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Research Article

Impact of Stocking Density on Bioeconomic Performances of Blue Swimming Crab (*Portunus pelagicus*) Culture in Grow-Out Ponds

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ABSTRACT

The blue swimming crab (BSC) is a commercially important species with high consumer demand, but escalating exploitation has negatively impacted its natural populations. Establishing effective cultivation methods for BSC offered a promising long-term solution to this issue. This study aimed to enhance stocking density in grow-out ponds by analyzing the effects on bioeconomic performance of BSC farming. The research involved rearing juvenile BSC in 1,600 m² earthen ponds at three stocking densities: low (1 crab/m²), medium (3 crabs/m²), and high (5 crabs/m²). Each group had three replicates (n = 3). BSC were fed an artificial shrimp feed (38% protein) at 5% of body weight per day, with feedings occurring twice daily. Over a 90-day period, survival rate (SR), weight gain (WG), average daily growth (ADG), specific growth rate (SGR), and feed conversion ratio (FCR) were assessed, alongside economic metrics such as total revenue (TR), break-even point (BEP), and payback period (PBP). Results indicated that stocking density significantly (p<0.05, one-way ANOVA) influenced the SR, WG, ADG, SGR, and revenue in BSC cultivation. As density increased, SR declined, and higher densities resulted in lower growth rates, reduced TR, and elevated FCR. In terms of culture efficiency, the densities of 1 and 3 crabs/m² proved to be more suitable for BSC culture compared to 5 crabs/m². However, economically, it was determined that rearing BSC at these three densities was not a worthwhile investment, with the density of 5 crabs/m² having the highest BEP (1.08 kg/m²) and PBP (7.5 years), while 1 crab/m² had the lowest BEP (0.38 kg/m²) and PBP (3.9 years). Therefore, appropriate BSC rearing guidelines should consider a density of no more than 3 crabs/m^2 for future production.

1. Introduction

Global food and nutrition security depended on the growth and development of aquaculture production systems, as fisheries and aquaculture contributed approximately 17% of total animal-source protein for human consumption. Among these, crustaceans held second place in importance (Boyd *et al*., 2022). Cai and Galli (2021) reported that marine crabs accounted for 447,372 tons of the 120 million tons of aquaculture produced worldwide in 2019, reflecting a 3.74% increase over 2018.

The blue swimming crab, *Portunus pelagicus* (BSC), is a valuable commercial species widespread across the tropical coastal waters of the western Indian Ocean and eastern Pacific. Thailand ranked as one of the world's leading producers of marine crabs (e.g., *Portunus pelagicus*, *Scylla serrata*), exporting about 42.2 million tons of BSC annually, valued at USD 35 million. Unfortunately, overexploitation led to decreasing crab populations, resulting in a decline in BSC landings and exports over the past few decades. In 2020, fishery trends showed that BSC catches remained at their highest levels. Notably, the demand for seafood is increasing, while natural marine resources are decreasing, due to overexploitation and habitat destruction, with the BSC being one of the species under threat in many Asian countries (FAO, 2022; Yulianto *et al*., 2024). Culture development of the BSC is one potential and promising long-term solution to cope with this problem. BSC culture development is a potential and promising long-term strategy to address the challenges

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facing the aquaculture sector. It offers a viable pathway to increase seafood production while reducing pressure on wild stocks, enhancing food security, and supporting rural livelihoods. By expanding culture systems ranging from hatchery-reared juveniles to grow-out operations and value-added products, this approach can improve production efficiency, enable resource diversification, and promote responsible management of coastal ecosystems.

Recently, technologies associated with BSC aquaculture had been developed or improved, including broodstock rearing (Oniam and Arkronrat, 2022; Efrizal *et al*., 2024), nursing (Konsantad *et al*., 2024; Leearam *et al*., 2024), and grow-out culture (Phinrub *et al*., 2023). However, in most of the research studies conducted up to that point, it became evident that the economic sustainability of BSC farming remained a significant issue that needed further investigation to build confidence among farmers and establish tangible sustainability in commercial crab farming.

Bioeconomic and profitability analyses were crucial for understanding the dynamics of aquaculture, as these assessments employed mathematical models to evaluate the economic benefits of productivity enhancements, such as growth, survival, and feed efficiency, while also considering broader impacts on ecosystems and economies (Rabassó and Hernández, 2015; Llorente and Luna, 2016).

Bioeconomic studies provided valuable insights by examining the interactions between biological processes, economic factors, and environmental conditions in aquaculture systems (Llorente and Luna, 2016; Boyd *et al*., 2020). For crab aquaculture, stocking density was a critical factor that influenced the success of production, yet the optimal level for crab cultivation remained uncertain, with studies reporting varying outcomes (Mugwanya *et al*., 2022; Gençer, 2023; Zhang *et al*., 2023). Determining the ideal stocking density for aquatic animal cultivation proved complex, requiring a balance of factors such as species, growth rates, behavior, water quality, and the overall welfare of the animals (Farhaduzzaman *et al*., 2020). These factors impacted the bioeconomic and profitability outcomes of the cultured species (Llorente and Luna, 2016).

Although advances in BSC culture technology have been made, there is still no clear data on the stocking density that is appropriate from a bioeconomic perspective. The current study aimed to investigate the effects of varying stocking densities on bioeconomic parameters (growth rate, survival rate, and feed conversion ratio) and profitability, with the objective of optimizing production while ensuring the health and well-being of the cultured BSC.

2. Materials and Methods

2.1 Experimental design and set-up

The study was conducted at the Klongwan Fisheries Research Station (KFRS) in Thailand. Juvenile blue swimming crabs, *Portunus pelagicus* (BSC), with a carapace width of 1.5-2.0 cm (about 40-45 days after hatching) were transferred from the KFRS hatchery to be reared in a 1,600 m² grow-out pond. This experiment was designed (CRD) to investigate the impact of three stocking densities on BSC cultivation: low (1 crab/m²), medium (3 crabs/m²), and high (5 crabs/m²). Each treatment group had three replicates (n = 3). The duration of the study was from April 2022 to March 2024.

BSCs were fed artificial shrimp feed according to Oniam *et al*. (2012). In the first 30 days, crabs received shrimp feed No. 2 (pellet size 0.8 – 1 mm, 38% protein) at 30% of body weight/day. From days 31 to 60, BSCs were given shrimp feed No. 4S (pellet size 3.5 mm, 38% protein) at 5% of body weight/day, followed by 3% until day 90. Throughout the experiment, BSCs were fed twice a day at 0900 and 1700 hours.

2.2 Data collection

During the experiments, approximately half of the pond water was exchanged weekly, and water quality parameters were monitored twice a week. Salinity was measured using a refractometer (Prima Tech), and pH was assessed with a portable pH meter (Cyber Scan pH 11). Dissolved oxygen and temperature were recorded with an oxygen probe (YSI 550A), while total ammonia, nitrite, and alkalinity were determined according to the standard methods of APHA, AWWA and WEF (2023).

Over a 90-day period, for bioeconomic considerations, survival (SR), growth rates such as weight gain (WG), average daily growth (ADG) and specific growth rate (SGR), as well as feed conversion ratio (FCR) were calculated using Equations 1, 2, 3, 4 and 5, respectively:

$$\mathrm{SR}\ (\%) = \left(\frac{\text{Number of crab surviving}}{\text{Number of crab stocked}}\right) \times 100 \quad (1)$$

$$\mathrm{WG}\ (\mathrm{g}) = \text{Final BW} - \text{Initial BW} \quad (2)$$

$$\mathrm{ADG}\ (\mathrm{g/day}) = \frac{\text{Final BW} - \text{Initial BW}}{\mathrm{t}} \quad (3)$$

$$\mathrm{SGR}(\%\mathrm{day}) = \left(\frac{ln\ \text{final BW} - ln\ \text{initial BW}}{\mathrm{t}}\right) \times 100 \quad (4)$$

$$\mathrm{FCR} = \frac{\text{Total feed given}}{\text{Total crab weight gain}} \quad (5)$$

where BW is the mean body weight, t is the growth period in days and *ln* is the Napierian logarithm.

For profitability factors, we evaluated several economic indicators, total cost (TC) of BSC farming was divided into production cost (PC) and marketing cost (MC). PC included fixed costs (FC) like land, labor, tools and equipment depreciation, and variable costs (VC) such as seeds, feed, and transportation. MC covered distribution, packaging, and advertising expenses. Total revenue (TR) and net return (NR) represented sales values, with TR calculated by subtracting TC from gross returns at various stocking densities. The break-even point (BEP) indicated when TR equaled TC, showing no profit or loss, and helped determine the quantity of BSC needed to cover all costs. Including, the payback period (PBP) is the amount of time that is expected before an investment will be returned in the form of income.

TC, PC, TR, NR, BEP and PBP were calculated using Equations 6, 7, 8, 9, 10 and 11, respectively:

$$\mathrm{TC} = \mathrm{PC} + \mathrm{MC} \quad (6)$$

$$\mathrm{PC} = \mathrm{TFC} + \mathrm{TVC} \quad (7)$$

$$\mathrm{TR} = \mathrm{P} \times \mathrm{Q} \quad (8)$$

$$\mathrm{NR} = \mathrm{TR} - \mathrm{TC} \quad (9)$$

$$\mathrm{BEP\ (kg/pond)} = \frac{\mathrm{TFC}}{(\mathrm{P} - \mathrm{VCU})} \quad (10)$$

$$\mathrm{PBP\ (year)} = \frac{\mathrm{Initial\ investment}}{\mathrm{TR\ per\ year}} \quad (11)$$

where TFC is the total fixed costs, TVC is the total variable costs, P is the price per unit of BSC/kg, Q is the total quantity of BSC in kg and VCU is the variable cost per unit of yield = TVC / Q measured in cost per kilograms, where all costs are in THB.

2.3 Data analysis

Statistical analysis was conducted using IBM SPSS Statistics (version 26.0; IBM Corp.; Armonk, NY, USA). Group differences were assessed with one-way ANOVA and Duncan's multiple range test at the 95% confidence level. Data were presented as mean ± SD values, and key measures (average, percentage, and ratios) were summarized in tables to evaluate economic characteristics, while profitability was assessed using a quantitative method.

3. Results and Discussion

3.1 Stocking density on growth and survival

The initial size of blue swimming crab *Portunus pelagicus* (BSC) released into ponds was similar across all density groups (body weight ranged between 0.08±0.02 and 0.10±0.03 g), as shown in Table 1. It was apparent that stocking densities affected the weight gain of BSC reared; density-dependent growth was evident, with low-density (1 crab/m^2) (85.47±10.21 g BW) and medium-density (3 crabs/m^2) (77.37±6.22 g BW) groups being the largest (p<0.05) followed by high-density group (5 crabs/m^2) (55.94±6.42 g BW). Likewise, ADG and SGR decreased with high-density group (p<0.05). The survival rate of low-density group (45.50±5.91%) was significantly higher (p<0.05) than that of the medium-density group (18.51±1.29%) meanwhile the lowest survival (p<0.05) was noted in the high-density group (10.17±1.21%) (Table 1).

3.2 Stocking density on bioeconomic performance

The yield and bioeconomic data of BSC harvested after 90 days of rearing showed that an increase in FCR was observed in the high-density group. The most favorable FCR was recorded in the low-density (1.48±0.24) and medium-density (2.24±0.14) groups, while the highest FCR (5.44±1.43) (p<0.05) was observed in the high-density group. As expected, the high-density group yielded the lowest yield. However, the yields of the low- and medium-density groups were similar and higher than those of the high-density group (Table 1).

The mean water conditions in the rearing ponds of BSC showed no significant differences among treatments (p>0.05). Water quality parameters, including salinity (31.25±1.15 – 32.82±0.75 ppt), temperature (29.18±0.94 – 30.15±0.73°C), dissolved oxygen (4.35±0.46–5.01±0.63 mg/L), pH (7.89±0.16 – 8.12±0.22), total ammonia (0.21±0.16 – 0.32±0.11 mg-N/L), nitrite (0.00±0.01 – 0.01±0.01 mg-N/L), and alkalinity (117.98±12.42 – 124.56±16.80 mg/L as $CaCO_3$), remained within suitable ranges and did not impact BSC rearing (Oniam and Arkronrat, 2022; Phinrub *et al*., 2023; Efrizal *et al*., 2024). Thus, the differences in BSC productivity in grow-out ponds were attributed to stocking density rather than water quality.

For profitability, the expenses and profits related to rearing BSC in this study are detailed in Table 2. The production costs, especially for variable costs, such as seed and feed, tended to increase with higher stocking densities. Based on the results, rearing BSC at high-density had the highest total cost (THB 95,897) compared to the medium-density and low-density groups. The highest average total revenue per pond (per crop) was also achieved with the medium-density group (THB 17,152), suggesting that an optimum density might lead to increased revenue. However, for BSC farming at these three densities, the returns received were still not worth the investment which yielded a negative net return of -34.55 to -52.81 THB/m^2 of pond (Table 2). Farming at group incurred the highest capital cost per production unit, followed by medium density, while low-density group experienced the least losses.

In terms of break-even points, the BSC farming operations at low-, medium-, and high-density groups reported values of 0.38, 0.72, and 1.08 kg/m², respectively. These figures highlighted a clear need for substantial mass production in order to reach a break-even status. Furthermore, the payback periods for the different farming densities were also notable, with periods of 3.9 years for low-density, 4.2 years for medium-density, and a significantly longer 7.5 years for high density groups (Table 2). The payback periods in aquaculture were highly context-specific (species, system, scale, location, input costs, market prices). There was no single "ideal" payback that applied universally to marine crabs or other aquaculture. In practice, operators aimed for payback ranges of about 2–5 years for intensive systems and 3–7 years for semi-intensive or extensive setups, but these varied widely (Llorente and Luna, 2016; Farhaduzzaman *et al*., 2020; Arkronrat *et al*., 2024).

The current study showed that, despite efforts to optimize BSC farming at three different densities, the returns ultimately fell short of justifying the investment made. Among the various farming densities, high density proved to incur the highest capital costs per production unit. This was followed closely by medium-density, while low-density operations, although less profitable, experienced the least financial losses. These results underscore the challenges faced in achieving profitability within the BSC farming sector, particularly at higher densities where the financial risks and capital investments were markedly elevated.

Stocking density, the number of aquatic organisms per unit area or volume, played a pivotal role in the success of aquaculture operations (Boyd *et al*., 2020). The optimal stocking density varied among species, with each having a specific range that maximized growth (Farhaduzzaman *et al*., 2020). For crustacean, such as crabs, shrimps, and lobsters, at higher densities, competition for food and space hindered individual growth rates and led to size disparities within population. While the initial production rate may have increased at high density, the long-term effects often included reduced growth and higher mortality (Madzivanzira *et al*., 2020; Liew *et al*., 2024). From an economic standpoint, higher densities reduced per-unit production costs due to increased output. However, this had to be weighed against potential costs related to culture management and the need for improved water quality (Farhaduzzaman *et al*., 2020; Arkronrat *et al*., 2024). The market demand for specific sizes and qualities of crab also significantly influenced economic viability; overcrowding led to smaller, less marketable crabs (Liew *et al*., 2024). High stocking densities elevated stress levels among aquatic animals, making them more vulnerable to diseases. Stress negatively impacted feed conversion ratios and resulted in increased mortality rates (Boyd *et al*., 2020).

In the present study, it was observed that varying the density of the BSC during grow-out pond cultivation affected bioeconomic outcomes. As the stocking density increased, growth performance parameters (AG, ADG and SGR) declined, and the FCR worsened. The effects of stocking density on crab culture were multifaceted and varied with several factors: species, life stage, culture system and environmental conditions (Mugwanya *et al*., 2022; Gençer, 2023; Zhang *et al*., 2023). In crustacean cultivation, at lower stocking densities, they demonstrated diminished cannibalism, decreased resource competition (such as food and shelter), and reduced stress levels, thereby potentially enhancing their growth and survival rates (Farhaduzzaman *et al*., 2020; Madzivanzira *et al*., 2020; Manh *et al*., 2023).

Table 1 Bioeconomic data after 90 days of rearing in terms of growth, survival, feed conversion ratio, and yield of blue swimming crab (*Portunus pelagicus*) cultivated in 1,600 m^2 earthen pond at different stocking densities (n = 3).

Parameters	Density		
	Low (1 crab/m^2)	Medium (3 crabs/m^2)	High (5 crabs/m^2)
Initial body weight (g)	0.09±0.03^a	0.10±0.03^a	0.08±0.02^a
Weight gain (g)	85.47±10.21^a	77.37±6.22^a	55.94±6.42^b
Average daily growth (g/day)	0.95±0.11^a	0.86±0.07^a	0.62±0.07^b
Specific growth rate (%/day)	7.61±0.13^a	7.50±0.09^a	7.14±0.12^b
Survival rate (%)	45.50±5.91^a	18.51±1.29^b	10.17±1.21^c
Feed conversion ratio	1.48±0.24^a	2.24±0.14^a	5.44±1.43^b
Yield (kg/pond)	62.14±10.26^a	68.63±5.44^a	45.61±7.90^b

Means in each row followed by different letters indicate a significant difference ($p<0.05$).

Table 2 Fixed, variable, average production, and marketing costs and total costs and benefits for blue swimming crab (*Portunus pelagicus*) cultivated in 1,600 m^2 earthen pond at different stocking densities after 90 days (n = 3).

Parameters	Density		
	Low (1 crab/m^2)	Medium (3 crabs/m^2)	High (5 crabs/m^2)
Fixed cost			
Land cost (THB)[(1)]	2,500	2,500	2,500
Labor cost (THB)	27,000	27,000	27,000
Tools (THB)	30,000	30,000	30,000
Equipment depreciation (THB)[(2)]	2,466	2,466	2,466
Total (THB)	61,966	61,966	61,966

Table 2 (Continuous)

Parameters	Density		
	Low (1 crab/m^2)	**Medium (3 crabs/m^2)**	**High (5 crabs/m^2)**
Variable cost			
Seed cost (THB)	4,800	14,400	24,000
Feed cost (THB)	3,545	6,042	9,431
Other miscellaneous costs (THB)	200	200	200
Total (THB)	8,545	20,642	33,631
Production cost (THB)	70,511	82,608	95,597
Marketing cost (THB)(3)	300	300	300
Total cost (THB)	70,811	82,908	95,897
Initial investment (THB/year)	177,969	214,159	253,126
Benefit			
Total quantity of crab (kg/pond)	62.14	68.63	45.61
Price per unit of crab (THB/kg)	250	250	250
Total revenue (THB/pond/crop)	15,536	17,152	11,408
Net return (THB/m^2 of pond)	-34.55	-41.09	-52.81
Break-even point (kg/ m^2 of pond)	0.38	0.72	1.08
Pay back period (year)	3.9	4.2	7.5

Note: (1) Typically, farmers pay rental fees for pond areas, which vary based on factors such as area size, location, and government regulations. On average, fees are in the range of THB 5,000–20,000/rai/year, with an average of approximately THB 10,000/year. (2) Annual depreciation calculated using (cost of asset - salvage value) / useful life, with a service life of 3 years. (3) MC derived from shipping and packaging expenses associated with transporting crab per pond.

In the present study, it was observed that varying the density of the BSC during grow-out pond cultivation affected bioeconomic outcomes. As the stocking density increased, growth performance parameters (AG, ADG and SGR) declined, and the FCR worsened. The effects of stocking density on crab culture were multifaceted and varied with several factors: species, life stage, culture system and environmental conditions (Mugwanya *et al*., 2022; Gençer, 2023; Zhang *et al*., 2023). In crustacean cultivation, at lower stocking densities, they demonstrated diminished cannibalism, decreased resource competition (such as food and shelter), and reduced stress levels, thereby potentially enhancing their growth and survival rates (Farhaduzzaman *et al*., 2020; Madzivanzira *et al*., 2020; Manh *et al*., 2023).

Several studies examined the relationship between stocking density and various performance indicators in crab cultivation. For instance, Gençer (2023) reported that a stocking density of 5 crabs per 0.7 L tank resulted in the highest growth and survival rates for the blue crab (*Callinectes sapidus*) compared to densities of 10 and 15 crabs per 0.7 L tank. Similarly, research on the Chinese mitten crab (*Eriocheir sinensis*) by Zhang *et al*. (2023), the mud crab (*Scylla* spp.) by Liew *et al*. (2024), and other crustaceans (Bardera *et al*., 2021; Arkronrat *et al*., 2024) indicated that optimum stocking densities contributed to better overall welfare and enhanced physiological functioning, including reduced stress hormone levels and improved immune function.

These studies suggested that the optimal stocking density for crab cultivation varied significantly depending on the specific species and their respective life stages. Additionally, it was noted that other critical factors, such as the availability of shelter and the implemented feeding strategies, also needed to be taken into account in order to achieve the best results in crab farming practices.

4. Conclusion

Increasing the stocking density of blue swimming crab (*Portunus pelagicus*) in the pond reduced their survival and growth rates while increasing the FCR. Although the three stocking densities (1, 3, and 5 crabs/m^2) in this study did not yield a return on investment, the most cost-effective density was the one that provided the highest biomass per unit area, the lowest break-even point, and the highest net income. It was clear that a stocking density of 1-3 crabs/m^2 was the most profitable of the densities tested. The interaction between stocking density and bioeconomic efficiency proved complex, requiring careful balance to ensure the growth and economic success of this crab. Emphasizing sustainable and cost-effective crab farming practices remained essential and warranted further research.

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