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Growth and survival rate of post-puerulus spiny lobster *Panulirus homarus* at different rearing systems

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Abstract. *Sahibuddin MQ, Effendi I, Diatin I, Budiardi T, Setiawati M. 2025. Growth and survival rate of post-puerulus spiny lobster* Panulirus homarus *at different rearing systems. Biodiversitas 26: 6285-6304.* Mariculture of lobsters utilizes Floating Net Cages (FNC), Submersible Net Cages (SNC), and Bottom Net Cages (BNC). This study analyzed the growth and Survival Rate (SR) of post-puerulus *Panulirus homarus* in these three rearing systems. Post-puerulus individuals (0.86±0.06 cm carapace length; 0.28±0.04 g body weight) were reared in net cages (height 0.8 m; diameter 1 m) at a stocking density of 100 individuals cage^{-1}, with three replicates. The lobsters were fed a moist diet once daily (4:00-5:00 PM). The different rearing system significantly influenced specific growth rate (SGR), Absolute Growth Rate (AGR), total molting, Feed Conversion Ratio (FCR), Intermoult Period (IMP), and SR. The FNC and BNC treatments demonstrated the highest SGR (*p*: 0.012), at 2.80±0.022% day^{-1} and 2.76±0.078% day^{-1}, respectively. These treatments also produced the highest AGR (*p*: 0.013), at 0.07±0.004 g day^{-1} and 0.06±0.006 g day^{-1}, respectively. The highest total molting (*p*: 0.025) occurred in the FNC (45.33±9.074 times cage^{-1}) and BNC (43.67±5.033 times cage^{-1}) treatments. The BNC treatment achieved the lowest FCR (7.34±0.372), which was not significantly different from FNC but was significantly lower than SNC (*p*: 0.032). The FNC treatment resulted in the shortest IMP (14.37±0.38 days, *p*: 0.000), while the highest SR was observed in the BNC treatment (71.00±2.00%, *p*: 0.000). Additionally, the lowest glucose (14.14±1.58 mg dL^{-1}, *p*: 0.031) and total hemocyte count (1.81±0.29x10^{7} cells mL^{-1}, *p*: 0.000) were recorded in the BNC treatment. These findings indicate that the BNC treatment provided the highest SR and the lowest stress response for post-puerulus *P. homarus*.

Keywords: Crustacea, growth, post-puerulus *Panulirus homarus*, rearing system, survival

INTRODUCTION

Panulirus homarus (Linnaeus, 1758) is a valuable fishery resource in the Indo-West Pacific region. This species typically lives in coral reefs and rough waters with strong currents, at depths from 1 to 90 meters (FAO 2025). Due to its high-quality meat and nutritional value, *P. homarus* is highly prized for human consumption (Radhakrishnan 2015; Arumugam et al. 2020), with market prices ranging from USD 30-40 kg^{-1} (FAO 2024b). From 2010 to 2023, a 2.99% annual increase in demand has driven the global market value to USD 4.45 billion (UN Comtrade 2024). However, most of the 3,124,458 tonnes produced between 2013 and 2022 come from capture fisheries (99.26%), with aquaculture making up only 0.74% (FAO 2024a). This high demand has put unsustainable pressure on wild populations, leading to stock depletion (Radhakrishnan 2015; Yeap et al. 2022).

Mariculture could be a solution to lessen pressure on wild stocks and possibly boost future production (Filippi et al. 2024). The success of lobster mariculture depends heavily on producing high-quality seed stock (Jones et al. 2019). The rearing phase is especially important for producing strong juveniles for grow-out (Effendi et al. 2021). Nonetheless, challenges like low adaptability, post-transport mortality, cannibalism, size variability, and unsuitable rearing systems continue to limit productivity (Radhakrishnan 2015; Sætran 2023; Filippi et al. 2024). Vietnam has successfully developed rearing methods that support its domestic industry (Yeap et al. 2022), which has sparked interest in neighboring countries like Indonesia (Jones et al. 2019), but a lack of detailed information on optimal rearing systems remains a major obstacle to producing quality juveniles.

Current lobster mariculture mostly uses floating, submerged, or bottom cage systems (Anissah et al. 2015; Jones et al. 2019; Liu et al. 2019; Aonullah and Ahmadi 2021). In Indonesia, Floating Net Cages (FNC) are the most common (Sievers et al. 2021). However, FNC systems are vulnerable to extreme weather, disease, and environmental changes (Anissah et al. 2015; Sievers et al. 2021). These surface conditions can negatively impact stress responses, metabolism, growth, feed efficiency, immunity, and survival rates (Verghese et al. 2007; Radhakrishnan and Kizhakudan 2019; Ross and Behringer 2019; Joo and Kim 2024), especially since they are often not ideal for bottom-dwelling species like lobsters (Anissah et al. 2015; Sievers et al. 2021).

In contrast, Submerged Net Cages (SNC) and Bottom Net Cages (BNC), at depths of around 5-10 meters, are thought to provide more stable environmental conditions (Liu et al. 2019; Aonullah and Ahmadi 2021; Sievers et al. 2021). This approach makes sense considering lobsters' biological preference for certain depths during different life stages (Butler et al. 2006). As lobsters move from planktonic larvae to benthic post-puerulus, they settle on the substrate (Lellis and Russell 1990; Kulmiye and Mavuti 2005). Settlement depths vary by species: *P. argus* post-larvae settle at 5 meters or less (Goldstein and Butler 2009), while *P. ornatus* and *P. homarus* puerulus are usually found between 3 and 21 meters deep (Dennis et al. 1997; Priyambodo et al. 2015).

Different cultivation systems create unique microhabitats shaped by water quality, ecosystem interactions, hydro-oceanography, and pressure. Since hydrostatic pressure influences physiology in crustaceans and correlates with depth (Campenot 1975), and because lobsters adapt differently at each stage, it is essential to evaluate rearing performance across various systems. This study aims to compare how FNC, SNC, and BNC systems affect the growth and survival of *P. homarus* post-puerulus. By examining environmental factors and their effects on lobster performance, the research seeks to determine the best system for reducing stress and increasing survival. Ultimately, these results will help develop sustainable methods for consistently producing high-quality lobster seed.

MATERIALS AND METHODS

Research location and materials

The study was conducted from August to December 2023 at the Sea Farming Field Station, Center for Coastal and Marine Resources Studies (CCMRS), Institut Pertanian Bogor, in Semak Daun Lagoon, north of Panggang Island in the Seribu Islands, Indonesia (Figure 1). The location is protected waters, depths between 5-10 m, an average current speed of 12.9 cm s^{-1}, and a sandy and coral substrate. A total of 1,200 *P. homarus* puerulus (~1.95 cm, ~0.21 g) were collected from Ujung Genteng, Sukabumi District (Figure 2.A), quarantined for 32 hours in a recirculating aquaculture system (temperature: 22°C, dissolved oxygen: 5-6 mg L^{-1}, pH: 8.22, salinity: 31 g L^{-1}), and subsequently transported to the research site. After 17 days of rearing, post-puerulus were produced (total length 2.14±0.04 cm, carapace 0.86±0.06 cm, body weight 0.28±0.04 g) (Figure 2.B).

Experimental design

The experimental design was completely randomized, with three rearing system treatments (FNC, SNC, BNC) (Table 1) and three replications (Figure 3). Treatment placement followed previous studies (Dennis et al. 1997; Goldstein and Butler 2009; Priyambodo et al. 2015) and was conducted during the highest tide.

Table 1. Average weight, total length, and post-puerulus carapace size of *Panulirus homarus* at the start of stocking in each rearing system (FNC, SNC, and BNC)

Item	Units	Rearing systems		
		FNC	SNC	BNC
Weight	g	0.29±0.04	0.28±0.03	0.28±0.04
Total length	cm	2.13±0.08	2.14±0.07	2.15±0.09
Carapace length	cm	0.88±0.08	0.85±0.05	0.86±0.05

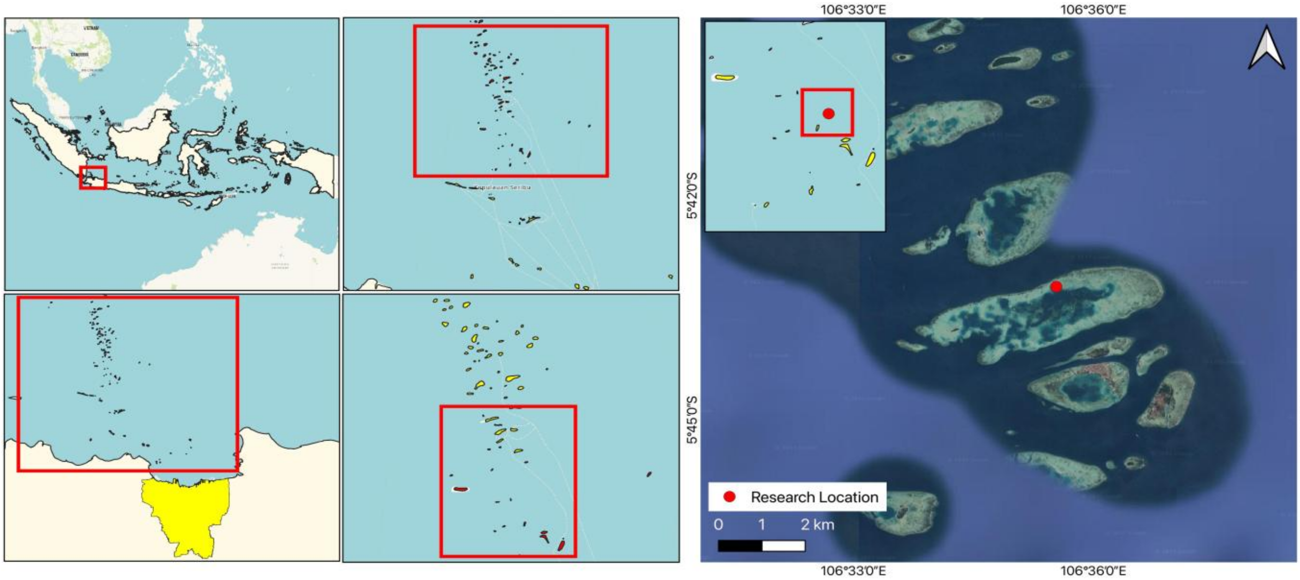

Figure 1. Map of the research location (5°43'12.8" S and 106°35'32.2" E) at the Sea Farming Field Station of the Center for Coastal and Marine Resources Studies (CCMRS), Institut Pertanian Bogor (Bogor), Semak Daun Lagoon, Panggang Island Village, North Seribu Islands District, Seribu Islands Administrative District, Jakarta Province, Indonesia

Post-puerulus were randomly distributed into net cages (n: 100 individuals cage^{-1}) for each treatment and replication, totaling 300 individuals treatment^{-1} and replication. Cylindrical rearing cages (height: 0.8 m, diameter: 1 m) were constructed with iron frames (diameter 10 mm). Each treatment and replication received 10 net shelters (fan-shaped, 20 cm × 40 cm). The FNC system was positioned at the water surface (1.5 m), SNC in the water column (3.5 m), and BNC at the bottom (5.5 m).

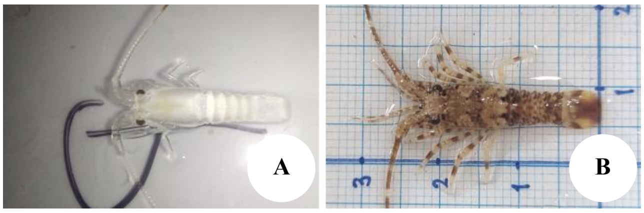

Figure 2. A. Puerulus *Panulirus homarus*, B. Post-puerulus *Panulirus homarus*

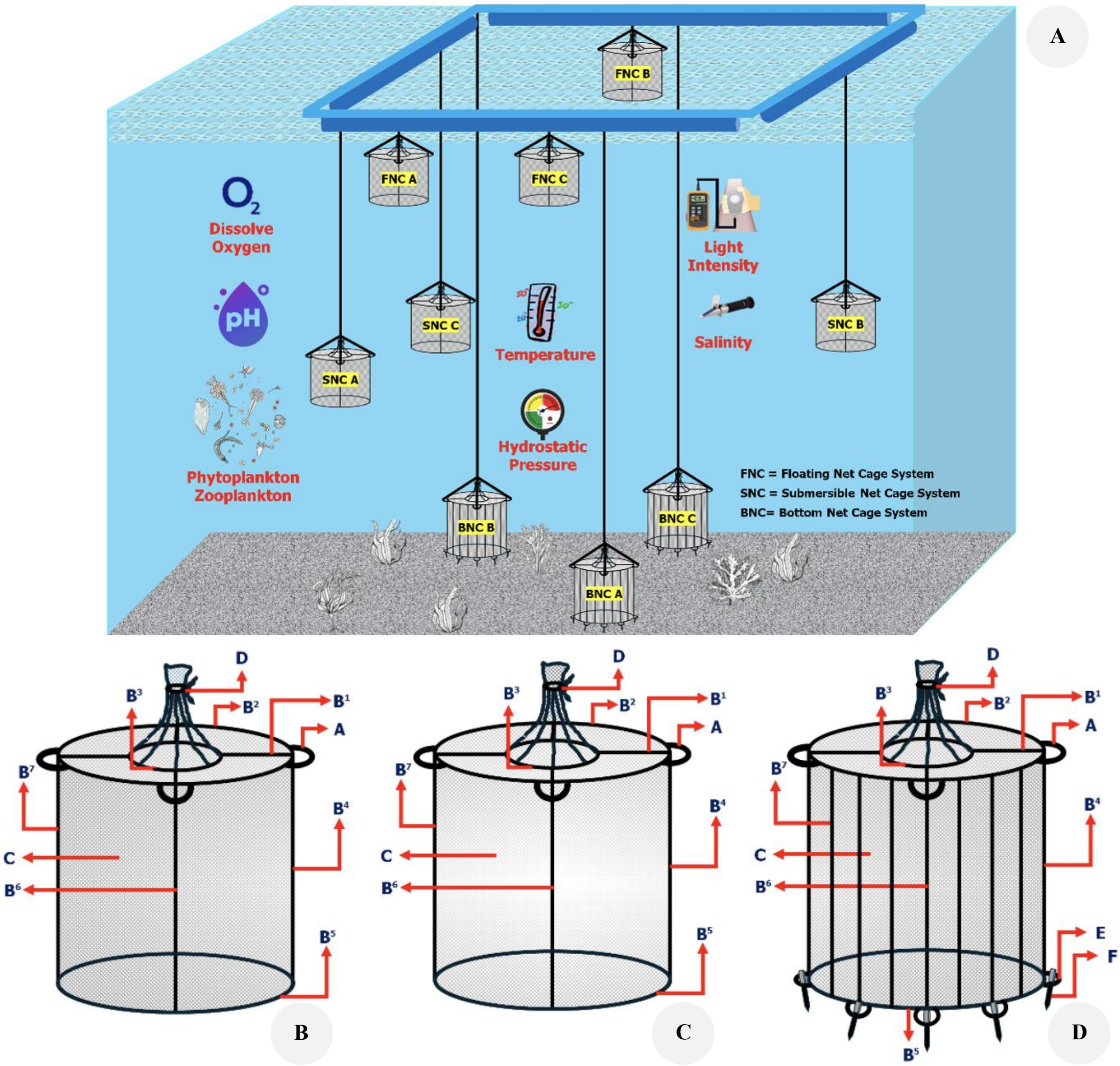

Figure 3. Research and cage-rearing design. A. Research design of post-puerulus *Panulirus homarus* at different rearing systems (FNC, SNC, and BNC): FNC system (1.5A, 1.5B, 1.5C), SNC system (3.5A, 3.5B, 3.5C), BNC system (5.5A, 5.5B, 5.5C). B. The cage-rearing design at FNC system consists of: four units of rope connector (A), monitoring pit connector (0.8 m) (B1), iron frame 10 mm and ⌀ 1 m (B2 and B5), monitoring pit ⌀ 0.4 m (B3), iron frame 10 mm, high 0.8 m (B4, B6, and B7), protector net (outside size 5 mm and inside size 1 mm) (C), rope monitoring pit protector (D). C. The cage-rearing design at SNC system consists of: four units of rope connector (A), monitoring pit connector (0.8 m) (B1), iron frame 10 mm and ⌀ 1 m (B2 and B5), monitoring pit ⌀ 0.4 m (B3), iron frame 10 mm, high 0.8 m (B4, B6, and B7), protector net (outside size 5 mm and inside size 1 mm) (C), rope monitoring pit protector (D). D. The cage-rearing design at BNC system consists of: units of rope connector (A) four, monitoring pit connector (0.8 m) (B1), iron frame 10 mm and ⌀ 1 m (B2 and B5), monitoring pit ⌀ 0.4 m (B3), iron frame 10 mm, high 0.8 m (B4, B6, and B7), protector net (outside size 5 mm and inside size 1 mm) (C), rope monitoring pit protector (D), eight units of iron stake connector (E), eight units of iron stake (20 cm) (F)

Rearing of post-puerulus Panulirus homarus

Post-puerulus were fed moist feed (diameter 9 mm, thickness 7 mm) formulated according to Priyambodo (2020) with modifications (Table 2). All ingredients were ground; green mussel meat and shell were processed separately. The mixture was combined with vanname shrimp feed (1:1) and 10% carboxymethyl cellulose. Feeding occurred once daily (04:00-05:00 PM). The Feeding Rate (FR) was 15% from the start until day 60, increasing to 20% from day 61 onward (Mustafa 2013). Feed was administered by snorkeling (FNC) or diving (SNC, BNC). Then, for proximate analysis results of the *P. homarus* post-puerulus artificial feed can be seen in Table 3

Procedures for growth performance measurement and hemolymph glucose sampling

Every 14 days, 30 post-puerulus were randomly sampled from each treatment and replication to measure weight, total length, and carapace. Glucose and Total Hemocyte Count (THC) were used as physiological indicators of crustacean stress responses (Verghese et al. 2007; Adiyana et al. 2014; Arifin et al. 2014; Effendi 2016; Pratiwi et al. 2016; Harrington et al. 2019; Minjoyo et al. 2024). Hemolymph samples were collected on days 0, 63, and 126. To minimize stress, the storage container temperature was gradually reduced over 15 minutes to 22°C. For glucose and THC analyses, three post-puerulus were randomly sampled from each treatment and replication.

Hemolymph (0.2 nL) was extracted from the 5th pereiopod using a 0.5 mL disposable syringe (30Gx1/2 needle). Glucose samples were placed in 1.5 mL microcentrifuge tubes, while 0.6 nL trisodium citrate-2-hydrate anticoagulant and formalin (1:4) were added to THC samples. In total, 27 glucose and THC samples were collected and stored in a cool box with dry ice at 1-4°C. Hemolymph sampling duration was 25-30 seconds individual^{-1}. Glucose analysis followed Wedemeyer and Yasutake (1977), and THC analysis followed Blaxhall and Daishley (1973).

Ethics statement and animal welfare protocols

This research was conducted at the Sea Farming Field Station facility of CCMRS Institut Pertanian Bogor (IPB University). This facility, which supports educational and laboratory activities, operates under Marine Space Conformity Confirmation License No. B.575/MEN-KP/XI/2021, in accordance with applicable laws and regulations in Indonesia. The procedures for rearing and sampling test animals in this study also ensure ethical treatment and animal welfare protocols based on the Decree of the Research Ethics Clearance for Animal Care and Use-Ethics Commission for Animal Care and Use-Indonesian National Research and Innovation Agency (In Indonesian, namely *Badan Riset dan Inovasi Nasional*) No. 156/KE.02/SK/07/2023.

Measurement of water quality and hydro-oceanographic parameters

Water physicochemical parameters were measured daily for each treatment and replication. Light intensity and hydrostatic pressure were measured on days 0, 63, and 126 (8:00 am, 12:00 pm, 4:00 pm) using a Secchi Disk Digital (SSD) logger with lux and pressure sensors (Table 4). Phyto-zooplankton samples were collected using a van Dorn water sampler and plankton net on days 0, 63, and 126. Wave data were obtained from Copernicus Marine Environment Monitoring Service (CMEMS) in 2023.

Research parameters

Data were analyzed to calculate Specific Growth Rate (SGR), Absolute Growth Rate (AGR), Total Length, Final Carapace Length (Final CL), Absolute Carapace Length (Absolute CL), final weight, total molting, Intermoult Period (IMP), Feed Conversion Ratio (FCR), Survival Rate (SR), hemolymph glucose, and THC. Water quality data were used as supplementary information. The observed parameters were based on previous studies: (i) SGR is the difference in post-puerulus weight over the experiment duration, SGR (% days^{-1}) = (ln Wt-ln Wo/t) x 100 (Solanki et al. 2012); (ii) AGR is the difference between the average lobster weight at the end and the beginning of the experiment, related to the length of the experiment, to determine the rate of change in day^{-1}. AGR (g days^{-1}) = $\bar{x}$Wt-$\bar{x}$Wo/t (Goddard 1996); (iii) Total length is the difference between final and initial lengths, Total length (cm) = Lt-Lo (Solanki et al. 2012); (iv) Final CL is the difference between final and initial carapace lengths, Absolute CL (cm) = CLt-CLo (Syafrizal et al. 2018); (v) Final weight is the difference between final and initial weights, Final weight = WGt-WGo (Syafrizal et al. 2018); (vi) FCR is the feed required to produce 1 kg of meat, FCR = Weight of total feed consumption/(Final weight of biomass-weight of dead biomass)-Initial weight of biomass (Goddard 1996); (vii) Total molting was recorded daily in each treatment and replication; (viii) IMP is the number of days between two molts, with the average used if more than two molts occurred (Kemp and Britz 2008); (ix) SR is the ratio of live lobsters at the end and beginning, SR (%) = (Nt/No) x 100 (Solanki et al. 2012); (x) Hemolymph glucose analysis followed Wedemeyer and Yasutake (1977), measured by GD = (AbsSp/AbsSt) x GSt; (xi) THC analysis followed Blaxhall and Daishley (1973), measured by THC = Number of counted cells x 1/Volume of large box x FP x 1000.

Table 2. Ingredients and composition of post-puerulus *Panulirus homarus* feed during 126 days of experiment in FNC, SNC, and BNC rearing systems

Feed ingredient	Form	Percentage (%)	Weight (g)
Trash fish meat	Fine	11	110
Mollusca (green mussel meat and shell)	Fine/powder	33	330
Crustacea (marine *Litopenaeus vannamei* meat)*	Fine	56	560
Total		100	1000

**Litopenaeus vannamei* from marine cultivation using floating net cages

Table 4. Measurement of water quality and hydro-oceanographic parameters, methodology, and testing frequency

Treatment	Parameter	Abbreviatior	Units	Sample treatment and processing	Analytical method	Frequency of measurement
FNC, SNC, BNC	Temperature	Temp	°C	Direct/on-location	Water quality meter 5 in 1 AZ instrument AZ86031	[a]Every day (08.00 am, 12.00 pm, 04.00 pm)
	Salinity		g L^{-1}	Direct/on-location	Atago refractometer	
	Dissolved oxygen	DO	mg L^{-1}	Direct/on-location	Water quality meter 5 in 1 AZ instrument AZ86031	
	pH	pH	pH units	Direct/on-location	Water quality meter 5 in 1 AZ instrument AZ86031	
FNC, SNC, BNC	Intensity of light		Lux	Direct/on-location	Secchi disk digital (SSD) logger[c)]	[b]Day 0, 63, 126 (08.00 am, 12.00 pm, 04.00 pm)
	Hydrostatic pressure		atm			
FNC, SNC, BNC	Phytoplankton		Cell m$^{3\ -1}$	Lab	Calculations using Ln Enumeration (Census-SRC) APHA, 24th Edition, 10200F, 2022 +: Accredited Parameters	[a]Day 0, 63, 126
	Zooplankton		Ind m$^{3\ -1}$	Lab	Calculations using Ln Enumeration (Census-SRC) APHA, 24th Edition, 10200G, 2022 +: Accredited Parameters	
	Wave		m	Data filter	Statistical description	Every day with a temporal of every 3 hours

Note: [a]: Government Regulation No. 22 of 2021 on the Implementation of Environmental Protection and Management, [b]: Ennis (1973) and Bermudes et al. (2008), [c]: The Secchi Disk Digital (SSD) logger used is equipped with a lux sensor model TSL2591/VEML7700 (0.001-100,000 lux, auto gain) and a pressure sensor MS5837-30BA (0-30 atm, 0.01 m resolution)

Table 3. The proximate analysis results of the *Panulirus homarus* post-puerulus artificial feed (per 100 g feed)

Component	Proximate content of feed (%)
Moisture content	22.95
Ash content	20.67
Fat	2.47
Protein	35.39
Crude fiber	14.96
Nitrogen-Free Extract (NFE)	3.56

Note: Source: Fish Nutrition Laboratory, Department of Aquaculture, Faculty of Fisheries and Marine Science, Institut Pertanian Bogor (2023)

Statistical and data analysis

Data processing and statistical analysis were performed using Microsoft Excel (Microsoft Office, USA) and IBM SPSS Statistics 26. Data are presented as mean±SD. The average final weight, total length, CL, SGR, AGR, Absolute CL, total molting, IMP, FCR, SR, glucose, THC, light intensity, hydrostatic pressure, and wave were analyzed using one-way ANOVA (significance level 0.05) to determine differences among treatments. If significant differences were found, Tukey's Honestly Significant Difference (HSD) test was applied ($p<0.05$). Water quality was analyzed descriptively using tables.

RESULTS AND DISCUSSION

Growth and survival rate

Different rearing system treatments resulted in average final weights of 8.24±2.17 g (FNC), 5.67±2.39 g (SNC), and 7.68±2.17 g (BNC) (Figure 5). The average total lengths were 6.50±0.62 cm (FNC), 5.65±0.79 cm (SNC), and 6.42±0.63 cm (BNC). Average CL were 2.90±0.32 cm (FNC), 2.48±0.40 cm (SNC), and 2.88±0.32 cm (BNC). SR were 41.67±2.08% (FNC), 43.67±3.06% (SNC), and 71.00±2.00% (BNC). During the initial and middle phases of the experiment, post-puerulus growth in the FNC treatment exceeded that of the other treatments. By the end of the experiment, no significant difference was observed between BNC and FNC treatments ($P>0.05$; Figure 4). One-way ANOVA indicated that rearing system differences significantly affected final weight, final length, CL, SR, SGR, AGR, absolute CL, total molting, IMP, and FCR (Table 5).

Post-hoc Tukey's HSD tests showed that FNC had the highest final weight (8.24±0.51 g), significantly greater than SNC (5.67±0.94 g), but not different from BNC (7.68±0.72 g, *p*: 0.013). Final length in FNC (6.49±0.18 cm) was also highest, significantly greater than SNC (5.65±0.31 cm), but not different from BNC (6.42±0.20 cm, *p*: 0.008). CL in FNC and BNC (2.90±0.10 cm and 2.88±0.10 cm) was not significantly different, but both were higher than SNC (2.48±0.15 cm, *p*: 0.008).

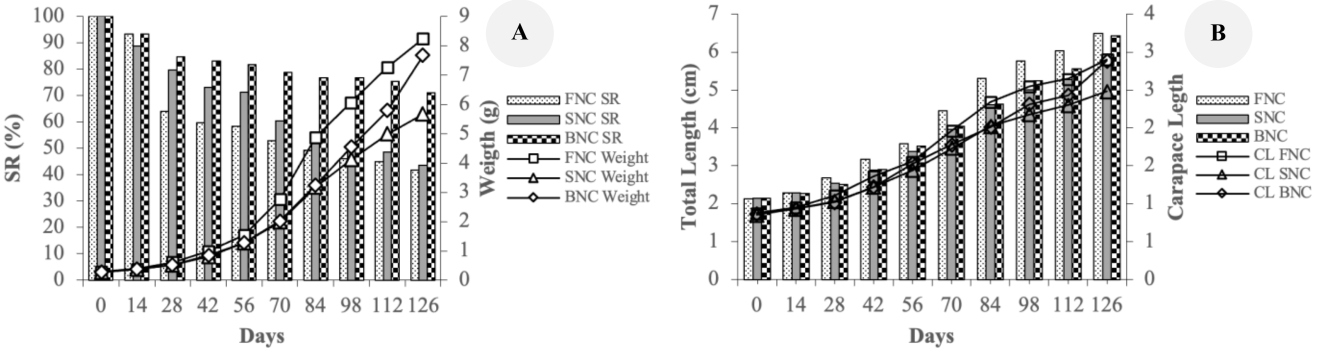

Figure 4. Growth graph and survival rate of post-puerulus *Panulirus homarus* in different rearing systems during 126 days of the experiment. A. Survival Rate (SR) and weight growth, B. Total Length (TL) and Carapace Length (CL) growth. Post-puerulus (n: 30 individuals) in each treatment (FNC, SNC, and BNC) and replication (1, 2, and 3) were measured and weighed every 14 days

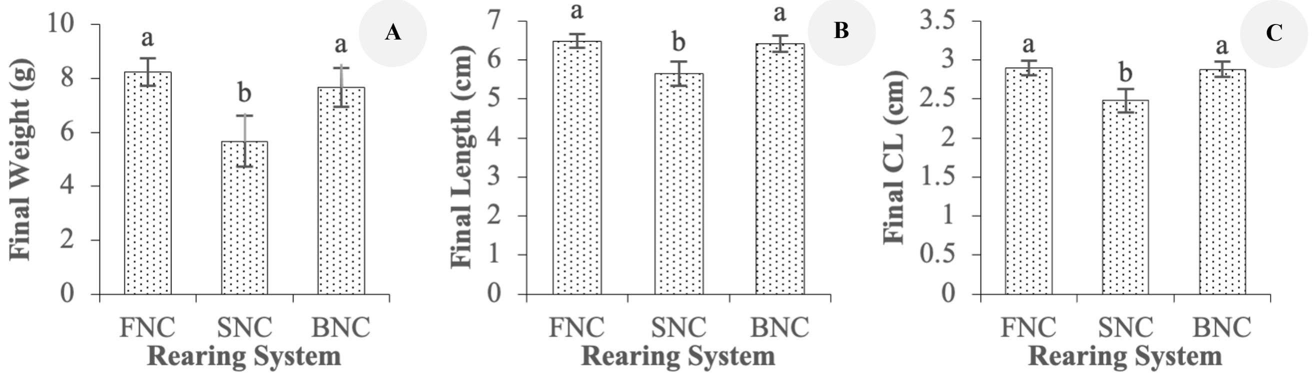

Figure 5. Graph of post-puerulus *Panulirus homarus* growth in different rearing systems during 126 days of the experiment (mean±SE). A. Final weight (FNC: 8.24±0.511^{a}, SNC: 5.67±0.939^{b}, BNC: 7.68±0.72^{a}), B. Final length (FNC: 6.49±0.175^{a}, SNC: 5.65±0.305^{b}, BNC: 6.42±0.199^{a}), C. Final CL (FNC: 2.90±0.096^{a}, SNC: 2.48±0.149^{b}, BNC: 2.88±0.100^{a}). Different superscript letters indicate statistically significant differences between treatments (P<0.05), and bars represent standard errors of the means

Table 5. The one-way ANOVA results of final weight, final length, CL, SR, SGR, AGR, Absolute CL, total molting, IMP, and FCR in post-puerulus *Panulirus homarus* rearing using different rearing systems (FNC, SNC, and BNC) for 126 days of experiment

Parameters	df	MS	F	*p*
Final weight (g)	8	0.552938	9.849	0.013
Final length (cm)	8	0.054387	12.089	0.008
Final carapace length (cm)	8	0.013875	12.042	0.008
Survival rate (%)	8	5.888889	136.830	0.000
Specific growth rate (% days^{-1})	8	0.007495	10.274	0.012
Absolute growth rate (g days^{-1})	8	0.000038	9.937	0.012
Absolute carapace length (cm)	8	0.013026	11.567	0.009
Total molting (times cage^{-1})	8	44.333333	7.221	0.025
Intermolt period (days)	8	0.388344	89.916	0.000
Feed conversion ratio	8	9.210246	6.430	0.032

FNC produced the highest SGR (2.80±0.02% days^{-1}) compared to SNC (2.50±0.13% days^{-1}), but was not different from BNC (2.76±0.08% days^{-1}, *p*: 0.012) (Figure 6). Similarly, AGR was highest in FNC (0.07±0.004 g days^{-1}) compared to SNC (0.04±0.008 g days^{-1}), but not different from BNC (0.06±0.006 g days^{-1}, *p*: 0.012). Absolute CL was highest in FNC and BNC (2.02±0.06 and 2.02±0.11 cm), and lowest in SNC (1.63±0.15 cm, *p*: 0.009)

FNC had the highest total molting (45.33±9.07 times cage^{-1}) compared to SNC (26.67±5.03 times cage^{-1}), but was not different from BNC (43.67±5.03 times cage^{-1}, *p*: 0.025) (Figure 7). The fastest IMP was observed in FNC (14.37±0.38 days), while SNC had the slowest (21.12±0.92 days, *p*: 0.000). BNC had the lowest FCR (7.34±0.37) compared to SNC (16.23±5.12), while FCR in FNC (11.75±1.11) was not different from SNC and BNC (*p*: 0.032). BNC produced the highest SR (71.00±2.00%, *p*: 0.000). The correlation between feed and AGR yielded an R^2 value of 0.8949, indicating a strong effect of feed on AGR in post-puerulus *P. homarus* (Figure 8).

Hemolymph glucose and total hemocyte count

One-way ANOVA showed that rearing system differences affected glucose concentrations on days 63 and 126 (Table 6). At the beginning, post-hoc Tukey's HSD test glucose levels did not differ significantly among treatments, ranging from 31.03±1.24 to 38.13±10.26 mg dL^{-1} (*p*: 0.381), likely due to handling stress (Figure 9). On day 63, BNC had the lowest glucose concentration

(18.72±1.96 mg dL^{-1}) compared to FNC and SNC (*p*: 0.001). On day 126, BNC again had the lowest glucose (14.14±1.58 mg dL^{-1}, *p*: 0.031). One-way ANOVA (Table 7) indicated that rearing system differences affected THC on days 63 and 126. Initial THC did not differ significantly (*p*: 0.695), ranging from 1.54±0.07 to 1.80±0.29x10^7 cells mL^{-1} (Figure 10). On day 63, THC in BNC was lowest (2.11±0.19x10^7 cells mL^{-1}) compared to FNC and SNC (*p*: 0.000), and this trend persisted at day 126 (1.81±0.29x10^7 cells mL^{-1}; *p*: 0.000).

Water physicochemical parameters

Water physicochemical parameters during the 126-day experiment were generally within optimal ranges. Table 8 presents minimum, maximum, and average values for each treatment. Average DO levels were 6.8 mg L^{-1}, 5.43 mg L^{-1}, and 4.99 mg L^{-1}, all within optimal ranges (SNI 2015; Amin et al. 2022c; KKP 2020). DO decreased with depth but remained suitable for post-puerulus requirements. Daily fluctuations in water physicochemical parameters were observed (Figure 11). On day 56, DO decreased in FNC (54%) and SNC (45%) from morning to afternoon. Similarly, pH decreased by 14% and 13% in FNC and SNC, respectively. On day 57, the highest daily mortality was 34 individuals: 16 in SNC, 10 in FNC, and 8 in BNC (Figure 12).

Table 6. The one-way ANOVA results of glucose (mg dL^{-1}) post-puerulus *Panulirus homarus* in different rearing systems (FNC, SNC, and BNC) at the experimental period of days 0, 63, and 126

Experimental period (days)	df	MS	F	*p*
0	8	38.815	1.139	0.381
63	8	3.362	24.747	0.001
126	8	70.234	6.561	0.031

Table 7. The one-way ANOVA results of total hemocyte count (x 10^7 cells mL^{-1}) of post-puerulus *Panulirus homarus* in different rearing systems (FNC, SNC, and BNC) at the experimental period of days 0, 63, and 126

Experimental period (days)	df	MS	F	*p*
0	8	0.130	0.386	0.695
63	8	0.091	60.616	0.000
126	8	0.239	51.714	0.000

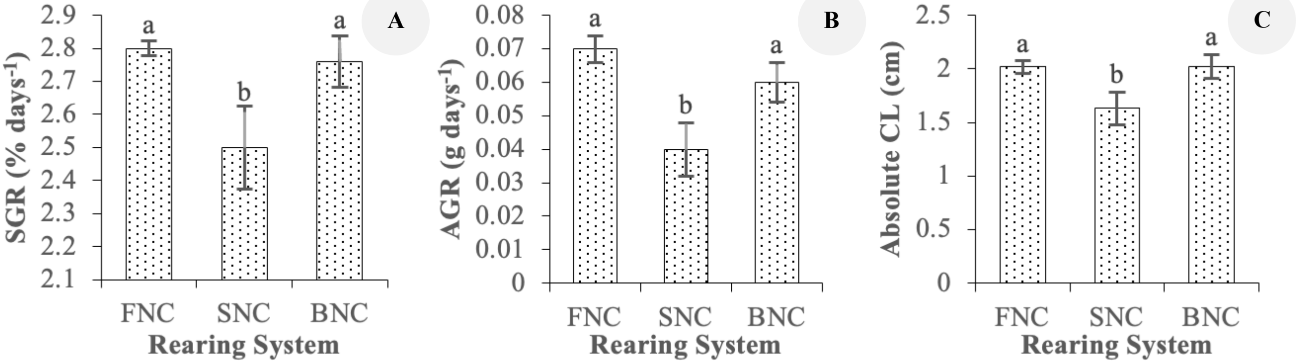

Figure 6. Graph of post-puerulus *Panulirus homarus* growth in different rearing systems during 126 days of the experiment (mean±SE). A. SGR (FNC: 2.80±0.022^{a}, SNC: 2.50±0.126^{b}, BNC: 2.76±0.078^{a}), B. AGR (FNC: 0.07±0.004^{a}, SNC: 0.04±0.008^{b}, BNC: 0.06±0.006^{a}), C. Absolute CL (FNC: 2.02±0.058^{a}, SNC: 1.63±0.154^{b}, BNC: 2.02±0.109^{a}). Different superscript letters indicate statistically significant differences between treatments (P<0.05), and bars represent standard errors of the means

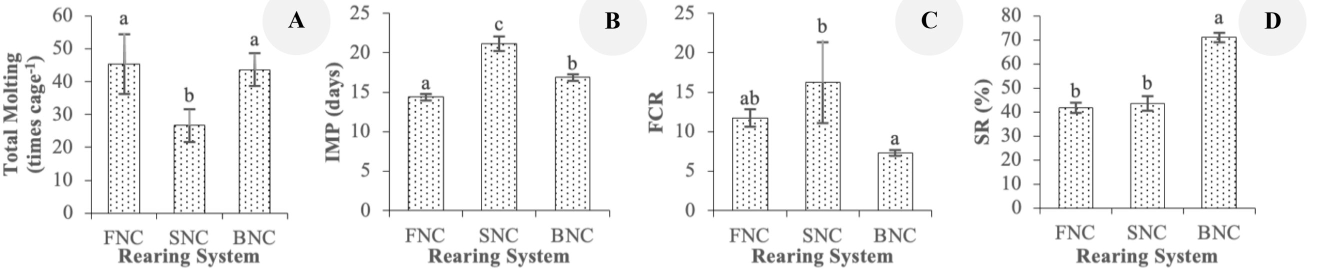

Figure 7. Graph of post-puerulus *Panulirus homarus* growth in different rearing systems during 126 days of experiment (mean±SE). A. total molting (FNC: 45.33±9.074^{a}, SNC: 26.67±5.033^{b}, BNC: 43.67±5.033^{a}), B. IMP (FNC: 14.37±0.38^{a}, SNC: 21.12±0.92^{c}, BNC: 16.86±0.42^{b}), C. FCR (FNC: 11.75±1.114^{ab}, SNC: 16.23±5.124^{b}, BNC: 7.34±0.372^{a}), D. SR (FNC: 41.67±2.082^{b}, SNC: 43.67±3.055^{b}, BNC: 71.00±2.00^{a}). Different superscript letters indicate statistically significant differences between treatments (P<0.05), and bars represent standard errors of the means

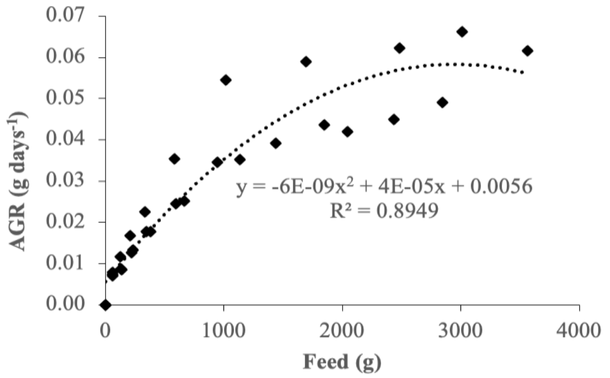

Figure 8. The correlation between feed and AGR of post-puerulus *Panulirus homarus* rearing in different systems during 126 days of experiment (*p*: 0.000)

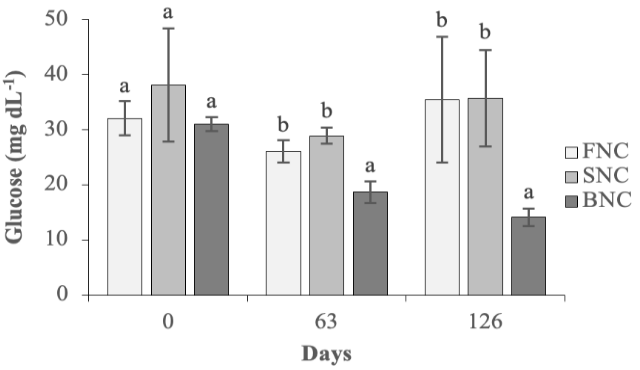

Figure 9. Graph of glucose concentration (mg dL^{-1}, mean±SE) of post-puerulus *Panulirus homarus* in different rearing systems at the experimental period day 0 (FNC: 32.06 ± 3.11^{a}, SNC: 38.13 ± 10.26^{a}, BNC: 31.03 ± 1.24^{a}), day 63 (FNC: 26.11 ± 2.04^{b}, SNC: 28.91 ± 1.45^{b}, BNC: 18.72 ± 1.96^{a}), and day 126 (FNC: 35.48 ± 11.44^{b}, SNC: 35.73 ± 8.80^{b}, BNC: 14.14 ± 1.58^{a}). Different superscript letters indicate statistically significant differences between treatments ($P<0.05$), and bars represent standard errors of the means

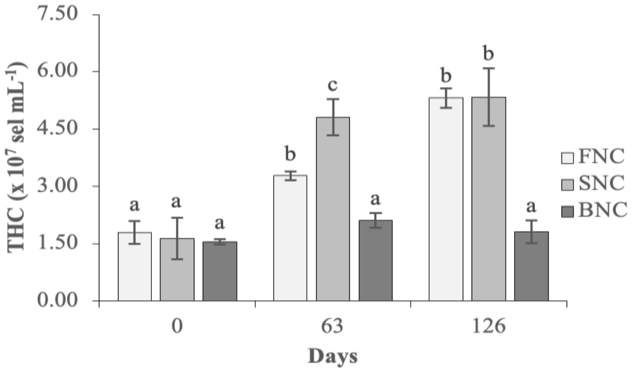

Figure 10. Graph THC (x10^{7} cells mL^{-1}, mean±SE) of post-puerulus *Panulirus homarus* in different rearing systems at the experimental period of day 0 (FNC: 1.80 ± 0.29^{a}, SNC: 1.64 ± 0.54^{a}, BNC: 1.54 ± 0.07^{a}), day 63 (FNC: 3.28 ± 0.12^{b}, SNC: 4.81 ± 0.473^{c}, BNC: 2.11 ± 0.19^{a}), and day 126 (FNC: 5.31 ± 0.25^{b}, SNC: 5.33 ± 0.75^{b}, BNC: 1.81 ± 0.29^{a}). Different superscript letters indicate statistically significant differences between treatments ($P<0.05$), and bars represent standard errors of the means

One-way ANOVA showed that rearing system influenced average temperature in October, November, and December (Table 9). Post-hoc Tukey's HSD test (Figure 13) indicated no significant temperature differences in September (28.69±0.4 to 29.07±0.7°C). In October, BNC had the lowest temperature (28.62±0.2°C) compared to FNC and SNC (29.89±0.5 and 29.76±0.4°C, *p*: 0.015). This trend continued in November and December, with BNC maintaining the lowest temperatures (28.62±0.1°C, *p*: 0.000 and 28.74±0.3°C, *p*: 0.000).

Monthly temperatures in FNC and SNC increased over time (Figure 14), likely due to temperature anomalies from September to December 2023 (BMKG 2023). Sea surface temperature (SST) at the study site also increased until February 2024 (BMKG 2023), while BNC temperatures remained stable until December.

Water biology parameters

At the experiment's start, FNC, SNC, and BNC contained 26, 28, and 23 phytoplankton genera, respectively, with *Trichodesmium* sp. dominating (44.16%, 46.97%, and 53.18%). By day 63, there were 25, 25, and 30 genera, with *Trichodesmium* sp. still dominant (90.38%, 92.18%, and 86.88%). On day 126, there were 20, 29, and 34 genera, with *Navicula* sp., *Asterionella* sp., and *Nitzschia* sp. dominating at 21.05%, 26.64%, and 58.36%, respectively.

Initial zooplankton genera were 7, 7, and 11, with *Nauplius* (stadia) dominant in FNC (32.74%), and *Globorotalia* sp. dominant in SNC and BNC (47.37% and 54.66%). By day 63, there were 9, 9, and 12 zooplankton genera, with *Nauplius* (stadia) dominant in FNC (28.91%), and *Globorotalia* sp. dominant in SNC and BNC (38.88% and 47.92%). At the end, FNC and SNC had 13 and 14 genera, with *Globorotalia* sp. dominant in FNC (32.79%), *Nauplius* (stadia) in SNC (28.33%), and *Globorotalia* sp. still dominant in BNC (26.53%). Phyto-zooplankton serve as natural food sources for *P. homarus* and *P. ornatus* during larval, post-larval, puerulus, and juvenile stages (Ihsan et al. 2019; Amin et al. 2022a, b). Figure 15 presents phyto-zooplankton dominant abundance.

Hydrostatic pressure, light intensity, and wave

One-way ANOVA showed that rearing system treatments significantly affected hydrostatic pressure ($P<0.05$) (Table 10). Post-hoc Tukey's HSD test (Figure 16) indicated that BNC had the highest hydrostatic pressure at the start (1.591±0.049 atm, *p*: 0.000), and on days 63 and 126 (1.628±0.006 atm, *p*: 0.000 and 1.623±0.056 atm, *p*: 0.000). One-way ANOVA showed rearing system also significantly affected light intensity ($P<0.05$) in the morning and afternoon.

Post-hoc Tukey's HSD test showed in the morning, BNC had the lowest light intensity (449±230 lux) compared to FNC and SNC (1220±232 and 1093±176 lux, *p*: 0.009) (Figure 18). During the day, light intensity did not differ among treatments (*p*: 0.266) (Table 11). In the afternoon, BNC again had the lowest light intensity (365±180 lux), not different from SNC (954±305 lux), but different from FNC (1116±335 lux, *p*: 0.037).

Table 8. The water physicochemical of post-puerulus *Panulirus homarus* with different rearing systems during 126 days of experiment

Parameters	**Units**	**Rearing Systems**									**Standard**
		FNC			**SNC**			**BNC**			
		Min	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	
Temperature	°C	28.4	31.5	29.9	28.3	31.3	29.7	26.2	29.5	28.6	27-31[1]
Dissolved oxygen	mg L^{-1}	3.4	8.5	6.8	3.5	6.8	5.4	4.3	5.9	5.0	4.99-6[2]
Salinity	g L^{-1}	32	35	33.3	32	35	33.6	32	35	33.7	28-35[3]
pH	-	7.5	8.4	8.2	7.6	8.4	8.2	8.1	8.4	8.2	8.1-8.3[1]

Note: [1]: Amin et al. (2022c), [2]: SNI (2015), KKP (2020) and Amin et al. (2022c), [3]: Drengstig dan Bergheim (2013)

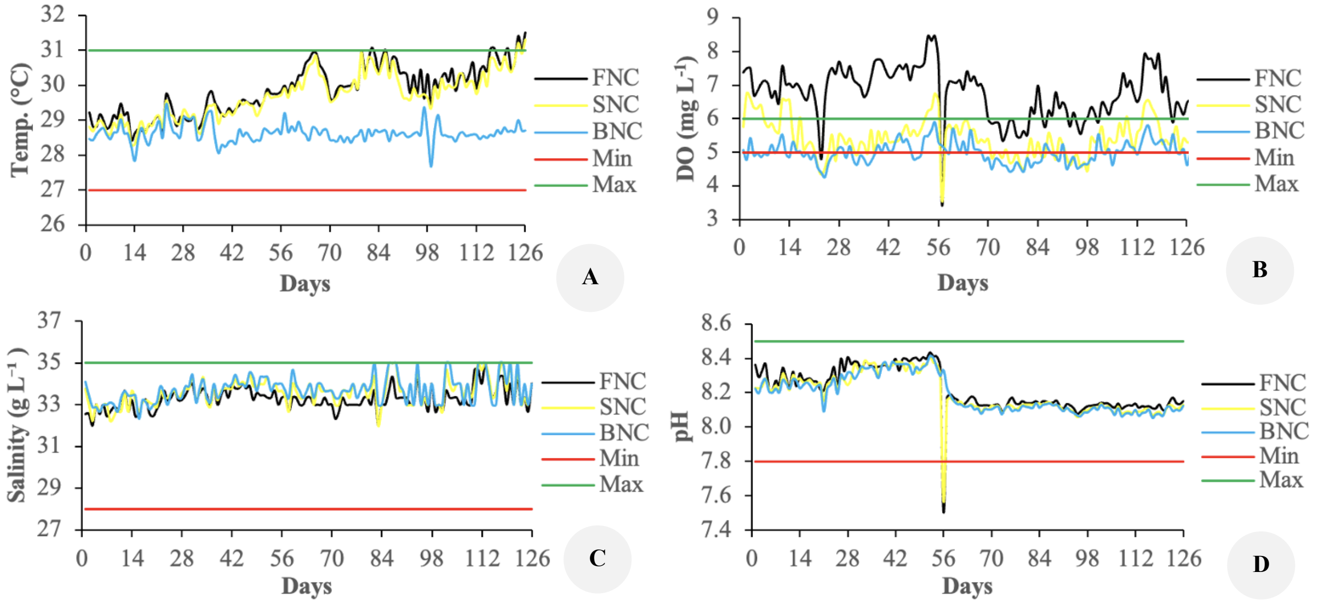

Figure 11. Graph of daily fluctuations of water physicochemical in post-puerulus *Panulirus homarus* rearing with different systems (FNC, SNC, and BNC) during 126 days of experiment. A. Daily conditions of temperature, B. Daily conditions of dissolved oxygen, C. Daily conditions of salinity, D. Daily conditions of pH

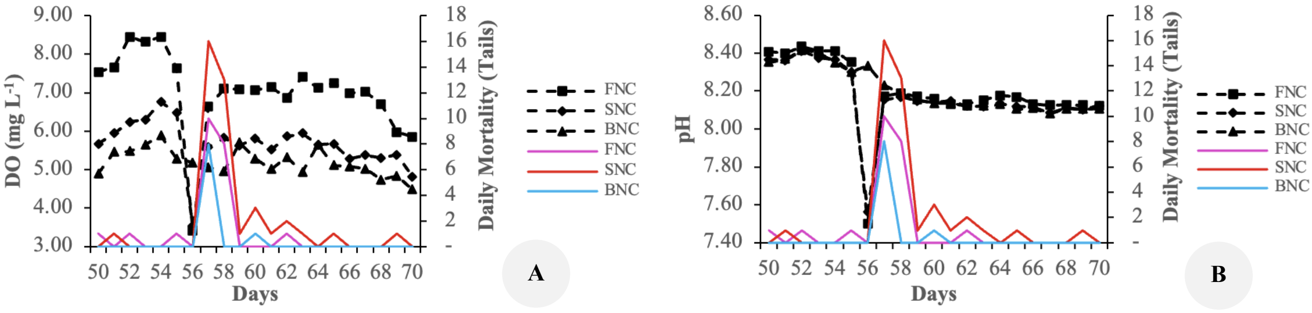

Figure 12. On the 56th day of the experiment, there was a decrease in DO (A) and pH (B). The FNC and SNC rearing systems experienced a decrease in DO in the morning, afternoon, and evening by 63%; 48%; 58%; 44%, and 42%; 45%, respectively. Likewise, the pH in the FNC and SNC rearing systems experienced a decrease in the morning and afternoon by 15%; 14%, and 13%; 12%, respectively. One day after the incident (day 57), the highest daily mortality of post-puerulus *Panulirus homarus* occurred during the 126 days of the experiment

Wave data were sourced from the Copernicus Marine Environment Monitoring Service (CMEMS), with global coverage, 0.2°x0.2° spatial resolution, and 3-hour intervals (August-December 2023). Significant wave heights and periods ranged from 0.06 to 0.99 m and 1.66 to 8.29 seconds, respectively, with averages of 0.346 m and 3.61 seconds (Table 12). Over the 126-day experiment, significant wave heights at the research location showed an increasing trend (Table 13).

Table 9. The one-way ANOVA results of the average temperature (°C) in September, October, November, and December for each rearing system treatment (FNC, SNC, and BNC) during the 126-day experiment

Months	df	MS	F	*p*
September	8	0.320	0.374	0.703
October	8	0.157	9.295	0.015
November	8	0.092	28.541	0.000
December	8	0.105	28.799	0.000

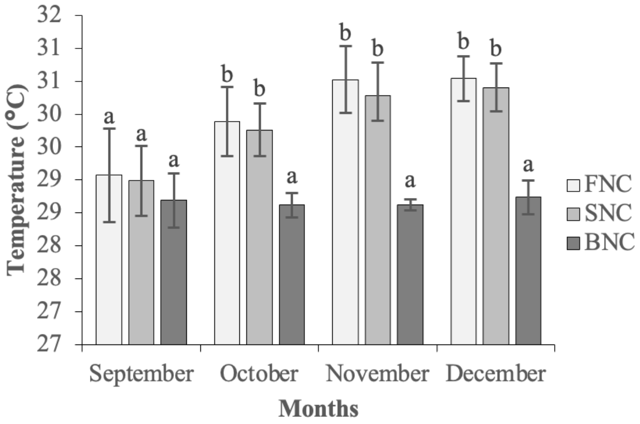

Figure 13. Graph of average temperature (°C, mean±SE) for September (FNC: 29.07±0.7[a], SNC: 28.99±0.53[a], BNC: 28.69±0.4[a]), October (FNC: 29.89±0.52[b], SNC: 29.76±0.40[b], BNC: 28.62±0.19[a]), November (FNC: 30.53±0.51[b], SNC: 30.28±0.38[b], BNC: 28.62±0.08[a]), and December (FNC: 30.54±0.34[b], SNC: 30.40±0.36[b], BNC: 28.74±0.25[a]) in rearing post-puerulus *Panulirus homarus* with different treatments during the 126-day experiment. Different superscript letters indicate statistically significant differences between treatments (P<0.05), and bars represent standard errors of the means

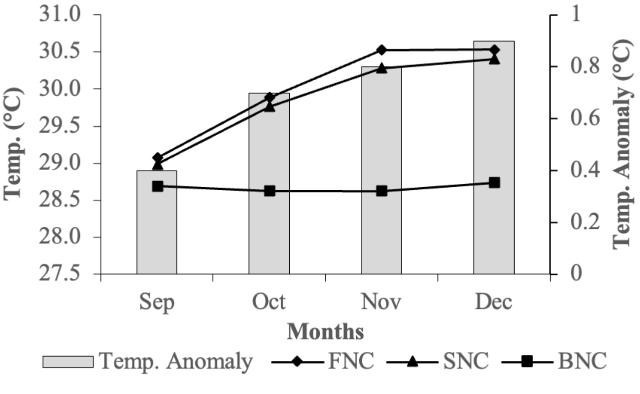

Figure 14. Graph of temperature increase trend in FNC and SNC rearing systems entering October, November, and December in the maintenance of post-puerulus *Panulirus homarus* with different rearing systems during 126 days of experiment

Discussion

The *Panulirus* sp. genus exhibits a life cycle comprising adult, egg, phyllosoma, puerulus, post-puerulus, and juvenile stages (Pratiwi et al. 2016). Each stage displays distinct characteristics, and ontogenic habitat shifts facilitate survival, growth, and predator avoidance (Butler et al. 2006). Understanding these characteristics informs the development of maintenance techniques that replicate natural environmental conditions (Minjoyo et al. 2024). Implementing alternative rearing systems for *P. homarus* at the post-puerulus stage represents one such approach.

Variations in rearing system treatments influenced growth and post-puerulus SR (Table 5). Crustacean growth is indicated by molting, increased body weight, total length, and carapace length, suggesting that feed energy is effectively utilized for growth (Menu-Courey et al. 2019; Wang et al. 2021). Growth data (Figures 5, 6, and 7) indicate that the FNC treatment outperformed the SNC treatment, though it did not differ significantly from the BNC. The FNC treatment achieved the fastest IMP (14.37±0.38 days), while the BNC exhibited a lower FCR (7.34±0.372 days). The BNC treatment also demonstrated a higher SR (71.00±2.00%) compared to FNC and SNC (*p*: 0.000). As shown in Figure 4, the FNC treatment experienced a greater increase in growth rate by the 70th day of the experiment relative to SNC and BNC. However, by the end of the experiment, FNC and BNC did not differ significantly (P>0.05), while FNC differed from SNC (P<0.05).

Moist feed appeared to enhance growth across treatments. Statistical analysis revealed a significant positive correlation (*p*: 0.000) with AGR in all treatments (Figure 8). The nutrient composition of the feed likely satisfied the post-puerulus energy requirements for growth. The ash content was 20.67%, exceeding the 14.15-14.85% reported by Lubis et al. (2023). Lobsters primarily obtain minerals from seawater, and the precise mineral composition of feed remains insufficiently characterized (Nelson et al. 2006). Minerals are essential for molting and shell hardening. The protein content was 35.39%, within the optimal range of 22%-55% (Williams 2007). Similarly, Ward et al. (2003) found that *Jasus edwarsii* exhibited optimal growth with feed containing 33-35% protein. The fat content was 2.47%, and previous studies reported that fat content does not significantly affect the growth of *J. edwarsii* (Ward et al. 2003). Glencross et al. (2001) also observed that *P. cygnus* grows well with low fat content.

The feed was supplemented with vanname shrimp pellets at a 1:1 ratio. Williams (2007) reported that adding shrimp pellets resulted in optimal growth for *P. cygnus*, *P. ornatus*, and *J. edwarsii*. Post-puerulus larvae in all treatments likely consumed phyto-zooplankton. In their natural habitat, post-puerulus *P. homarus* and *P. ornatus* have been reported to prey on phyto-zooplankton (Ihsan et al. 2019; Amin et al. 2022a, b). The abundance of natural food observed in previous studies was also present in this study (Figure 15), including *Oithona* sp., *Tintinopsis* sp., *Acartia* sp., *Paracalanus* sp., *Synedra* sp., *Rhizosolenia* sp., *Grammatophora* sp., and *Navicula* sp. (Ihsan et al. 2019; Amin et al. 2022a, b).

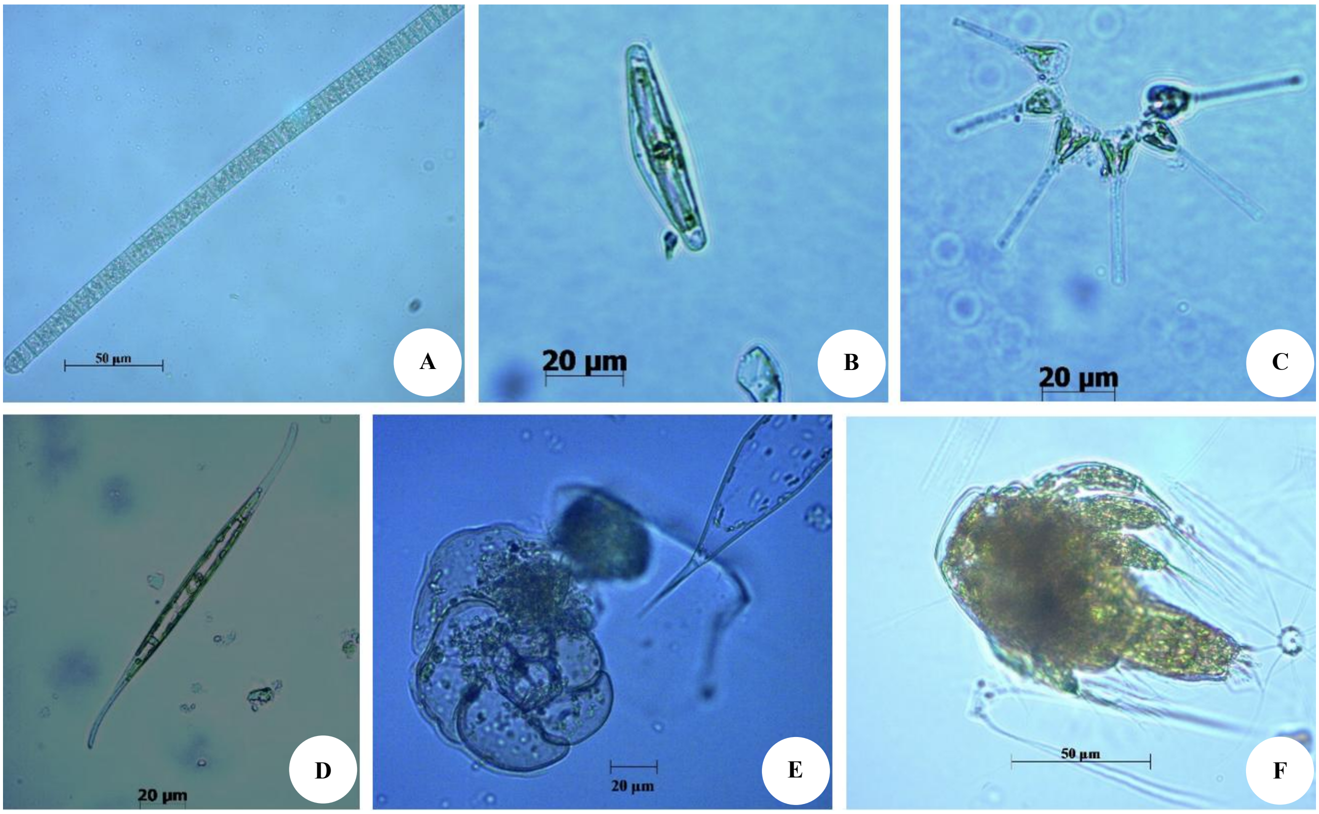

Figure 15. Phyto-zooplankton dominant abundance in the Semak Daun lagoon of each rearing system treatment (FNC, SNC, and BNC) during the 126-day experiment. A: *Trichodesmium* sp. (dominant phytoplankton day 0 and 63 in the FNC (44.16%, 90.38%), SNC (46.97%, 92.18%), and BNC (53.18%, 86,88%) treatment, respectively); B: *Navicula* sp. (dominant phytoplankton day 126 in the FNC (21.05%) treatment); C: *Asterionella* sp. (dominant phytoplankton day 126 in the SNC (26.64%) treatment); D: *Nitzschia* sp. (dominant phytpplankton day 126 in the BNC (58.36%) treatment); E: *Globorotalia* sp. (dominant zooplankton day 0 and 63 in the SNC (47.37%, 38.88%), BNC treatment (54.66%, 47.92%), day 126 in the FNC (32.79%) and BNC (26.53%) treatment respectively); F: *Nauplius* (stadia) (dominant zooplankton day 0 and 63 in the FNC (32.74%, 28.91%) treatment, respectively and day 126 in the SNC (28.33%) treatment

Table 10. The one-way ANOVA results of hydrostatic pressure (atm) in each post-puerulus *Panulirus homarus* rearing system (FNC, SNC, and BNC) at 08.00 am, 12.00 pm, and 04.00 pm on the experimental period of days 0, 63, and 126

Experimental period (days)	Time	df	MS	F	*p*
0	08.00 am	8	916.000	271.271	0.000
63					
126					
0	12.00 pm	8	244.444	1144.269	0.000
63					
126					
0	04.00 pm	8	1586.556	170.758	0.000
63					
126					

Table 11. The one-way ANOVA results of light intensity (lux) in each post-puerulus *Panulirus homarus* rearing system treatment (FNC, SNC, and BNC) at 08.00 am, 12.00 pm, and 04.00 pm on the experimental period of days 0, 63, and 126

Experimental period (days)	Time	df	MS	F	*p*
0	08.00 am	8	45781.076	11.190	0.009
63					
126					
0	12.00 pm	8	991285.236	1.667	0.266
63					
126					
0	04.00 pm	8	78240.862	6.024	0.037
63					
126					

Lobster prey preference is determined by nutritional adequacy, abundance, and size suitability (Ihsan et al. 2019). When preferred food species are scarce, lobsters shift to alternative food sources. The present study achieved a higher SGR (2.50±0.126-2.80±0.022% day^{-1}) compared to Lubis et al. (2023), who reported only 0.14±0.005-0.38±0.06% day^{-1}. Similarly, absolute CL was greater (1.63±0.154-2.02±0.109 cm) than that reported by Lubis et al. (2023) (0.08±0.008-0.46±0.06 cm). These findings suggest that the provided feed was preferred by lobsters, with phytoplankton serving as an alternative food source.

The superior growth rate observed in the FNC treatment corresponded to the fastest IMP (14.37±0.38 days; *p*: 0.000). Temperature likely contributed to these results (Radhakrishnan and Kizhakudan 2019; Ross and Behringer

2019). The average daily temperature in the FNC treatment was higher, ranging from 28.4°C to 31.5°C. Kemp and Britz (2008) reported that lower temperatures prolonged IMP in *P. h. rubellus*. Warmer temperatures accelerate the growth of *Homarus americanus* post-larvae (Harrington et al. 2019) by increasing metabolic activity, stimulating appetite, and promoting growth (Kemp and Britz 2008; Jones 2009; Drengstig and Bergheim 2013; Freitas et al. 2021). However, cannibalism increases among newly molted post-puerulus, and the likelihood of cannibalistic behavior was higher in the FNC treatment. Cannibalism has been documented in healthy lobsters immediately after molting (Jones 2009). The lower SR observed in the FNC treatment is likely attributable to cannibalism. Despite this, the IMP in the present study was faster (14-16 days) than that reported by Kemp and Britz (2008) (60-96 days). Similarly, the SGR was higher (2.50-2.80% days^{-1}) compared to Kemp and Britz (2008) (0.15-0.26% days^{-1}). These results corroborate the findings of Radhakrishnan and Kizhakudan (2019a), who reported that post-puerulus stage growth exceeds that of adult lobsters. The rearing system employed in this study produced higher final weight, CL, and SGR compared to the recirculating aquaculture system described by Supriyono et al. (2023).

The slow growth observed in the BNC treatment was likely due to low morning temperatures. Exposure to low temperatures reduces metabolic rate (Radhakrishnan et al. 2019b; Freitas et al. 2021), resulting in lower respiration, prolonged molting, and delayed IMP (Lellis and Russel 1990; Kemp and Britz 2008; Harrington et al. 2019). Nevertheless, the final growth of the BNC treatment did not differ from that of the FNC. The FCR efficiency of the BNC treatment was likely superior to that of the FNC. Kemp and Britz (2008) reported that FCR efficiency increases and approaches optimal levels at lower temperatures.

The aquatic environment significantly affects lobster growth quality (Minjoyo et al. 2024). Throughout the study, average daily temperatures for all treatments remained within the optimal range (Table 8). The BNC treatment exhibited relatively stable temperatures (28.6-28.7°C), whereas temperatures in the FNC and SNC treatments increased over time. In September, no significant temperature differences were observed among treatments (P>0.05, *p*: 0.703). However, in October, November, and December, temperatures in the FNC and SNC treatments were significantly higher than in the BNC treatment (P<0.05, *p*: 0.015, 0.001, and 0.001, respectively). These increases were likely due to temperature anomalies and elevated sea Surface Temperatures (SST). Variations in rearing system placement contributed to water temperature stratification (Freitas et al. 2021).

Since 1971, ocean temperatures have increased by 0.11°C decade^{-1} as a result of climate change (Karl et al. 2015). For example, a 2°C rise in average SST in Southeastern Australia resulted in the mortality of *Sagmariasus verreauxi* post-larvae (García-Echauri et al. 2020). Elevated temperatures induce stress responses and can lead to lobster mortality. Increased temperatures disrupt the moulting cycle of *H. americanus*, causing physiological stress (Antonio et al. 2025). Similarly, *H. americanus* larvae exhibit heightened stress and reduced SR under extreme temperatures (Harrington et al. 2019). Temperature is likely a key factor contributing to the lower SR observed in the FNC and SNC treatments compared to BNC. A significant correlation exists between temperature and SR (*p*: 0.000, Figure 17.B), consistent with findings by Harrington et al. (2019).

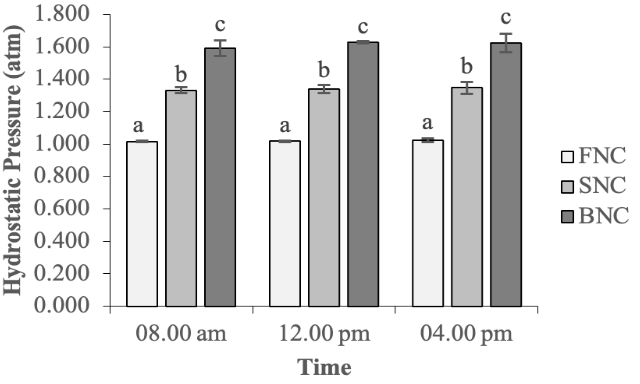

Figure 16. Graph of hydrostatic pressure (atm, mean±SE) in each post-puerulus *Panulirus homarus* rearing system at 08.00 am (FNC: 1.017±0.004^{c}, SNC: 1.332±0.018^{b}, BNC: 1.591±0.049^{a}), 12.00 pm (FNC: 1.018±0.004^{c}, SNC: 1.341±0.026^{b}, BNC: 1.628±0.006^{a}), and 04.00 pm (FNC: 1.023±0.012^{c}, SNC: 1.348±0.038^{b}, BNC: 1.623±0.056^{a}). Different superscript letters indicate statistically significant differences between treatments (P<0.05), and bars represent standard errors of the means

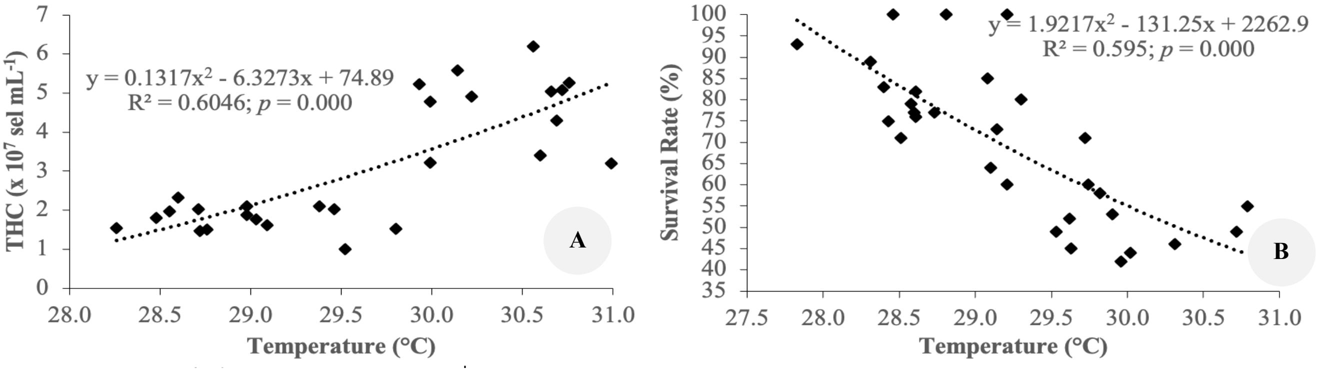

Figure 17. The correlation between temperature and THC (A) and survival rate (B) post-puerulus *Panulirus homarus* rearing in different systems during 126 days of experiment (*p*: 0.000)

Environmental changes induce physiological stress (Harrington et al. 2019; Supriyono et al. 2023), as indicated by glucose fluctuations in post-puerulus lobsters. Elevated initial glucose levels (Figure 9) were likely due to handling stress ($P>0.05$, *p*: 0.381). By day 63, the BNC treatment exhibited the lowest glucose levels ($P<0.05$, *p*: 0.001), decreasing by 24.47% by the end of the experiment ($P<0.05$, *p*: 0.001). In contrast, glucose levels in the FNC and SNC treatments increased by 35.89% and 23.59%, respectively, suggesting greater stress in this treatment. Heightened stress responses led to behavioral changes, such as reduced sheltering and social interaction, and increased aimless movement (Ross and Behringer 2019). Under stress, lobsters reallocate energy from growth to repair (Adiyana et al. 2014; Wang et al. 2017). Temperature is a primary stressor for most crustaceans (Minjoyo et al. 2024), although thermal preferences vary by developmental stage (Lellis and Russell 1990; Kulmiye and Mavuti 2005). Climate change may alter these preferences, particularly during the first juvenile stage (Antonio et al. 2025).

Increased stress also elevates THC in lobsters (Harrington et al. 2019). At the experiment's outset, THC levels did not differ among treatments ($P>0.05$, *p*: 0.695). By day 63, the BNC treatment had the lowest THC ($P<0.05$, *p*: 0.000), which continued to decrease by the experiment's end ($P<0.05$, *p*: 0.000). Conversely, THC levels in the FNC and SNC treatments increased (Figure 10). A significant correlation was found between temperature and THC (*p*: 0.000, Figure 17.A), aligning with Harrington et al. (2019), who reported increased THC in *H. americanus* post-larvae at 22°C compared to 16°C and 18°C. Elevated THC reduced phagocytic ability by approximately 60% in adult *H. americanus* after exposure to high temperatures (Dove et al. 2005), indicating potential health declines in post-puerulus lobsters in the FNC and SNC treatments. Other stressors may also contribute to prolonged stress and impaired growth.

Although water physicochemical parameters did not differ between SNC and FNC treatments, the SNC treatment exhibited the lowest growth ($P<0.05$, *p*: 0.012). By day 98, the SNC treatment's growth rate declined (Figure 4), consistent with Kemp and Britz (2008), who observed reduced growth of *P. h. rubellus* at 26ºC compared to 24ºC. Several SNC post-puerulus displayed abnormal development, including asymmetrical eyes, incomplete gill carapace closure (day 98), scoliosis, and big head syndrome (days 84 and 126). These abnormalities suggest suboptimal energy utilization for growth and prolonged stress, leading to increased susceptibility to disease, growth defects, and mortality (Harrington et al. 2019).

On day 56, water quality deteriorated (Figure 12), with DO dropping to 2.87 mg L^{-1} (FNC) and 3.30 mg L^{-1} (SNC), and pH falling to 7.10 (FNC) and 7.12 (SNC). Although no immediate mortality occurred, 34 post-puerulus died on day 57, the highest mortality recorded during the experiment: 16 in SNC, 10 in FNC, and 8 in BNC. Reduced appetite in FNC and SNC treatments was inferred from increased leftover feed. Observed behaviors included sluggish movement, trembling, and low antennular flicking frequency, suggesting declining health. The causes of decreased pH and DO remain undetermined due to the absence of water samples. Visual observations noted an initial brownish, sawdust-like layer on the water surface and column, which later became thicker, greenish, slimy, and malodorous following water agitation.

Decreasing pH and ocean acidification disrupt chemosensory neurons, alter the molting cycle, and impair cuticle development, thereby increasing susceptibility to disease and injury (Kim et al. 2016; Ross and Behringer 2019; Antonio et al. 2025). Reduced DO induces hypoxia in lobsters, weakens immune function, and can ultimately result in mortality (Young-Lai et al. 1991; Sébert et al. 1995).

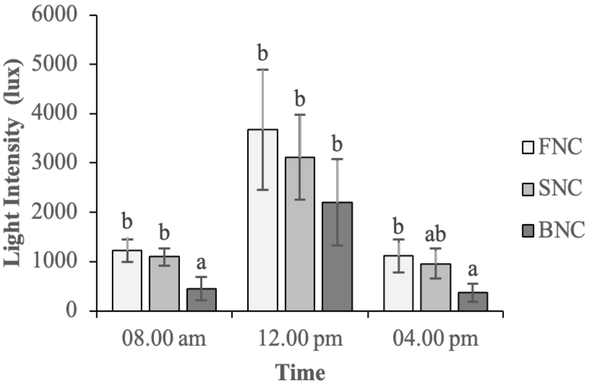

Figure 18. Graph of light intensity (lux; mean±SE) in each post-puerulus *Panulirus homarus* rearing system treatment at 08.00 am (FNC: 1,220±231.7^{b}, SNC: 1,093±175.9^{b}, BNC: 449±229.6^{a}), 12.00 pm (FNC: 3,670±1213.5^{b}, SNC: 3,112±858.5^{b}, BNC: 2,200±874.2^{b}), and 04.00 pm (FNC: 1,116±335.1^{b}, SNC: 954±305.2^{ab}, BNC: 365±180.5^{a}). Different superscript letters indicate statistically significant differences between treatments ($P<0.05$), and bars represent standard errors of the means

Table 12. Significant wave height and period (average, min, and max) at the research location in the period of August, September, October, November, and December 2023

Month	**Wave Heights (m)**			**Wave Periods (seconds)**		
	Mean	**Min**	**Max**	**Mean**	**Min**	**Max**
August	0.0867	0.0763	0.1013	2.59	2.16	3.13
September	0.1266	0.0688	0.1950	2.97	2.3125	4.8288
October	0.2772	0.1338	0.4713	0.2772	2.5525	4.9538
November	0.4399	0.2225	0.6488	0.4399	3.0563	4.6138
December	0.6471	0.4150	0.8463	0.6471	3.3025	4.7650

Table 13. Significant wave height and period at 3-hour intervals at the research site during 126 days of the experiment (August, September, October, November, December)

Location : Semak Daun Waters - Seribu Islands Regency Administration
Coordinates : 5°43'12.8"S 106°35'32.3"E
Source : Marine Environment Monitoring Service

Date	Wave Heights (m)								Wave Periods (seconds)							
	12:00 am	3:00 am	6:00 am	9:00 am	12:00 pm	3:00 pm	6:00 pm	9:00 pm	12:00 am	3:00 am	6:00 am	9:00 am	12:00 pm	3:00 pm	6:00 pm	9:00 pm
23-Aug-23	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	4.54	4.66	4.77	4.55	4.11	4.11	3.98	3.96
24-Aug-23	0.09	0.08	0.08	0.08	0.07	0.08	0.08	0.08	4.16	4.29	3.96	3.7	3.76	4.01	4.07	3.92
25-Aug-23	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	4.09	4.44	4.51	4.44	4.31	4.82	4.46	4.48
26-Aug-23	0.09	0.09	0.08	0.09	0.09	0.09	0.09	0.1	4.54	4.58	4.57	4.16	3.67	3.64	3.75	3.9
27-Aug-23	0.11	0.11	0.1	0.1	0.09	0.09	0.09	0.09	4.06	4.2	4.18	4.04	3.99	4.07	4.38	4.59
28-Aug-23	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	4.45	4.67	4.48	4.42	4.49	4.63	4.71	4.59
29-Aug-23	0.09	0.09	0.08	0.09	0.09	0.09	0.09	0.1	3.88	3.61	3.6	3.52	3.7	4.01	4.26	4.4
30-Aug-23	0.06	0.07	0.07	0.08	0.09	0.1	0.1	0.11	4.55	4.61	4.64	4.21	3.79	3.93	4.15	4.31
31-Aug-23	0.1	0.1	0.09	0.1	0.1	0.11	0.1	0.11	4.47	4.63	4.75	4.81	4.85	4.87	4.87	4.87
01-Sep-23	0.08	0.09	0.09	0.1	0.11	0.11	0.12	0.14	4.85	4.77	4.59	4.47	4.43	4.42	4.42	4.43
02-Sep-23	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	4.44	4.52	4.62	5.09	4.81	4.39	4.38	4.53
03-Sep-23	0.07	0.07	0.06	0.07	0.07	0.07	0.07	0.07	4.19	3.78	3.61	3.58	3.75	4	4.06	3.95
04-Sep-23	0.08	0.08	0.09	0.09	0.11	0.08	0.07	0.06	3.89	3.98	3.83	3.58	3.5	3.68	3.77	3.57
05-Sep-23	0.1	0.1	0.09	0.1	0.1	0.11	0.1	0.11	3.99	4.23	4.17	3.73	3.78	4.04	4.31	4.47
06-Sep-23	0.06	0.07	0.07	0.08	0.09	0.1	0.1	0.11	4.55	4.62	4.67	4.61	4.2	4.24	4.41	4.48
07-Sep-23	0.21	0.23	0.11	0.08	0.11	0.15	0.23	0.33	4.46	4.47	4.31	3.82	3.78	3.87	4.02	4.02
08-Sep-23	0.39	0.38	0.25	0.13	0.09	0.09	0.09	0.1	3.49	3.28	3.01	2.97	3.12	3.34	3.54	3.67
09-Sep-23	0.12	0.13	0.14	0.15	0.16	0.17	0.2	0.21	3.69	3.73	3.87	4	4.09	4.17	4.26	4.32
10-Sep-23	0.08	0.09	0.09	0.1	0.11	0.11	0.12	0.14	4.36	4.61	4.34	4.18	4.11	4.12	4.29	4.49
11-Sep-23	0.15	0.15	0.15	0.14	0.12	0.12	0.12	0.13	4.64	4.64	4.53	4.5	4.6	4.62	4.41	4.19
12-Sep-23	0.14	0.13	0.13	0.14	0.18	0.21	0.14	0.14	4.47	4.52	4.55	4.23	3.67	3.72	3.78	3.84
13-Sep-23	0.11	0.11	0.13	0.16	0.19	0.21	0.14	0.1	3.95	4.08	4.18	4.15	4.17	4.24	4.27	4.31
14-Sep-23	0.09	0.09	0.09	0.09	0.1	0.1	0.11	0.11	4.42	4.41	4.4	4.39	4.39	4.23	3.78	3.6
15-Sep-23	0.12	0.12	0.11	0.11	0.1	0.12	0.13	0.14	3.9	4.3	4.53	4.16	3.96	4.02	4.18	4.07
16-Sep-23	0.16	0.15	0.09	0.07	0.07	0.07	0.06	0.06	4.1	4.15	3.85	3.66	4.13	4.53	4.61	4.35
17-Sep-23	0.12	0.14	0.15	0.17	0.19	0.22	0.24	0.25	4.22	4.19	4.23	4.33	4.48	4.45	4.54	4.47
18-Sep-23	0.09	0.09	0.1	0.11	0.13	0.16	0.19	0.24	4.57	4.48	4.47	4.34	4.22	4.34	4.49	4.66
19-Sep-23	0.18	0.15	0.11	0.08	0.08	0.08	0.07	0.07	4.86	4.74	4.35	3.68	3.43	3.42	3.47	3.57
20-Sep-23	0.08	0.08	0.08	0.09	0.1	0.12	0.14	0.17	3.66	3.71	3.71	3.3	3.02	3.11	3.31	3.51
21-Sep-23	0.19	0.18	0.18	0.17	0.16	0.16	0.11	0.12	3.7	3.88	3.94	3.91	3.95	4.06	4.22	4.37
22-Sep-23	0.09	0.1	0.12	0.14	0.09	0.1	0.11	0.13	4.49	4.58	4.64	3.48	3.24	3.44	3.55	3.65
23-Sep-23	0.15	0.17	0.19	0.13	0.1	0.1	0.12	0.13	3.48	3.12	3.08	3.24	3.37	3.52	3.74	3.95
24-Sep-23	0.15	0.16	0.16	0.14	0.12	0.13	0.15	0.18	4.2	4.32	4.14	3.96	4.47	4.36	4.2	4.09
25-Sep-23	0.22	0.27	0.3	0.29	0.16	0.11	0.11	0.1	4.22	4.14	4.06	4.34	4.32	4.73	4.26	4.1
26-Sep-23	0.1	0.11	0.11	0.12	0.13	0.14	0.15	0.16	4.11	4.21	4.39	4.39	4.43	4.52	4.48	4.39
27-Sep-23	0.16	0.15	0.14	0.14	0.13	0.13	0.13	0.12	4.34	4.4	5.41	4.1	3.55	3.66	3.9	4.12

28-Sep-23	0.12	0.11	0.11	0.11	0.11	0.11	0.11	0.12	4.39	4.65	4.76	4.11	3.53	3.61	3.85	4.12
29-Sep-23	0.13	0.13	0.13	0.13	0.12	0.12	0.12	0.12	4.37	4.55	4.72	4.45	4.46	4.73	4.8	4.83
30-Sep-23	0.11	0.11	0.11	0.12	0.12	0.13	0.13	0.14	4.84	4.79	4.68	4.36	4.29	4.41	3.99	4.13
01-Oct-23	0.14	0.17	0.49	0.14	0.14	0.14	0.14	0.15	4.28	4.4	4.41	4.39	4.41	4.53	4.75	4.8
02-Oct-23	0.19	0.13	0.12	0.11	0.12	0.13	0.15	0.16	4.57	4.53	4.46	4.29	3.97	3.71	3.81	3.92
03-Oct-23	0.18	0.21	0.23	0.24	0.22	0.19	0.2	0.21	4.03	4.14	4.15	3.97	3.67	4	4.7	4.46
04-Oct-23	0.2	0.21	0.18	0.09	0.09	0.1	0.1	0.1	4.31	4.01	3.73	3.64	3.74	3.97	4.12	4.17
05-Oct-23	0.16	0.17	0.17	0.17	0.17	0.17	0.17	0.18	3.91	3.43	3.12	2.88	3.16	3.41	3.62	3.75
06-Oct-23	0.23	0.27	0.31	0.37	0.38	0.24	0.24	0.3	3.84	3.94	3.99	4.04	4.1	4.12	4.13	4.17
07-Oct-23	0.36	0.45	0.58	0.61	0.45	0.26	0.24	0.27	4.24	4.52	4.48	4.14	4.36	4.26	4.26	4.2
08-Oct-23	0.37	0.56	0.76	0.68	0.51	0.31	0.27	0.31	4.16	3.81	3.88	3.28	3.41	3.81	4.08	4.4
09-Oct-23	0.33	0.38	0.46	0.48	0.34	0.27	0.25	0.29	4.46	4.33	3.64	3.34	3.31	3.47	3.48	3.46
10-Oct-23	0.35	0.4	0.45	0.39	0.3	0.26	0.3	0.37	3.61	3.67	3.35	3.2	3.31	3.45	3.55	3.66
11-Oct-23	0.41	0.46	0.47	0.41	0.28	0.24	0.3	0.35	3.69	3.64	3.34	2.64	2.64	2.88	3.04	3.16
12-Oct-23	0.37	0.43	0.39	0.24	0.13	0.16	0.21	0.28	3.21	2.75	2.52	2.56	2.94	3.22	3.5	3.75
13-Oct-23	0.36	0.46	0.52	0.45	0.25	0.26	0.36	0.33	3.95	4.08	4.1	3.97	3.93	4.81	4.32	4.21
14-Oct-23	0.43	0.49	0.47	0.38	0.23	0.24	0.29	0.35	4.22	4.27	4.28	4.31	4.37	4.62	5.04	5.09
15-Oct-23	0.26	0.26	0.26	0.26	0.24	0.22	0.22	0.23	4.9	4.8	4.74	4.42	3.75	3.62	3.73	3.86
16-Oct-23	0.24	0.26	0.28	0.29	0.31	0.32	0.34	0.33	3.96	4.05	4.1	3.84	3.67	4.03	4.33	4.33
17-Oct-23	0.32	0.31	0.31	0.33	0.35	0.38	0.41	0.43	4.26	4.22	4.25	3.88	4.08	4.23	4.15	4.15
18-Oct-23	0.4	0.34	0.22	0.21	0.17	0.11	0.1	0.11	4.24	4.35	4.4	4.01	3.97	4.11	3.94	3.48
19-Oct-23	0.2	0.24	0.28	0.33	0.35	0.28	0.24	0.21	3.51	3.37	3.32	3.19	3.14	3.21	3.3	3.35
20-Oct-23	0.17	0.18	0.19	0.21	0.21	0.21	0.22	0.23	3.34	3.42	3.36	3.4	3.55	3.68	3.83	4
21-Oct-23	0.24	0.27	0.3	0.33	0.34	0.31	0.28	0.3	4.16	4.05	3.35	2.65	2.99	3.4	3.7	3.84
22-Oct-23	0.36	0.35	0.27	0.26	0.25	0.24	0.23	0.21	3.94	4.09	4.12	4.21	4.48	4.68	4.73	4.71
23-Oct-23	0.19	0.18	0.18	0.19	0.21	0.23	0.26	0.29	4.66	4.62	4.11	4.17	4.36	8.29	4.85	4.57
24-Oct-23	0.25	0.25	0.27	0.33	0.22	0.22	0.21	0.22	4.54	4.53	3.97	4.1	4.29	4.27	3.79	3.81
25-Oct-23	0.22	0.22	0.22	0.21	0.21	0.21	0.21	0.22	3.99	4.18	3.86	3.86	3.8	3.64	3.53	3.52
26-Oct-23	0.22	0.24	0.25	0.29	0.3	0.28	0.29	0.32	3.57	3.64	3.37	3.42	3.46	3.58	3.72	3.71
27-Oct-23	0.33	0.29	0.26	0.27	0.26	0.26	0.26	0.26	3.85	3.96	3.74	3.72	3.74	3.64	3.54	3.54
28-Oct-23	0.27	0.28	0.29	0.31	0.31	0.31	0.31	0.31	3.5	3.59	3.52	3.18	2.68	3.23	3.88	4.12
29-Oct-23	0.31	0.3	0.26	0.22	0.19	0.18	0.17	0.17	4.31	4.49	4.52	4.39	4.15	4.25	4.27	4.25
30-Oct-23	0.2	0.21	0.23	0.26	0.3	0.28	0.3	0.32	4.29	4.35	4.36	4.36	4.42	4.58	4.94	5.28
31-Oct-23	0.3	0.29	0.31	0.33	0.36	0.39	0.42	0.46	5.16	4.95	4.29	2.51	2.84	3.33	3.64	3.83
01-Nov-23	0.39	0.38	0.36	0.33	0.3	0.27	0.28	0.3	3.94	4.04	4.02	3.97	3.76	3.84	3.94	4.02
02-Nov-23	0.34	0.28	0.28	0.28	0.29	0.3	0.31	0.31	4.1	4.21	4.19	4.41	5.55	5.11	4.97	5.04
03-Nov-23	0.31	0.32	0.33	0.33	0.31	0.27	0.28	0.29	5.34	4.87	4.61	4.52	4.52	4.4	4.32	4.54
04-Nov-23	0.29	0.28	0.29	0.32	0.34	0.37	0.39	0.42	4.85	5.03	4.87	4.4	3.61	3.57	3.79	3.87
05-Nov-23	0.42	0.4	0.34	0.32	0.33	0.35	0.37	0.4	3.7	3.16	2.56	2.77	2.99	3.13	3.23	3.38
06-Nov-23	0.42	0.42	0.41	0.4	0.35	0.25	0.18	0.16	3.6	3.79	3.89	3.99	4.11	4.16	4.18	4.25
07-Nov-23	0.17	0.18	0.19	0.22	0.24	0.25	0.25	0.28	4.3	4.34	4	3.85	3.86	3.92	3.91	3.91
08-Nov-23	0.46	0.49	0.39	0.4	0.34	0.33	0.34	0.31	3.91	3.93	3.35	3.26	3.4	3.61	3.34	3.31
09-Nov-23	0.56	0.55	0.53	0.51	0.45	0.39	0.37	0.38	3.12	3.14	3.13	2.15	2.2	2.44	2.4	2.5
10-Nov-23	0.4	0.43	0.41	0.42	0.42	0.43	0.45	0.48	2.59	2.71	2.82	2.83	2.66	2.73	2.69	2.73
11-Nov-23	0.51	0.53	0.52	0.48	0.45	0.43	0.4	0.41	2.79	2.85	2.83	2.88	1.97	2.12	2.4	2.58
12-Nov-23	0.44	0.45	0.47	0.48	0.5	0.53	0.56	0.59	2.72	2.82	2.81	2.84	3.85	3.37	3.25	3.17

13-Nov-23	0.31	0.35	0.4	0.45	0.49	0.5	0.51	0.53	3.87	2.88	1.92	2.13	2.33	2.51	2.63	2.74
14-Nov-23	0.59	0.67	0.72	0.7	0.66	0.64	0.63	0.58	2.56	2.35	2.62	3.04	3.06	3.02	3.01	2.99
15-Nov-23	0.48	0.44	0.43	0.45	0.46	0.49	0.55	0.47	2.98	3.01	2.94	3.02	3.06	3.2	3.26	3.37
16-Nov-23	0.51	0.55	0.6	0.47	0.42	0.39	0.34	0.34	3.46	3.55	3.04	2.99	2.96	2.72	2.85	3.06
17-Nov-23	0.36	0.39	0.4	0.41	0.42	0.43	0.44	0.46	3.23	3.33	3.06	2.99	3.21	3.48	3.7	3.85
18-Nov-23	0.49	0.51	0.53	0.52	0.44	0.41	0.39	0.39	3.95	4.02	3.04	3.06	2.78	3.09	2.82	3.07
19-Nov-23	0.45	0.5	0.63	0.44	0.43	0.41	0.41	0.42	3.27	3.06	2.71	2.64	2.54	2.27	2.4	2.25
20-Nov-23	0.33	0.38	0.44	0.36	0.41	0.48	0.49	0.49	2.14	2.31	2.37	2.42	2.5	2.62	2.78	2.89
21-Nov-23	0.52	0.54	0.57	0.59	0.55	0.46	0.42	0.45	2.93	2.96	2.97	2.98	2.93	2.8	2.8	2.84
22-Nov-23	0.47	0.5	0.51	0.44	0.4	0.4	0.41	0.4	2.83	2.94	2.85	2.38	2.19	2.74	4.11	4.57
23-Nov-23	0.45	0.48	0.49	0.5	0.52	0.57	0.61	0.59	4.79	4.78	4.7	4.66	4.7	4.82	4.99	5.19
24-Nov-23	0.57	0.54	0.51	0.53	0.56	0.61	0.68	0.69	5.39	5.46	5.23	4.69	3.83	4.03	4.27	4.39
25-Nov-23	0.56	0.48	0.46	0.47	0.5	0.54	0.58	0.56	4.44	4.36	4.06	4.1	4.02	4.03	4.15	4.24
26-Nov-23	0.55	0.52	0.49	0.48	0.47	0.47	0.48	0.47	4.33	4.35	4.24	4.05	3.89	3.69	3.54	3.46
27-Nov-23	0.46	0.47	0.48	0.49	0.52	0.54	0.55	0.48	3.45	3.06	2.68	2.41	2.72	2.76	3.1	3.43
28-Nov-23	0.49	0.5	0.44	0.44	0.45	0.48	0.5	0.5	3.71	3.87	3.12	3.12	2.91	2.13	2.12	2.38
29-Nov-23	0.48	0.46	0.45	0.45	0.45	0.48	0.45	0.46	2.51	2.62	2.69	2.63	2.25	2.32	2.47	2.58
30-Nov-23	0.48	0.49	0.5	0.5	0.49	0.46	0.47	0.5	2.67	2.75	2.81	2.74	2.83	2.79	2.84	2.76
01-Dec-23	0.48	0.44	0.43	0.41	0.39	0.38	0.39	0.4	2.58	2.06	2.2	2.45	2.51	2.55	2.74	2.34
02-Dec-23	0.42	0.44	0.46	0.47	0.48	0.5	0.53	0.58	2.2	2.4	3.03	3.13	2.82	2.26	2.28	2.67
03-Dec-23	0.5	0.48	0.55	0.58	0.46	0.43	0.41	0.41	2.76	2.82	2.79	2.79	2.86	2.93	2.99	3.03
04-Dec-23	0.41	0.42	0.44	0.45	0.46	0.46	0.48	0.5	3.07	3.12	3.17	2.99	3	3.11	3.25	3.39
05-Dec-23	0.62	0.65	0.65	0.69	0.7	0.72	0.76	0.8	3.35	3.55	3.75	3.4	3.49	3.45	3.35	3.38
06-Dec-23	0.81	0.79	0.77	0.72	0.74	0.76	0.76	0.76	3.05	3.34	3.66	4.02	2.94	2.77	2.85	2.3
07-Dec-23	0.73	0.69	0.61	0.62	0.82	0.57	0.57	0.56	2.33	2.47	2.58	2.61	2.36	1.66	2.22	2.27
08-Dec-23	0.55	0.56	0.57	0.55	0.52	0.48	0.47	0.47	2.38	2.49	2.32	2.17	2.28	2.44	2.56	2.51
09-Dec-23	0.73	0.71	0.69	0.67	0.69	0.69	0.7	0.72	2.5	2.64	2.7	2.75	2.53	2.22	2.17	1.98
10-Dec-23	0.78	0.84	0.85	0.77	0.73	0.74	0.82	0.93	2.28	2.47	2.62	2.67	2.62	2.66	2.68	2.76
11-Dec-23	0.99	0.83	0.83	0.81	0.77	0.75	0.75	0.69	2.86	3.01	3.36	3.41	3.4	3.39	3.49	3.5
12-Dec-23	0.61	0.58	0.55	0.55	0.58	0.62	0.67	0.71	3.49	3.48	3.46	2.96	2.3	2.56	2.69	2.58
13-Dec-23	0.75	0.76	0.75	0.72	0.74	0.81	0.88	0.79	2.57	2.58	2.57	2.25	2.31	2.58	2.59	2.66
14-Dec-23	0.79	0.79	0.77	0.75	0.74	0.76	0.79	0.8	2.67	3.24	3.16	2.28	2.43	2.69	2.68	2.57
15-Dec-23	0.78	0.77	0.73	0.71	0.68	0.63	0.58	0.54	2.52	2.55	2.62	2.51	2.03	2.51	2.81	2.64
16-Dec-23	0.5	0.56	0.62	0.66	0.68	0.69	0.7	0.68	2.38	2.52	2.5	2.14	2.37	2.51	2.53	2.48
17-Dec-23	0.68	0.65	0.66	0.65	0.61	0.56	0.54	0.56	2.4	2.42	2.13	2.17	2.32	2.53	2.46	2.32
18-Dec-23	0.52	0.55	0.57	0.6	0.63	0.65	0.68	0.7	2.31	2.16	2.12	2.24	2.46	2.58	2.45	2.33
19-Dec-23	0.71	0.71	0.67	0.63	0.63	0.66	0.7	0.73	2.26	2.41	2.14	2.53	2.86	3.17	2.91	2.65
20-Dec-23	0.78	0.81	0.78	0.75	0.69	0.67	0.65	0.64	2.32	2.2	2.14	2.41	2.71	2.82	2.64	2.5
21-Dec-23	0.64	0.61	0.58	0.58	0.61	0.65	0.54	0.52	2.42	2.47	1.97	2.25	2.34	2.23	2.15	2.15
22-Dec-23	0.54	0.59	0.59	0.57	0.49	0.44	0.43	0.42	2.99	2.93	2.83	2.86	2.98	1.93	2.02	2.29
23-Dec-23	0.42	0.43	0.46	0.49	0.51	0.54	0.57	0.61	2.41	2.45	2.27	1.8	1.72	2	2.23	2.41
24-Dec-23	0.63	0.78	0.63	0.66	0.7	0.76	0.76	0.78	2.53	2.62	2.64	2.85	3.19	3.49	3.78	3.96
25-Dec-23	0.8	0.82	0.8	0.76	0.73	0.77	0.81	0.85	4.09	3.15	1.99	1.8	1.94	2.09	2.37	2.79
26-Dec-23	0.85	0.8	0.8	0.85	0.88	0.86	0.88	0.85	3.3	3.21	2.42	2	2.41	3.02	3.54	3.83

In addition to these direct effects, declining pH and DO alter the balance between ammonia (NH_3) and ammonium (NH_4^+) in the water (Young-Lai et al. 1991). Elevated hemolymph ammonia, which triggers ammonium toxicity, leads to stress and mortality in lobsters (Young-Lai et al. 1991; Schmitt and Uglow 1997). Post-puerulus individuals in the BNC treatment exhibited normal movement and responded well to feed, suggesting that the environmental conditions of the BNC treatment may facilitate recovery (Young-Lai et al. 1991).

Light is a key variable influencing SR, growth, and development in crustaceans (Dou et al. 2021). Significant differences in light intensity were observed among treatments in the morning and afternoon ($P<0.05$). The BNC treatment had significantly lower morning light intensity ($P<0.05$, p: 0.009), while no significant differences were found during the day ($P>0.05$, p: 0.266). In the afternoon, the BNC treatment again exhibited the lowest light intensity ($P<0.05$, p: 0.037), which was not significantly different from the SNC treatment. Filippi et al. (2024) reported that the SR of *P. elephas* phyllosoma stage VI was highest at medium (359 lux) and high (910 lux) light compared to low light (26 lux). In contrast, the present study found that exposure to low light in the BNC treatment produced the highest SR (71.00±2.00%, p: 0.000). These findings support the observed decline in positive phototaxis as lobsters mature (Berry 1971; Radhakrishnan and Kizhakudan 2019). Similarly, the light requirements of *Portunus trituberculatus* decrease as the zoea and megalopa stages transition to juveniles (Dou et al. 2021). The low SR observed in the FNC and SNC treatments is likely attributable to increased light and temperature. Light and temperature jointly influence the type and magnitude of species responses in marine environments (Sulkin 1984).

Lobsters typically inhabit pressurised waters. Figure 16 demonstrates significant differences in hydrostatic pressure among treatments ($P<0.05$), with the BNC treatment exhibiting the highest pressure. Post-puerulus in the FNC and SNC treatments displayed hyperactivity during the day and frequently left shelter, whereas those in the BNC treatment were more sedentary and tended to remain in groups within shelters. Lobsters undergo a transformation from planktonic to benthic forms, settling on the substrate (Goldstein and Butler 2009). The post-larval stage of *H. gammarus* is sensitive to pressure changes, but this sensitivity diminishes as the first juvenile stage approaches (Ennis 1973). The nervous system of benthic crustaceans likely adapts to hydrostatic pressure, although pressure changes can induce depression, affect muscle fiber contraction, and result in hyperactive behavior (Campenot 1975). Bottom-dwelling aquatic organisms are likely adapted to specific pressure ranges (Macdonald 1997). Current research limitations preclude definitive attribution of hyperactivity to hydrostatic pressure or other factors such as temperature. Temperature has been reported to correlate with hydrostatic pressure, inducing stress in marine organisms attempting to tolerate adverse conditions (Morris et al. 2015).

The study was conducted in aquaculture sites and traditional fishing grounds, where boat traffic is unavoidable. Boat engine noise has been reported to affect crustacean immune responses (Filiciotto et al. 2014; Celi et al. 2015). *Palinurus elephas* exhibited a 30% decrease in haemocytic count following exposure to boat noise (Filiciotto et al. 2014), and Celi et al. (2015) reported a 38% decrease in THC in *P. elephas* under similar conditions. This effect likely occurred across all treatments in the present study, although further research is required to confirm this hypothesis.

Waves are also suspected to influence the physiology of cultured organisms. At the Semak Daun Waters research site, wave height ranged from 0.06 to 0.99 m, and wave periods from 1.66 to 8.29 seconds, indicating short-period waves (Johannesen et al. 2020). Breaking waves generate turbulence and can have damaging effects (Dean and Dalrymple 1991). Although adult *P. homarus* are reported to prefer wavy areas, they typically shelter in coral reefs and rock crevices in their natural habitat. Waves induce turbulence, vibration, and increased turbidity (Gabel et al. 2011; Joo and Kim 2024). In mariculture, shock is strictly avoided, as it may cause vibration in rearing containers. Vibration has been shown to increase energy consumption and stress responses in *Austruca lactea crabs* (Joo and Kim 2024). Vibration in the FNC and SNC treatments is likely greater than in the BNC treatment, potentially increasing stress responses. However, lifting maintenance containers to the surface during sampling may introduce vibrations in all treatments.

Waves also increase water turbidity by agitating suspended materials such as sediment and organic matter (Gabel et al. 2011). High turbidity has been associated with a four-fold increase in mortality risk for *Penaeus vannamei* (Kathyayani et al. 2019). Turbidity is a key parameter for detecting the distribution of 24 *Panulirus* species in shallow waters up to 100 m depth (Radhakrishnan et al. 2019a). Excessive turbidity acts as a stressor for lobsters when it exceeds normal thresholds (Lin et al. 1992; Kathyayani et al. 2019).

The findings of this study provide valuable insights for lobster mariculture, particularly in optimizing rearing system selection. Although the FNC treatment resulted in a higher SGR and increment in IMP, the BNC treatment achieved the highest SR (71.00%) and the lowest stress response. Therefore, to reduce mortality risk and improve seed quality, the BNC treatment is recommended. The BNC treatment effectively mitigates the effects of temperature anomalies and other environmental variables, resulting in more reliable and higher-quality lobster juveniles for grow-out.

In conclusion, the results indicate that the BNC rearing system can buffer environmental changes. Despite slower growth, the post-puerulus SR was optimized at 71%, and the stress response was significantly reduced. This experimental study was limited by the research parameters, and environmental influences could not be fully controlled. Environmental changes outside the research parameters, such as boat noise, increased vibration, and turbidity, may have influenced the results. Nevertheless, this study provides valuable information for developing rearing protocols to enhance growth performance and post-puerulus SR of *P. homarus*. Further research is required to examine the effects of photoperiod, turbidity, and vibration on stress response, growth, and post-puerulus SR of *P. homarus* under controlled laboratory conditions.

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REFERENCES

Adiyana K, Supriyono E, Junior MZ, Thesiana L .2014. Application of various shelters on stress response and survival rate of spiny lobster *Panulirus homarus* nursery. Jurnal Kelautan Nasional 9 (1): 1-9. DOI: 10.15578/jkn.v9i1.6197.

Agency for Meteorology, Climatology, and Geophysics (BMKG). 2023. Analysis of Atmosphere-Ocean Dynamics; Analysis and Prediction of Rainfall. BMKG, Indonesia. https://www.bmkg.go.id/iklim/anomali-suhu-udara/page/2.

Amin M, Fitria A, Mukti AT, Manguntungi AB, Amrullah S, Alim S, Martin MB. 2022b. Evaluating the stomach content of Wild Scalloped Spiny Lobster (*Panulirus homarus*). Biodiversitas 23 (12): 6397-6403. DOI: 10.13057/biodiv/d231237.

Amin M, Harlyan LI, Khamad K, Diantari R. 2022c. Profiling the natural settlement habitat of spiny lobster, *Panulirus* spp. to determine potential diets and rearing conditions in a lobster hatchery. Biodiversitas 23 (6): 2893-2898. DOI: 10.13057/biodiv/d230615.

Amin M, Taha H, Samara SH, Fitria A, Muslichah NA, Musdalifah L, Odeyemi OA, Alimuddin A, Arai T. 2022a. Revealing diets of wild-caught ornate spiny lobster, *Panulirus ornatus*, at puerulus, post-puerulus, and juvenile stages using environmental DNA (eDNA) metabarcoding. Aquac Rep 27: 101361. DOI: 10.1016/j.aqrep.2022.101361.

Anissah U, Pamungkas A, Waryanto, Sukoraharjo SS. Sea cage effectiveness test for spiny lobster (*Panulirus homarus*) in Sepanjang Coast, Gunung Kidul District. 2015. Jurnal Kelautan Nasional 10 (2): 91-102. DOI: 10.15578/jkn.v10i2.6160.

Antonio CS, Poyton H, Krick K, Robyn H. 2025. Ocean warming and acidification alter calcification and innate immune system gene expression in juvenile American lobsters, *Homarus americanus*. Comp Biochem Physiol Part D Genom Proteom 54: 101404. DOI: 10.1016/j.cbd.2024.101404.

Aonullah AA, Ahmadi F. 2021. Growth Monitoring of sand lobster (*Panulirus homarus*) using the bottom cage method in the example unit of marine lobster cultivation, Banyuwangi Regency, East Java Province. J Aquac Dev Environ 4 (2): 272-276. DOI: 10.31002/jade.v4i2.4794.

Arifin MY, Supriyono E, Widanarni. 2014. Total hemosit, glucose and survival rate mantis shrimp (*Harpiosquilla raphidea*) post transportation with two different system. Jurnal Kelautan Nasional 9 (2): 111-119. DOI: 10.15578/jkn.v9i2.6207.

Arumugam A, Dineshkumar R, Rasheeq Ahamed A, Prabakaran G, Sampathkumar P, Murugan S. 2020. Biochemical profile of spiny lobsters *P. homarus* and *P. ornatus*. Agric Sci Digest 40 (4): 411-417. DOI: 10.18805/ag.D-5091.

Bermudes M, Ritar AJ, Carter CG, 2008. The ontogeny of physiological response to light intensity in early stage spiny lobster (*Jasus edwardsii*) larvae. Comp Biochem Physiol Part A Mol Integr Physiol 150 (1): 40-45. DOI: 10.1016/j.cbpa.2008.02.023.

Berry PF. 1971. The Spiny Lobster (*Palinuridae*) of the East Coast of Southern Africa: Distribution and Ecological Notes. In: Berry PF (eds). Investigational Report No. 27. The Oceanographic Research Institute, Durban, Republic of South Africa. https://www.researchgate.net/publication/285777241_The_spiny_lobsters_Palinuridae_of_the_east_coast_of_Southern_Africa_Distribution_and_ecological_notes.

Blaxhall PC, Daisley KW. 1973. Routine haematological methods for use with fish blood. J Fish Biol 5: 577-581. DOI: 10.1111/j.1095-8649.1973.tb04510.x.

Butler MJIV, Steneck RS, Herrnkind WF. 2006. Juvenile and adult ecology. In: Phillips BF (eds). Lobsters: Biology and Management. Blackwell Publishing, Oxford, UK. DOI: 10.1002/9780470995969.ch8.

Campenot RB.1975. The effects of high hydrostatic pressure on transmission at the crustacean neuromuscular junction. Comp Biochem Physiol Part B Biochem Mol Biol 52 (1): 133-140. DOI: 10.1016/0305-0491(75)90128-5.

Celi M, Filiciotto F, Vazzana M, Arizza V, Maccarrone V, Ceraulo M, Mazzola S, Buscaino G. 2015. Shipping noise affecting immune responses of European spiny lobster (*Palinurus elephas*). Can J Zool 93 (2): 113-121. DOI: 10.1139/cjz-2014-0219.

Dean RG, Dalrymple RA. 1991. Water Wave Mechanics for Engineers and Scientists Vol 2. World Scientific Publishing, Singapore. DOI: 10.1142/1232.

Dennis DM, Skewes TD, Pitcher CR. 1997. Habitat use and growth of juvenile ornate rock lobsters, *Panulirus ornatus* (Fabricius, 1798), in Torres Strait, Australia. Mar Freshw Res 48 (8): 663-670. DOI: 10.1071/MF97184.

Dou J, Zhang GL, Shi C, Song CB, Mu Ck, Ye YF, Wang CL. 2021. High-intensity light of full-spectrum LED promotes survival rate but not development of the larval swimming crab *Portunus trituberculatus*. Aquac Eng 93: 102158. DOI: 10.1016/j.aquaeng.2021.102158.

Dove AD, Allam B, Powers JJ, Sokolowski MS. 2005. A prolonged thermal stress experiment on the American lobster, *homarus americanus*. J Shellfish Res 24 (3): 761-765. DOI: 10.2983/0730-8000(2005)24[761:APTSEO]2.0.CO;2.

Drengstig A, Bergheim A. 2013. Commercial land-based farming of European lobster (*Homarus gammarus* L.) in Recirculating Aquaculture System (RAS) using a single cage approach. Aquac Eng 53: 14-18. DOI: 10.1016/j.aquaeng.2012.11.007.

Effendi I, Diatin I, Budiardi T, Haderoseyani Y. 2021. Grouper nursery development through group capacity building for leading commodity strengthen of Seribu Islands Administrative District, Jakarta. Agrokreatif 7 (2): 148-161. DOI: 10.29244/agrokreatif.7.2.148-161.

Effendi I. 2016. Intensive Culture of White Shrimp *Litopenaeus vannamei* in Sea Net Cages: Location, Physiologycal and Biochemical Studies. [Dissertation]. Institut Pertanian Bogor, Bogor. [Indonesia]

Ennis GP. 1973. Behavioral responses to changes in hydrostatic pressure and light during larval development of the lobster *Homarus gammarus*. J Fish Res Board Can 30 (9): 1349-1360. DOI: 10.1139/f73-216.

Filiciotto F, Vazzana M, Celi M, Maccarrone V, Ceraulo M, Buffa G, Di Stefano V, Mazzola S, Buscaino G. 2014. Behavioural and biochemical stress responses of *Palinurus elephas* after exposure to boat noise pollution in tank. Mar Pollut Bull 84 (1-2): 104-114. DOI: 10.1016/j.marpolbul.2014.05.029.

Filippi J-J, Rémi M, Bracconi J, Ligorini V, Nicolas G, Crescioni A, Ronchi-Perfetti J-B, Demolliens M, Pugliese S, Alban D, Boussard A, Vela A, Bastien R, Pasqualini V, Aiello A. 2024. Effect of light intensity on the survival of European spiny lobster (*Palinurus elephas*) larvae reared in aquaculture system. Aquac Rep 36: 102083. DOI: 10.1016/j.aqrep.2024.102083.s.

Fish Nutrition Laboratory, Department of Aquaculture, Faculty of Fisheries and Marine Science, Institut Pertanian Bogor. 2023. Fish Nutrition. Institut Pertanian Bogor, Bogor. [Indonesian]

Food and Agriculture Organization (FAO). 2024a. FishStat: Global Capture Production 1950-2022. (FAO) available at www.fao.org/fishery/en/statistics/software/fishstatj. Licence: CC-BY-4.0.

Food and Agriculture Organization (FAO). 2024b. *Panulirus homarus* (Linnaeus, 1878). Cultured Aquatic Species Information Programme. Food and Agriculture Organization of the United Nations, Fisheries and Aquaculture Department, Rome.

Food and Agriculture Organization (FAO). 2025. *Panulirus homarus* (Linnaeus, 1878). Cultured Aquatic Species Information Programme. Food and Agriculture Organization of the United Nations, Fisheries and Aquaculture Department, Rome.

Freitas C, Villegas-Ríos D, Moland E, Olsen EM. 2021. Sea temperature effects on depth use and habitat selection in a marine fish community. J Anim Ecol 90: 1787-1800. DOI: 10.1111/1365-2656.13497.

Gabel F, Pusch MT, Breyer P, Burmester V, Walz N, Garcia X-F. 2011. Differential effect of wave stress on the physiology and behaviour of native versus non-native benthic invertebrates. Biol Invasions 13 (8): 1843-1853. DOI: 10.1007/s10530-011-0003-1.

García-Echauri LL, Liggins G, Cetina-Heredia P, Roughan M, Coleman MA, Jeffs A. 2020. Future ocean temperature impacting the survival prospects of post-larval spiny lobsters. Mar Environ Res 156: 104918. DOI: 10.1016/j.marenvres.2020.104918.

Glencross B, Smith M, Curnow J, Smith D, Williams K. 2001. The dietary protein and lipid requirements of post-puerulus western rock lobster, *Panulirus cygnus*. Aquaculture 199 (1-2): 119-129. DOI: 10.1016/s0044-8486(01)00520-8.

Goddard S. 1996. Feed Management in Intensive Aquaculture (1st edition). Chapman and Hall, New York. DOI: 10.1007/978-1-4613-1173-7_1.

Goldstein JS, Butler IV MJ. 2009. Behavioral enhancement of onshore transport by postlarval Caribbean spiny lobster (*Panulirus argus*). Limnol Oceanogr 54 (5): 1669-1678. DOI: 10.4319/lo. 2009. 54.5.1669.

Government Regulation. 2021. Government Regulation of the Republic Indonesia No. 22 of 2021 on the Implementation of Environmental Protection and Management. Jakarta. [Indonesian]

Harrington AM, Tudor MS, Reese HR, Bauchard DA, Hamlin HJ. 2019. Effects of temperature on larval American lobster (*Homarus americanus*): Is there a trade-off between growth rate and developmental stability? Ecol Indic 96: 404-411. DOI: 10.1016/j.ecolind.2018.09.022.

Ihsan M, Suhirman, Jayadi EM, Sagista R, Hardianti YE, Ilahi WB, Muliasari H, Kalih LATWS. 2019. Analysis of natural diet in stomach and microhabitat of puerulus spiny lobster (*Panulirus homarus*) in Awang Bay. Jurnal Riset Akuakultur 14 (3): 183-191. DOI: 10.15578/jra.14.3.2019.183-191.

Indonesian National Standard (SNI). 2015. Produksi Lobster Pasir (*Panulirus homarus*, Linn 1758) di Karamba Jaring Apung (KJA) [Production of Sand Lobster (*Panulirus homarus*, Linn 1758) in Floating Net Cages]. Indonesian National Standard, Jakarta. [Indonesian]

Johannesen Á, Patursson Ø, Kristmundsson J, Klebert P. 2020. How caged salmon respond to waves depends on time of day and currents. PeerJ Live Environ 8: e9313. DOI: 10.7717/peerj.9313.

Jones CM, Le Anh T, Priyambodo B. 2019. Lobster aquaculture development in Vietnam and Indonesia. In: Radhakrishnan E, Phillips B, Achamveetil G (eds). Lobsters: Biology, Fisheries and Aquaculture. Springer, Singapore. DOI: 10.1007/978-981-32-9094-5_12.

Jones CM. 2009. Temperature and salinity tolerances of the tropical spiny lobster, *Panulirus ornatus*. J World Aquac Soc 40 (6): 744-752. DOI: 10.1111/j.1749-7345.2009.00294.x.

Joo S, Kim T. 2024. The effect of anthropogenic substrate-borne vibrations on locomotion of the fiddler crab *Austruca lactea*. Mar Pollut Bull 200: 116107. DOI: 10.1016/j.marpolbul.2024.116107.

Karl TR, Arguez A, Huang B, Lawrimore JH, McMahon JR, Menne MJ, Peterson TC, Vose RS, Zhang H-M. 2015. Possible artifacts of data biases in the recent global surface warming hiatus. Science 348 (6242): 1469-1472. DOI: 10.1126/science.aaa5632.

Kathyayani SA, Muralidhar M, Kumar TS, Alavandi SV. 2019. Stress quantification in *Penaeus vannamei* exposed to varying levels of turbidity. J Coast Res 86: 177-183. DOI: 10.2112/ SI86-027.1.

Kemp JOG, Britz PJ. 2008. The effect of temperature on the growth, survival and food consumption of the east coast rock lobster *Panulirus homarus rubellus*. Aquaculture 280 (1-4): 227-231. DOI: 10.1016/j.aquaculture.2008.05.002.

Kim TW, Taylor J, Lovera C, Barry JP. 2016. CO_2-driven decrease in pH disrupts olfactory behaviour and increases individual variation in deep-sea hermit crabs. ICES J Mar Sci 73 (3): 613-619. DOI: 10.1093/icesjms/fsv019.

Kulmiye AJ, Mavuti KM, 2005. Growth and moulting of captive *Panulirus homarus homarus* in Kenya, western Indian Ocean. New Zeal J Mar Fresh 39 (3): 539-549. DOI: 10.1080/00288330.2005.9517332.

Lellis WA, Russell JA. 1990. Effect of temperature on survival, growth and feed intake of postlarval spiny lobsters, *Panulirus argus*. Aquaculture 90 (1): 1-9. DOI: 10.1016/0044-8486(90)90277-t.

Lin HP, Charmantier G, Thuet P, Trilles JP. 1992. Effects of turbidity on survival, osmoregulation and gill Na^+ -K^+ ATPase in juvenile shrimp *Penaeus japonicus*. Mar Ecol Prog Ser 90 (1): 31-37. DOI: 10.3354/meps090031.

Liu S, Bi C, Yang H, Liang Z, Zhao Y. 2019. Experimental study on the hydrodynamic characteristics of a submersible fish cage at various depths in waves. J Ocean Univ China 18 (3): 701-709. DOI: https://doi.org/10.1007/s11802-019-3880-z.

Lubis AS, Efrizal, Syaifullah, Rusnam, Nurmiati, Puari AT. 2023. Growth performance and survival rate of spiny lobster *Panulirus homarus* (Linnaeus, 1758) with formulated feeding enriched by spinach extract. Biodiversitas 24 (11): 6010-6016. DOI: 10.13057/biodiv/d241121.

Macdonald A. 1997. Hydrostatic pressure as an environmental factor in life processes. Comp Biochem Physiol Part A Mol Integr Physiol 116 (4): 291-297. DOI: 10.1016/s0300-9629(96)00354-4.

Menu-Courey K, Noisette F, Piedalue S, Daoud D, Blair T, Blier PU, Azetsu-Scott K, Calosi P. 2019. Energy metabolism and survival of the juvenile recruits of the American lobster (*Homarus americanus*) exposed to a gradient of elevated seawater pCO_2. Mar Environ Res 143: 111-123. DOI: 10.1016/j.marenvres.2018.10.002.

Ministry of Marine Affairs and Fisheries (KKP). 2020. Standard Operational Procedure for Lobster Culture (*Panulirus* spp.). Center for Data, Statistics, and Information, Ministry of Marine Affairs and Fisheries, Jakarta. [Indonesian]

Minjoyo H, Rivaie AR, Saputra S, Puja Y, Putro DH, Dhoe SB, Meiyana M, Antoro S, Slamet B. 2024. Effect of stocking density on survival and growth of spiny sand lobsters *Panulirus homarus* in cages at 7-m depth. North Am J Aquac 86 (4): 485-494. DOI: 10.1002/naaq.10356.

Morris JP, Thatje S, Ravaux J, Shillito B, Fernando D, Hauton C. 2015. Acute combined pressure and temperature exposures on a shallow-water crustacean: Novel insights into the stress response and high pressure neurological syndrome. Comp Biochem Physiol A Mol Integr Physiol 181: 9-17. DOI: 10.1016/j.cbpa.2014.10.028.

Mustafa A. 2013. Budidaya lobster (*Panulirus* sp.) di Vietnam dan aplikasinya di Indonesia. Media Akuakultur 8 (2): 73-84. DOI: 10.15578/ma.8.2.2013.73-84. [Indonesian]

Nelson MM, Bruce MP, Nichols PD, Jeffs AG, Phleger CF. 2006. Nutrition of wild and cultured lobsters. In: Phillips BF (eds). Lobsters: Biology, Management, Aquaculture and Fisheries. Blackwell Publishing, Oxford, UK. DOI: 10.1002/9780470995969.ch6.

Pratiwi R, Supriyono E, Widanarni. 2016. Total hemocytes, glucose hemolymph, and production performance of spiny lobster *Panulirus homarus* cultured in the individual compartements system. Jurnal Ilmu Teknologi Kelautan Tropis 8 (1): 321-333. DOI: 10.29244/jitkt.v8i1.13768.

Priyambodo B, Jones C, Sammut J. 2015. The effect of trap type and water depth on puerulus settlement in the spiny lobster aquaculture industry in Indonesia. Aquaculture 422: 132-137. DOI: 10.1016/j.aquaculture.2015.02.037.

Priyambodo B. 2020. Pengembangan Budidaya Lobster di Tanah Air: Tantangan dan Peluang. Seminar Budidaya Lobster di Indonesia: Prospek, Peluang Bisnis, dan Tantangan Pengembangan [Seminar on Lobster Aquaculture in Indonesia: Prospects, Business Opportunities, and Development Challenges]. Faculty of Agriculture, University of Lampung, Lampung, Indonesia, 28 May 2020. [Indonesian]

Radhakrishnan EV, Kizhakudan JK, Vijayakumaran M, Vijayagopal P, Koya M, Jeena NS. 2019b. Breeding, hatchery production and mariculture. In: Radhakrishnan EV, Phillips BF, Achamveetil G (eds). Lobsters: Biology, Fisheries and Aquaculture. Springer, Singapore. DOI: 10.1007/978-981-32-9094-5_10.

Radhakrishnan EV, Kizhakudan JK. 2019. Food, feeding behaviour, growth and neuroendocrine control of moulting and reproduction. In: Radhakrishnan EV, Phillips BF, Achamveetil G (eds). Lobsters: Biology, Fisheries and Aquaculture. Springer, Singapore. DOI: 10.1007/978-981-32-9094-5_6.

Radhakrishnan EV, Phillips BF, Pilai SL, Padua S. 2019a. Ecology and global distribution pattern of lobsters. In: Radhakrishnan EV, Phillips BF, Achamveetil G (eds). Lobsters: Biology, Fisheries and Aquaculture. Springer, Singapore. DOI: 10.1007/978-981-32-9094-5.

Radhakrishnan EV. 2015. Review of prospects for lobster farming. In: Perumal S, Thirunavukkarasu AR, Perumal P (eds). Advances in Marine and Brackishwater Aquaculture. Springer, New Delhi. DOI: 10.1007/978-81-322-2271-2_15.

Ross E, Behringer D. 2019. Changes in temperature, pH, and salinity affect the sheltering responses of Caribbean spiny lobsters to chemosensory cues. Sci Rep 9 (4375): 1-11. DOI: 10.1038/s41598-019-40832-y.

Sætran BE. 2023. Industrial Lobster Farming: A Technical Investigation and Comparison of Three Different Farming Concepts. [Thesis]. Norwegian University of Science and Technology, Trondheim. [Norway].

Schmitt ASC, Uglow RF. 1997. Effects of ambient ammonia levels on blood ammonia, ammonia excretion and heart and scaphognathite rates of *Nephrops norvegicus*. Mar Biol 127 (3): 411-418. DOI: 10.1007/s002270050028.

Sébert P, Péqueux A, Simon B, Barthélémy L. 1995. Effects of hydrostatic pressure and temperature on the energy metabolism of the Chinese crab (*Eriocheir sinensis*) and the yellow eel (*Anguilla anguilla*). Comp Biochem Physiol Part A Mol Integr Physiol 112 (1): 131-136. DOI: 10.1016/0300-9629(95)00079-m.

Sievers M, Korsøen Ø, Warren-Myers F, Oppedal F, Macaulay G, Folkedal O, Dempster T. 2021. Submerged cage aquaculture of marine fish: A review of the biological challenges and opportunities. Rev Aquac 14 (1): 106-119. DOI: 10.1111/raq.12587.

Solanki Y, Jetani KL, Khan SI, Kotiya AS, Makawana NP, Rather MA. 2012. Effect of stocking density on growth and survival rate of Spiny Lobster (*Panulirus polyphagus*) in cage culture system. Intl J Aquat Sci 3 (1): 3-14.

Sulkin SD. 1984. Behavioural basis of depth regulation in the larvae of brachyuran crabs. Mar Ecol Progr Ser 15 (1): 181-205. DOI: 10.3354/meps015181.

Supriyono E, Adiyana K, Thesiana L. 2023. A study of environmentally friendly recirculating aquaculture system on lobster *Panulirus homarus* Nursery. Pol J Environ Stud 32 (5): 4805-4811. DOI: 10.15244/pjoes/166596.

Syafrizal, Jones CM, Permana IG, Utomo NBP. 2018. Effect of feeding frequency on survival and growth of juvenile spiny lobster *Panulirus versicolor* in Indonesia. AACL Bioflux 11 (5): 1427-1434.

UN Comtrade. 2024. Statistics Database. https://comtradeplus.un.org/TradeFlow.

Verghese B, Radhakrishnan EV, Padhi A. 2007. Effect of environmental parameters on immune response of the Indian spiny lobster, *Panulirus homarus* (Linnaeus, 1758). Fish Shellfish Immunol 23 (5): 928-936. DOI: 10.1016/j.fsi.2007.01.021.

Wang S, Carter CG, Fitzgibbon QP, Codabaccus BM, Smith GG. 2021. Effect of dietary protein on energy metabolism including protein synthesis in the spiny lobster *Sagmariasus verreauxi*. Sci Rep 11 (1): 11814. DOI: 10.1038/s41598-021-91304-1.

Wang X, Li E, Xu Z, Li T, Xu C, Chen L. 2017. Molecular response of carbohydrate metabolism to dietary carbohydrate and acute low salinity stress in Pacific white shrimp *Litopenaeus vannamei*. Turk J Fish Aquat Sci 17 (1): 153-169. DOI: 10.4194/1303-2712-v17_1_18.

Ward LR, Carter C, Crear BJ, Smith DM. 2003. Optimal dietary protein level for juvenile southern rock lobster, *Jasus edwardsii*, at two lipid levels. Aquaculture 217: 483-500. DOI: 10.1016/S0044-8486(02)00258-2.

Wedemeyer GA, Yasutake WT. 1977. Clinical Methods for the Assessment of the Effects of Environmental Stress on Fish Health. [Technical Papers]. United States Fish and Wildlife Service, Washington DC, America. https://pubs.usgs.gov/publication/tp89.

Williams KC. 2007. Nutritional requirements and feeds development for post-larval spiny lobster: A review. Aquaculture 263 (1-4): 1-14. DOI: 10.1016/j.aquaculture.2006.10.019.

Yeap ALK, de Souza Valente C, Hartnett F, Conneely Ellie-Ann, Majbritt Bolton-Warberg, Davies SJ, Johson MP, Wan AHL. 2022. Barriers in European spiny lobster (*Palinurus elephas*) aquaculture: What we know so far? Rev Aquac 14 (4): 2099-2121. DOI: 10.1111/raq.12693.

Young-Lai WW, Charmantier-Daures M, Charmantier G. 1991. Effect of ammonia on survival and osmoregulation in different life stages of the lobster *Homarus americanus*. Mar Biol 110 (2): 293-300. DOI: 10.1007/bf01313716.