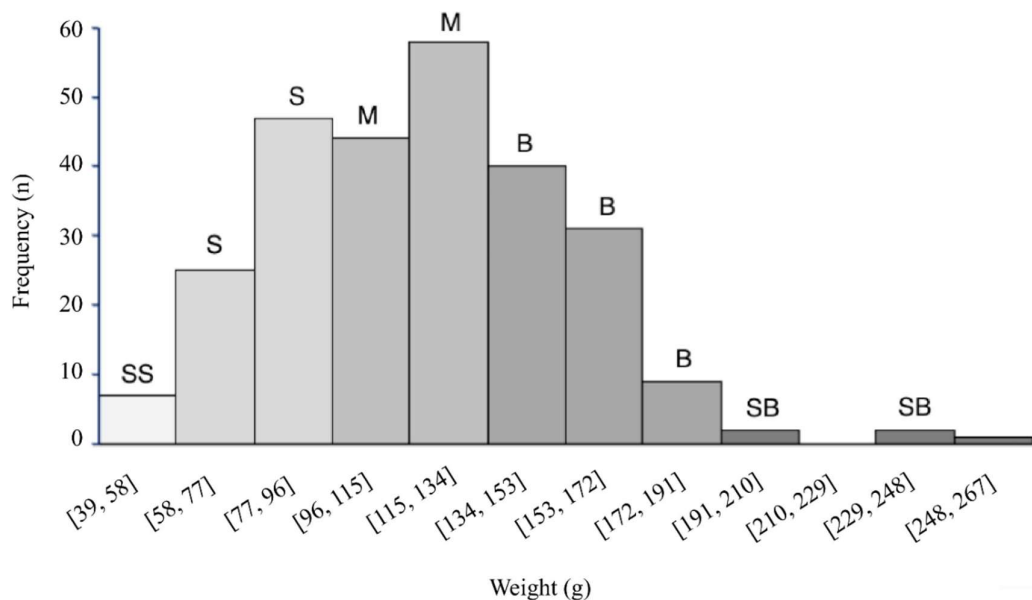
**Figure 5.** (A) Survival of performance of juvenile fat snook (*Centropomus parallelus*) farmed at different densities (30, 60, 90, and 120 fish/pen) in fish pens integrated with marine shrimp farming after 202



days of culture from November to May. (B) Final biomass (g) of fat snook juveniles at different densities (fish/pen).

### Size distribution and heterogeneity

The coefficient of variation (CV) for final weight ranged from 18.1% to 31.7%, representing a decrease from the initial values (25.0–40.7%) and indicating a trend towards lower heterogeneity. Frequency histograms (Figure 6) allowed the fish to be classified into specific weight categories. Most fish fell into the “Small” (58–96 g, 27.1%), “Median” (96–134 g, 38.3%), and “Big” (134–191 g, 30.1%) categories, with only 1.9% reaching the “Super Big” category (>191 g) and 2.6% falling into the “Super Small” category (<58 g).



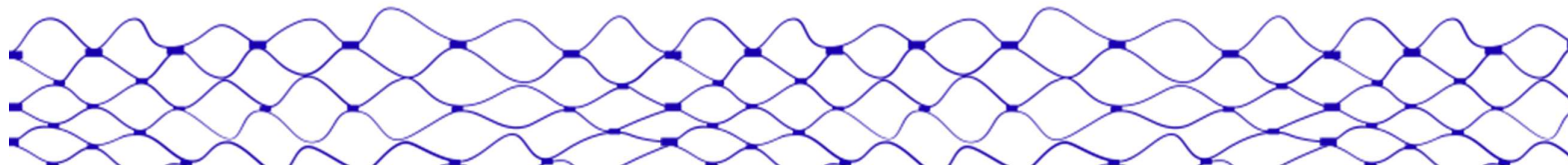
**Figure 6.** Frequency histogram of final weight of performance of juvenile fat snook (*Centropomus parallelus*) farmed at different densities (30, 60, 90, and 120 fish/pen) in fish pens integrated with marine shrimp farming after 202 days of culture from November to May. SS=super small, S=small, M=median, B=big, SB= super big. A: n=266, mean=118.5 g, sd=35.3, cv=29.8%. B: n=74, mean=221.1 g, sd=50.3, cv=22.7%.

### Production and economic simulation

Simulations for fat snook (Table 2) showed that while density 120 projected the highest biomass under experimental conditions, transitioning to commercial sizes (250 g and 450 g) would yield much more significant gains in both biomass and income. The simulated values are competitive for both the domestic (R\$ 30.00/kg) and international (US\$ 10.00/kg) markets, with the latter being more viable for larger fish.

**Table 2.** Simulation of production and yield per hectare for fat snook (*Centropomus parallelus*) varying density (30, 60, 90, and 120 fish/pen), final weight, and sales price after 202 days of culture.

| Density | Density (fish/m <sup>2</sup> ) |       | Weight (g) | Biomass (kg/ha) | Yield (R\$/ha) |            |
|---------|--------------------------------|-------|------------|-----------------|----------------|------------|
|         | Initial                        | Final |            |                 | R\$ 30/kg      | 10 US\$/kg |
| 30      | 1.14                           | 0.61  | 129.8      | 785.8           | 23,573.02      | 41,881.41  |
| 60      | 2.27                           | 0.62  | 128.4      | 801.8           | 24,054.76      | 42,737.28  |
| 90      | 3.41                           | 1.59  | 115.8      | 1,841.1         | 55,233.60      | 98,131.70  |



|            |      |      |       |         |            |            |
|------------|------|------|-------|---------|------------|------------|
| 120        | 4.54 | 1.55 | 113.0 | 1,752.9 | 52,587.69  | 93,430.80  |
| Scenario 1 | 1.00 | 1.00 | 250.0 | 2,500.0 | 75,000.00  | 133,250.00 |
| Scenario 2 | 1.00 | 1.00 | 450.0 | 4,500.0 | 135,000.00 | 239,850.00 |

## Discussion

This study represents the first report of snook rearing in fish pens integrated with shrimp-farming infrastructure, demonstrating both the technical feasibility and operational challenges of this novel production approach. Water quality, particularly dissolved oxygen, emerged as the most critical factor influencing survival and performance. Although centropomids are known to tolerate dissolved oxygen concentrations below 1 mg/L for short periods, normal development and optimal growth require concentrations of 4.0–5.0 mg/L (Rocha & Okada, 1980). The hypoxic events observed in the present study, during which dissolved oxygen concentrations dropped below 2 mg/L inside the pens while remaining above 4 mg/L in the surrounding pond, highlight the vulnerability of fish confined in net enclosures when water exchange is restricted by net fouling or inadequate circulation. Temperature also played a significant role, as temperatures below 20 °C are known to impair metabolic function in snook (Silva et al., 2021), and the observed growth stagnation during the autumn–winter period in this subtropical region is consistent with the species' thermal requirements. The higher survival rate observed in fat snook (90% in some treatments) under these suboptimal conditions is consistent with previous findings by Liebl et al. (2016), who reported similar species-specific differences in stress tolerance. This species is euryhaline and has been successfully reared across a wide range of salinities, including in freshwater environments (Tucker Jr., 1987; Costa Filho et al., 2017), confirming that salinity variation was not a limiting factor in the present study. Importantly, the mortality events observed were primarily linked to operational constraints—specifically, inadequate aeration and net fouling that restricted water flow—rather than to intrinsic species sensitivity, indicating that improved husbandry practices could substantially enhance survival outcomes in integrated pen systems.

Growth performance and biomass gain in the present study were likely constrained by adverse environmental conditions and the use of a commercial salmonid diet that was not specifically formulated to meet the nutritional requirements of snook. Despite this limitation, no evident nutritional deficiencies were observed, and parasitological analyses revealed no probable causes of performance impairment (Tancredo et al., 2015), suggesting that the diet was adequate for maintenance and moderate growth. The observed growth rates were within the expected range based on previous studies of snook culture in cages and ponds. Ostini et al. (2007) reported weight gains of approximately 98.6 g over 160 days for fat snook juveniles stocked at 20 fish/m<sup>3</sup> in floating net cages, while Liebl et al. (2016) documented final weights of 34.5–42.4 g for fat snook juveniles reared at densities of 12.5–37.5 fish/m<sup>3</sup> over a similar period. Barbosa et al. (2011) and other studies have similarly reported moderate growth rates for fat snook under



suboptimal temperature regimes. For common snook in cage culture at densities of 10, 20, and 40 fish/m<sup>3</sup>, a final weight of up to 364.7 g and a yield of 11.6 kg/m<sup>3</sup> were obtained (Silva et al., 2021). Under favourable temperature conditions (26–30 °C), fat snook can reach approximately 250 g in about one year, while common snook can attain approximately 450 g over the same period (Cerqueira et al., 2020). The slower growth observed in the present study reflects the combined effects of cooler autumn–winter temperatures and the non-optimised diet, underscoring the importance of thermal management and species-specific feed formulation for achieving commercial production targets in integrated systems.

The influence of stocking density on growth and biomass production observed in this study corroborates findings from previous research on snook cage culture. Ostini et al. (2007) studied fat snook in floating net cages and found that higher stocking densities yielded greater total biomass per cage but resulted in lower individual weight gain. Similarly, Liebl et al. (2016) reported a linear increase in biomass with increasing stocking density, with survival rates of around 90% for fat snook and no significant negative effect on growth at moderate densities. Souza-Filho and Cerqueira (2003) demonstrated in laboratory tanks that lower densities (3 fish/m<sup>3</sup>) maximised individual growth and feed conversion efficiency, whereas higher densities (9 fish/m<sup>3</sup>) increased biomass per unit volume. These findings reinforce the viability of moderate-to-high stocking densities in integrated pen systems, provided that water quality and feeding management are adequate. The results of the present study align with this body of evidence, showing that although individual growth may be slightly reduced at higher densities, total biomass production per unit area increases, which is economically favourable when operational constraints such as dissolved oxygen and net maintenance are properly managed.

Size variation within cohorts was a notable feature, necessitating size grading at different production stages and batch harvesting as fish reached commercial size. This heterogeneity is a common challenge in intensive aquaculture and has been extensively documented in other marine species, such as European sea bass and barramundi (Parazo et al., 1991; Ribeiro & Qin, 2013). Size grading is routinely used to reduce cannibalism, improve feeding efficiency, and enhance harvest uniformity. Cannibalism has been specifically documented in snook culture, with studies reporting higher mortality in groups with heterogeneous sizes and at elevated stocking densities (Correa & Cerqueira, 2007; Hans et al., 2020). The observed size variation in the present study, reflected in the coefficient of variation for final weight (18.1–31.7%), underscores the need for regular size-grading protocols to minimise competitive interactions and cannibalistic behaviour, thereby improving overall survival and production efficiency in integrated pen systems.

Stocking densities in cages and net pens for snook are typically much higher than those used in earthen ponds or shrimp ponds, with reported densities ranging from 12 to 40 fish/m<sup>3</sup> in grow-out systems and up to 100–200 fish/m<sup>3</sup> in intensive nurseries (Ostini et al., 2007; Tsuzuki & Berestinas, 2008). In contrast, barramundi culture in shrimp ponds in Asia employs densities of around 1–5 fish/m<sup>2</sup> in grow-out



ponds, with reported production yields of up to 740 kg/ha/year in successful polyculture systems (Singh, 2000).

The time required to reach commercial size is a critical determinant of economic feasibility: fat snook can reach approximately 250 g in about one year under optimal temperature conditions, while common snook can attain approximately 450 g over the same period (Cerqueira et al., 2020). Market value and production cost analyses are essential for assessing viability. Silva et al. (2022) reported a production cost of USD 6.79/kg for common snook in floating cages in Brazil, with economic viability requiring a sales price above USD 8.39/kg under the modelled scale and production targets. Sanches et al. (2014) proposed a minimum market price of R\$20.00/kg for snook cultured in shrimp-farm ponds in north-eastern Brazil.

In Mexico, bioeconomic modelling for *Centropomus viridis* demonstrated strong profitability potential at a commercial size of 600 g (Montoya-Ponce et al., 2014). Giovanni et al. (2022) conducted a technical-economic assessment of *C. viridis* production in floating cages in a north-western Mexican coastal lagoon, further supporting the feasibility of cage grow-out operations. Almendarez-Hernández et al. (2024) examined consumer purchasing factors for snook, providing insights into market demand and pricing dynamics. Collectively, these economic analyses indicate that snook culture in integrated systems can be economically attractive. The simulations presented in the present study, showing potential yields of 2,500–10,000 kg/ha/year at commercial sizes of 250–1,000 g, suggest that integrated snook–shrimp farming could generate competitive returns in both domestic and international markets.

Future research is needed to advance this novel culture approach and optimise production protocols for snook in integrated shrimp-farming systems. Key areas for investigation include the development of stage-specific rearing protocols that separate the different production phases—nursery, pre-grow-out, and grow-out—within pen systems, with appropriate size grading implemented at each transition to minimise size heterogeneity. Net mesh size should be adjusted as the fish grow to maintain adequate water exchange and reduce fouling. The feasibility of culturing snook directly in shrimp ponds without pens should also be explored. Adequate oxygen management through strategic aeration and temperature control during critical seasonal periods will be essential. Conservative initial stocking densities of around 1 fish/m are recommended as a starting point for integrated pond systems, with density optimisation based on site-specific water quality. Continued research and on-farm trials will be critical for translating the technical feasibility demonstrated in this study into economically viable commercial production systems.

## Conclusion

This study demonstrated the technical feasibility of pre-fattening juvenile *Centropomus parallelus* in shrimp ponds at densities that may allow commercial production, provided that measures are taken to maintain adequate water quality, particularly with respect to dissolved oxygen. This approach may represent a viable



alternative for small and large shrimp farms with deactivated facilities, requiring only minor modifications to existing management routines to adopt fish farming.

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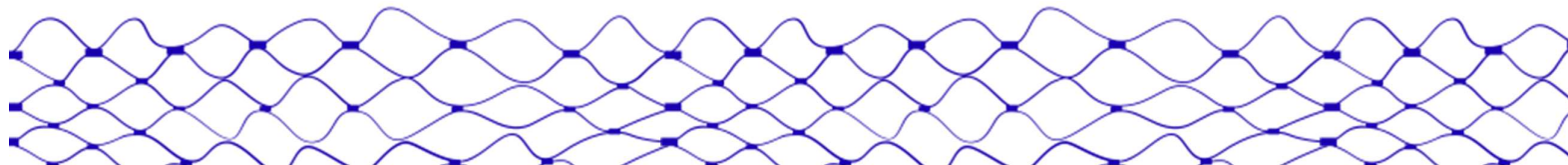
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### Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used “SciSpace AI” and “Jenni AI” to improve the English language, grammar, and readability of the text. After using this tool, the authors thoroughly reviewed, verified, and edited all text and visual content as needed, and take full responsibility for the final content of the publication.

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