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Effects of Different Seaweed Shelters on Survival and Molting of *Scylla paramamosain* during Megalopa-to-First-Crablet Transition

Afnan Machu[1,2], Gunanti Mahasri[1*], Sukree Hajisamae[2], Sofiyudin Maae[2]

[1]Department of Aquaculture, Faculty of Fisheries and Marine, Universitas Airlangga, MERR (C) Campus Mulyorejo, Surabaya 60115 Indonesia
[2]Faculty of Science and Technology, Prince of Songkla University, Pattani 94000 Thailand

*Corresponding Author: gunanti.m@fpk.unair.ac.id

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ABSTRACT

The megalopa-to-first-crablet transition constitutes a critical developmental stage in the hatchery rearing of mud crab, *Scylla paramamosain*, during which newly metamorphosed crablets are particularly susceptible to cannibalism and physical injury. This study evaluated the effects of different seaweed species and shelter densities on the survival and molting rates of *S. paramamosain* during this developmental transition. The 4-day-old megalopae were reared for three days in seven treatments consisting of a control without shelter and three seaweed species, *Caulerpa lentillifera*, *Gracilaria fisheri*, and *Kappaphycus alvarezii,* each provided at 1 and 2 kg/m^2. The experiment was conducted using a completely randomized design with three replicates per treatment. Survival and molting rates were determined at the end of the rearing period. It was found that seaweed shelter significantly affected both survival and molting rates. The highest survival (83.3 ± 15.0%) and molting rate (81.9 ± 16.8%) were observed in crablets provided with *G. fisheri* at 2 kg/m^2, whereas the control showed the lowest survival (54.2 ± 4.17%) and molting rate (13.9 ± 10.5%). These findings indicate that *G. fisheri* at 0.32 kg/tank is the most effective shelter to enhance survival during the megalopa-to-first-crablet transition and may use to improved nursery production of *S. paramamosain*.

INTRODUCTION

The mud crab *Scylla paramamosain* is an economically important portunid species and a valuable fishery commodity throughout the Asia–Pacific region, particularly in Southeast Asia and Australia, with its distribution extending to the Gulf of Aden, the Arabian and Persian Gulfs, and East Africa (Alberts-Hubatsch *et al*., 2016; FAO, 2022). Among the four mud crab species of the genus *Scylla* sp. described by Keenan *et al*. (1998), *S. paramamosain* has gained increasing importance in coastal aquaculture owing to its high market value, strong consumer demand, export potential, and suitability for brackish-water farming (Balasubramanian *et al*., 2016).. However, hatchery operations face numerous challenges, including insufficient seed stock production and high larval mortality rates. During the nursery phase, cannibalism remains a major concern. Seed production in mud crab hatcheries involves rearing larvae, megalopae, and crablet instar stages. The megalopa is a transitional stage between the larval and subsequent crab instar stages. Compared with the five earlier molts from zoea I to megalopa, the megalopa stage has a relatively longer developmental period, lasting approximately 7–10 days before metamorphosis into the first crablet instar. During this period, megalopae undergo significant morphological changes and transition from a pelagic to a benthic lifestyle (Li & Liu, 2018; Ma *et al*., 2023). Maintaining suitable environmental conditions is therefore critical for successful metamorphosis. Although previous studies have examined the effects of environmental factors,

such as temperature, salinity, and feeding regimes, the transition from megalopa to the first crablet remains a critical period because individuals may molt asynchronously. Newly molted crablets have marked morphological differences from remaining megalopae and possess soft exoskeletons, making them particularly vulnerable to aggressive interactions and cannibalism. After metamorphosis, first-crablet instars become morphologically adapted to benthic life and exhibit increasingly aggressive behavior, which can contribute substantially to mortality and reduced production efficiency when adequate shelter is unavailable.

The use of substrates or shelters has been proposed as an effective strategy to reduce these problems. Fatihah *et al*. (2017) reported that mud crab juveniles provided with sand substrate as shelter exhibited significantly higher survival, whereas crabs provided with black net shelters showed the highest molting frequency among the treatments. Similarly, rearing *Scylla olivacea* at lower stocking densities with sufficient shelters resulted in better survival and a higher proportion of intact individuals (Sakib *et al*., 2022). However, information on the use of seaweed species as natural shelters during the megalopa-to-first-crablet transition of *S. paramamosain* remains limited. Therefore, this study aimed to evaluate the effects of different seaweed species used as shelters on the survival and molting rates of *S. paramamosain* during the megalopa-to-first-crablet transition.

Seaweeds have gained increasing attention in sustainable aquaculture because of their dual functions as natural shelters and biological filters. Their three-dimensional thalli can provide refuge for cultured organisms, reducing direct encounters, aggressive interactions, and cannibalism in crustacean nursery systems, while simultaneously assimilating dissolved inorganic nutrients such as ammonia, nitrate, and phosphate, thereby contributing to improved water quality (Ly Van *et al*., 2022; Stuthmann *et al*., 2023; Lovatelli *et al*., 2025). The use of macroalgae as shelter may therefore provide both physical and environmental benefits, particularly during developmental stages when cultured crustaceans are highly vulnerable to aggressive interactions and mortality. Among tropical macroalgae, *Caulerpa lentillifera*, *Gracilaria fisheri,* and *Kappaphycus alvarezii* are widely cultivated because of their relatively rapid growth, nutrient assimilation capacity, and economic importance. These species have also been considered promising natural shelter materials because differences in thallus morphology, branching patterns, and structural complexity may influence the availability and accessibility of refuge spaces for cultured organisms (Syakilla *et al*., 2022; Cáceres-Farias *et al*., 2025). Such differences in habitat structure may consequently affect the ability of seaweed shelters to reduce encounters among individuals and support survival and molting during nursery culture.

However, cannibalism associated with asynchronous molting remains one of the major constraints during the megalopa-to-first-crablet transition of *S. paramamosain*. Therefore, identifying suitable natural shelter materials is essential for improving nursery performance. Comparative information on the effectiveness of *C. lentillifera*, *G. fisher*i, and *K. alvarezii* as shelter materials remains limited. Accordingly, this study is aimed to evaluate the effects of these three seaweed species and density on the survival and molting performance of hatchery-based mud crab seed production.

METHOD

Based on the objectives of the study, an experimental approach was conducted at the Brackish Water Aquaculture Development Centre (BBPBAP) Jepara, Central Java, Indonesia, in july 2026 to evaluate the effects of different seaweed species and stocking densities used as shelters on the rearing performance of mud crab *S. paramamosain* during the transition from four-day-old megalopae to the first crablet instar. The experimental treatments consisted of a control without shelter and six treatments in which seaweeds were provided as shelters. The seaweed species used were *Caulerpa lentillifera* (CL*), Gracilaria fisheri* (GF*) and Kappaphycus alvarezii* (KA), with two stocking densities of 1 and 2 kg/m^2 These densities were selected based on those used by Ly Van *et al*., (2022), representing low- and high-density regimes, respectively. The experimental tanks measured 45 × 35 × 50 cm, with a bottom area of

approximately 0.16 m^2. Therefore, the corresponding seaweed amounts were 0.16 and 0.32 kg per tank for the 1 and 2 kg/m^2 stocking densities, respectively. and 4-day-old megalopa are stocked at a density of 150 individuals/m^2 for all tanks.

This study used a Completely Randomized Design (CRD) with 7 treatments and 3 replicates. The treatments given is as follows:
Treatment 1: 24 megalopae + Without Seaweed (Control)
Treatment 2: 24 megalopae + 0.16 kg/tank *C. Lentillifera*
Treatment 3: 24 megalopae + 0.32 kg/tank *C. Lentillifera*
Treatment 4: 24 megalopae + 0.16 kg/tank *G. Fisheri*
Treatment 5: 24 megalopae + 0.32 kg/tank *G. Fisheri*
Treatment 6: 24 megalopae + 0.16 kg/tank *K. alvarezii*
Treatment 7: 24 megalopae + 0.32 kg/tank *K. alvarezii*

Soure of *S. paramamosain* megalopa larvae

The four-day-old *S. paramamosain* megalopae used in this study originated from hatchery-produced larvae at the Brackish Water Aquaculture Development Center (BBPBAP) Jepara (110°38'40''E, 6°35'08''S), Central Java, Indonesia. Following the completion of the fifth zoeal stage and metamorphosis into the megalopa stage, the larvae were maintained in the hatchery following hatchery monitoring until four days after metamorphosis. Four-day-old *Scylla paramamosain* megalopae from a single hatchery batch were gently scooped and transferred to the experimental tanks.

Seaweeds Preparation and Acclimation

Three seaweed species, *C. lentillifera* (CL), *G. fisheri* (GF), and *K. alvarezii* (KA), were obtained from the Brackishwater Aquaculture Development Center (BBPBAP) Jepara, Central Java, Indonesia, seven days before the experiment began. The seaweeds were cleaned of debris and sediment, epiphytes, and other unwanted materials. healthy and intact thalli were selected. The seaweeds were maintained separately by species and acclimated under experimental conditions at a salinity of 30 ppt, with continuous and vigorous aeration provided through an air stone. The holding tanks were placed indoors under a transparent roof adjacent to the experimental tanks to maintain similar temperature conditions (26.5–33.0 °C) and pH (7.91–8.09). The seaweeds were maintained under these conditions until the beginning of the experiment and subsequently used as shelters according to the assigned treatments.

Experimental maintenance

The experiment was conducted indoors under a transparent roof at ambient temperature. The experimental rearing system consisted of round plastic tanks measuring 45 × 35 × 50 cm., with a bottom area of approximately 0.16 m^2. Each tank was filled with 19 L of seawater at a salinity of 30 ppt and supplied with continuous aeration.

The 4-day-old *S. paramamosain* megalopae from a single hatchery batch were gently scooped from the rearing tanks and transferred to the experimental tanks. Twenty-four megalopae were stocked in each experimental tank, with an initial body weight (BW), carapace length (CL), and carapace width (CW) of 4.92 ± 0.14 mg., 3.75 ± 0.01 mm, and 1.79 ± 0.01 mm, respectively. In addition, 11 megalopae were randomly selected from the same rearing tank to represent each experimental replicate and were not included in the experimental stocking. Excess water was gently removed from each individual using tissue paper before weighted body weight (BW) was measured using a digital balance with a precision of 0.0001 g.

The selected megalopae were subsequently preserved in 10% formalin for morphometric measurements. Morphological characteristics of the megalopae were assessed following Sri Juwana et al. (1987). Carapace length (CL) and carapace width (CW) were measured using a digital microscope camera (OptiLab Advance MTN004, 5.0 MP CMOS; PT Micron Technology Indonesia) mounted on an Olympus SZ61 stereomicroscope (Olympus Corporation, Tokyo, Japan). Images were captured using OptiLab Viewer 2.2 software (Miconos, Indonesia), and CL and CW were measured using Image Raster 3.0 software (Miconos,

Indonesia) after calibration with a stage micrometer. These measurements were conducted to characterize the initial size of the experimental megalopae, thereby minimizing potential variation in subsequent survival and molting, responses attributable to differences in initial body size.

The three seaweed species, *C. lentillifera* (CL), *G. fisheri* (GF), and *K. alvarezii* (KA), had been cleaned and acclimated to the experimental conditions before use. During acclimation, the seaweeds were maintained at a salinity of 30 ppt and an ambient temperature ranging from 26 to 33 °C. Before the experiment, excess water was gently removed, and the seaweeds were wet weighted using a digital balance with a precision of 0.01 g. Based on the assigned treatments, 0.16 or 0.32 kg of each seaweed species was introduced into the respective experimental tanks, which had been randomly assigned and labelled prior to stocking.

The megalopae were fed live Artemia nauplii obtained from the Brackish water Aquaculture Development Centre (BBPBAP) Jepara mud crab nursery. Feed was provided at approximately 5 ind/ml. per tank, following Nur Syafaat *et al*., (2020), twice daily at 08:00 and 17:00 h throughout the experimental period.

Water temperature, pH, and dissolved oxygen (DO) were monitored daily at 07:00 h before the morning feeding and at 14:00 h. Temperature was measured using a digital thermometer, pH was measured using a portable digital pH meter (Metravi PH-600), and DO was measured using a portable dissolved oxygen meter. Salinity was measured using a handheld optical refractometer and maintained at 29-30 ppt throughout the experimental period. Free ammonia (NH_3), nitrite (NO_2^-), and nitrate (NO_3^-) concentrations were measured once during the experimental period using commercial water-quality test kits. Were measured once during the experimental period, in the morning after the megalopae had reached the first-cablet instar and before the final sampling conducted later that day. No water exchange was conducted throughout the experimental period.

After three days of the experiment, surviving first-crablet instars were carefully harvested and counted from each experimental tank. Observation of molting was conducted by examining the experimental tanks once daily at 07:00 h throughout the experimental period, prior to water-quality measurements and feeding at 08:00 h. During each observation, the tanks were carefully examined to identify megalopae that had transitioned to the first-crablet stage. Because the exact time of molting could not be determined, individuals identified as first-crablets during the morning observation were recorded as successfully molted and collected in the same day and subjected to morphometric measurements. Morphometric characteristics of first-crablet instars were assessed following Hidir et al. (2022). Body weight (BW), carapace length (CL), and carapace width (CW) were measured to compare morphological differences between the megalopa and first-crablet stages. Megalopae identified as first-crablets during the morning observation were recorded as successfully molted and collected on the same day for morphometric measurements. BW was measured using a digital balance with 0.001 g precision, while CL and CW were measured from calibrated photographs using Image Raster 3.0 software (Miconos, Indonesia).

Observed Parameters

Survival Rate (SR)

By using information on the number of *S. paramamosain* 4-old-day megalopa at the beginning and end of the study, the survival rate of mud crab (SR) was calculated using the following formula (Zhou *et al*., 2023):

$$SR\ (\%) = 100\%\ X\ (Nf/Ni)$$

Description:
SR = Survival rate (%)
Nf = represents the final count of *S. Paramamosain*.(ind)
Ni = indicates the initial number of *S. paramamosain*.(ind)

Molting Rate (MR)

The molting percentage is the ratio between the number of *S. paramamosain* megalopa. that experienced molting and the number of mud crab. The molting percentage is calculated using the formula (Zhou *et al*., 2023):

$$MR\ (\%) = 100\%\ X\ (Nq/Ni)$$

Description:
MR = Molting rate (%)
Nq = indicates the number of *S. paramamosain* molts.(ind)
Ni = indicates the initial number of *S. Paramamosain.*(ind)

Data Analysis

Statistical analyses were performed using RStudio version 4.5.1 (R Core Team, Vienna, Austria). One-way analysis of variance (ANOVA) was used to evaluate the effects of seaweed species and stocking density on survival, molting rate. The normality of the data and homogeneity of variances were assessed prior to ANOVA. When significant differences were detected ($P < 0.05$), Tukey's honestly significant difference (HSD) test was performed to identify differences among treatment means. All results are presented as mean ± standard deviation (SD), with $P < 0.05$ considered statistically significant.

RESULT AND DISCUSSION

Survival rate

Seaweed shelter provision had a significant effect on the survival of *S. paramamosain* ($F_{6,14} = 3.064$, $P = 0.0395$). The survival rate increased from 54.2 ± 4.17% in the control group without seaweed to 83.3 ± 15.0% in crabs provided with *G. fisheri* at 0.32 kg/tank, representing the highest survival among the treatments. The remaining seaweed treatments showed survival rates ranging from 56.9 to 72.2% and were statistically comparable with both the control and the 0.32 kg GF treatment.

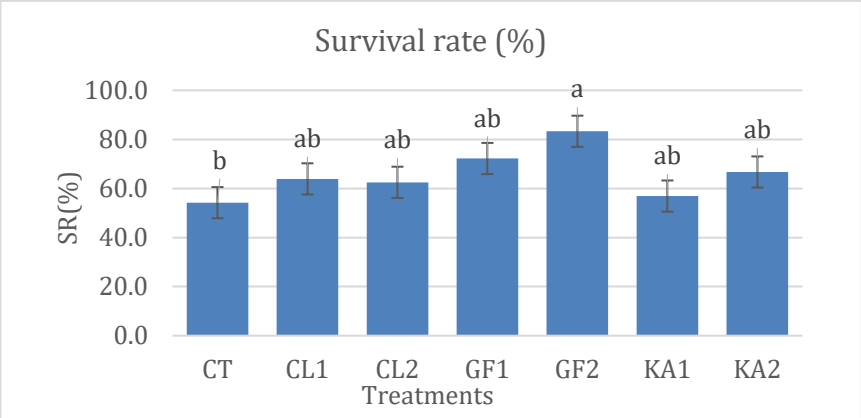


Figure 1. The survival rate of 4-day-old megalopae transitioning to the first crablet instar (C1) after 3 days of rearing across the experimental systems.

The present study demonstrated that the provision of seaweed shelters significantly enhanced the survival of *S. paramamosain* during the transition from the megalopa to the first crablet stage. The highest survival rate was recorded in crabs reared with *G. fisheri* at a density of 0.32 kg tank^{-1} (83.3 ± 15.0%), whereas the lowest survival occurred in the control treatment without shelter (54.2 ± 4.17%). The improved survival observed in the sheltered treatments is likely attributable to the availability of physical refuges, which reduce aggressive encounters and cannibalism, particularly during the vulnerable molting period. Similar positive effects of

seaweed shelters on the survival of *S. paramamosain* have been reported previously (Ly Van *et al*., 2022; Zhou *et al*., 2023). Moreover, the superior performance of *G. fisheri* at the higher density suggests that the effectiveness of seaweed shelters depends not only on their presence but also on the combination of shelter type and density. This interpretation is supported by previous studies showing that *Gracilaria* provides an effective refuge for mud crab nursery culture and promotes higher survival than alternative shelter materials (Ly Van *et al*., 2022; Toi *et al*., 2023).

These results are further supported by Ly Van *et al*., (2022), who compared different seaweed species as shelters for *S. paramamosain* crablets. Their study showed that crabsreared without shelter exhibited the lowest survival, whereas the use of *Gracilaria tenuistipitata* significantly improved survival compared with both the controland *Enteromorpha intestinalis* treatments. In addition to providing physical refuge, *Gracilaria* also improved water quality by reducing total ammonia nitrogen (TAN), nitrite, nitrate, and phosphate concentrations, suggesting that the beneficial effects of seaweed shelters may arise from both habitat complexity and enhanced environmental conditions. Although all seaweed treatments significantly improved survival relative to the control, the response varied according to the combination of seaweed species and shelter density. Increasing the biomass of *G. fisheri* from 0.16 to 0.32 kg/tank increased survival from 72.2% to 83.3%, whereas the same increase in *C. lentillifera* resulted in a slight decline in survival. These contrasting responses indicate that the effectiveness of seaweed shelters is species-specific and density-dependent rather than being determined solely by the presence of shelter. A similar pattern has been reported in juvenile *S. paramamosain*, where the interaction between seaweed species and crab stocking density significantly influenced production performance. Specifically, Toi *et al*., (2023) found that the red seaweed *G. tenuistipitata* produced the highest crab yield when combined with the highest stocking density.

Table 1 Mean ± SD of survival rate and molting rate of *S. paramamosain* from 4-day-old megalopa to the first crablet instar (C1) after 3 days of rearing across the experimental systems.

	Survival rate	Molting Rate
Control	54.2 ± 4.17^{b}	13.9 ± 10.5^{b}
CL1	63.9 ± 6.36^{ab}	61.1 ± 4.81^{a}
CL2	62.5 ± 8.33^{ab}	54.2 ± 8.33^{a}
GF1	72.2 ± 2.41^{ab}	68.1 ± 4.81^{a}
GF2	83.3 ± 15.0^{a}	81.9 ± 16.8^{a}
KA1	$56.9 + 15.8^{ab}$	$54.2 + 18.2^{a}$
KA2	66.7 ± 7.22^{ab}	65.3 ± 4.81^{a}
df-between group	6	6
df - within group	14	14
F-value	3.064	10.98
p- value	0.0395 ($p < 0.05$)	0.000131 ($p < 0.05$)

Note: CT = Control (Without seaweed), CL = *Caulerpa lentillifera*, GF = *Gracilaria fisheri*, KA = *Kappaphycus alvarezii,* Density of seaweed =(1= 1 kg/m^2 , 2 = 2 kg/m^2). Superscripts in the same column indicate significant differences ($p<0.05$).

Molting rate

The molting is a fundamental biological process in crustaceans that facilitates growth through the periodic shedding and regeneration of the exoskeleton. The megalopa stage represents a critical developmental transition between the larval and juvenile phases, involving extensive morphological remodelling before reaching the first-crablet stage. In the present study, four-day-old *S. paramamosain* megalopae exhibited an initial body weight (BW), carapace length (CL), and carapace width (CW) of 4.92 ± 0.14 mg, 3.75 ± 0.01 mm, and 1.79 ± 0.01 mm, respectively. Following the transition to the first-crablet stage, BW and CW increased to 7.19 ± 0.41 mg and 3.38 ± 0.06 mm, respectively, whereas CL decreased to 3.12 ± 0.06 mm.

These changes indicate that the megalopa-to-first-crablet transition involves not only an increase in body mass but also a reorganization of body proportions associated with metamorphosis. According to Ly *et al*., (2024), a similar pattern was observed in *S. paramamosain*, with BW and CW increasing from the megalopa to the crablet-1 stage, whereas CL decreased during this developmental transition. Therefore, the reduction in CL observed in the present study should be considered a consequence of morphological transformation rather than an indication of impaired growth. Furthermore, Cui *et al,.* (2023) reported that metamorphosis from megalopa to crablet in *S. paramamosain* involves extensive exoskeletal remodeling, including cuticle degradation and reconstruction, which may result in changes in body dimensions. Consequently, the variations in BW, CL, and CW observed in the present study likely reflect the combined effects of growth, molting, and morphological restructuring as *S. paramamosain* develops from the megalopa to the first-crablet stage.

The molting rate of *S. paramamosain* under different seaweed shelter treatments is presented in Figure 2 and Table 1. The highest molting rate was observed in the 0.32 kg GF treatment (81.9 ± 16.8%), followed by 0.16 kg GF (68.1 ± 4.81%), 0.32 kg KA (65.3 ± 4.81%), 0.16 kg CL (61.1 ± 4.81%), 0.32 kg CL (54.2 ± 8.33%), and 0.16 kg KA (54.2 ± 18.2%), while the lowest rate was recorded in the control (13.9 ± 10.5%). The molting rate differed significantly among treatments ($F_{6,14}$ = 10.98, P < 0.001). Tukey's HSD test showed that all seaweed treatments had significantly higher molting rates than the control but did not differ significantly from each other.

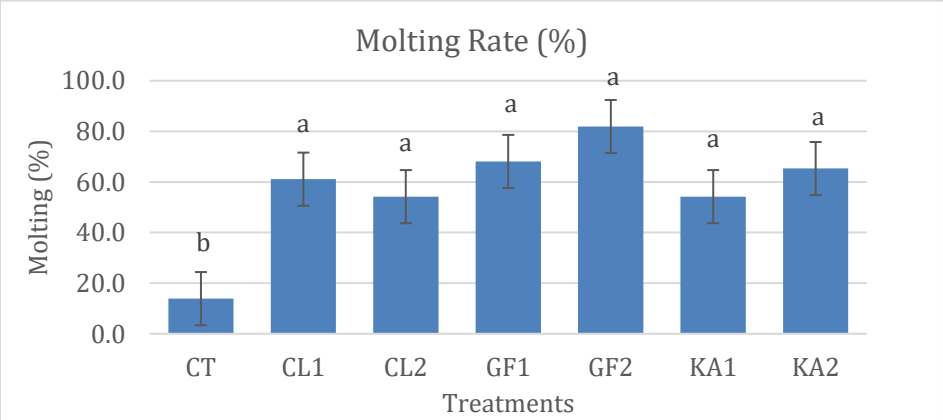


Figure 2. The molting rate of 4-day-old megalopae transitioning to the first crablet instar (C1) after 3 days of rearing across the experimental systems.

The present study demonstrated that the provision of seaweed shelters significantly enhanced the molting rate of *S. paramamosain* during the transition from the megalopa to the first crablet stage. The lowest molting rate was recorded in the control treatment without shelter (13.9 ± 10.5%), whereas the highest was observed in the *G. fisheri* treatment at 0.32 kg/tank (81.9 ± 16.8%). Although molting rates did not differ significantly among seaweed species or shelter densities, all sheltered treatments performed significantly better than the control. The improved molting performance is likely attributable to the availability of physical refuges that reduce aggressive interactions and disturbance during the highly vulnerable molting period. This explanation is supported by Zhou *et al*., (2023), who reported enhanced molting success in *S. paramamosain* provided with shelters compared with unsheltered crabs. Similarly, Thien *et al*., (2025) demonstrated that substrate-based shelters facilitated the successful metamorphosis of mud crab megalopae into early crablet stages by providing protection during this critical developmental period. Taken together, these results suggest that the presence of shelter, irrespective of seaweed species or biomass, is the primary factor promoting successful molting during the megalopa-to-first-crablet transition.

Water quality

The results of water quality monitoring in the ponds are presented in Table 2.

Table 2 Water quality of *S. paramamosain* rearing system during 4-day-old megalopa to crablet 1 stage rearing period.

Parameter	Optimal range		Monitoring frequency
	07.00 Hour	14.00 Hour	
Temperature	26.5 – 27.2 °C	32.0 – 33.0 °C	Twice a day
Dissolved Oxygen (Do)	3.38 – 6.55mg/L	6.00 – 6.98 mg/L	Twice a day
pH	7.91 – 8.09	8.25 – 8.41	Twice a day
Ammonia (NH_3)	0.025 – 0.037 mg/L	-	Once
Nitrite (NO_2^-	0.10 – 2.00 mg/L	-	Once
Nitrate (NO_3^-)	2.00 – 100.00 mg/L	-	Once
Salinity	29.4-30.0 ppt	-	Once

Water quality during the rearing period was generally sufficient to support the development of *S. paramamosain* . Temperature ranged from 26.5–27.2°C in the morning and 32.0–33.0°C in the afternoon. The morning values were close to the recommended range, whereas the afternoon temperature was relatively high compared with the optimal range of 28–30°C reported by Syafaat *et al*., (2021). Similarly, Ly Van *et al*., (2022) reported temperatures of 27.2–30.2°C in *S. paramamosain* nursery systems using seaweed shelters.

The pH ranged from 7.91–8.09 in the morning and 8.25–8.41 in the afternoon, remaining within the recommended range of 7.5–8.5 (Syafaat *et al*., 2021). These values were also comparable with those reported by Ly Van *et al*., (2022), who recorded pH values of 7.9–8.6 in seaweed-based nursery systems.

Dissolved oxygen (DO) ranged from 3.38–6.55 mg/L in the morning and 6.00–6.98 mg/L in the afternoon. Although most values were adequate, the minimum morning DO of 3.38 mg/L was below the recommended level of >5 mg/L (Syafaat *et al*., 2021). Similar studies generally maintained DO above 5–6 mg/L during *S. paramamosain* culture (Luo *et al*., 2022; Lu *et al*., 2024).

Nitrogenous compounds showed greater variation, with NH_3, NO_2^-, and NO_3^- ranging from 0.025–0.037, 0.10–2.00, and 2.00–100.00 mg/L, respectively. The NH_3 concentration exceeded the conservative level of <0.01 mg/L recommended by Syafaat *et al*., (2021), while the maximum NO_2^- and NO_3^- concentrations were higher than those reported in recent *S. paramamosain* culture systems (Ly Van *et al*., 2022; Lu *et al*., 2024; Zhou *et al*., 2025). Nevertheless, these conditions were sufficient to support successful development from megalopa to the first-crablet stage.

Salinity was maintained at 30 ppt, which was within the reported suitable range for mud crab larval and nursery culture (Syafaat *et al*., 2021). Overall, although some parameters fluctuated beyond commonly recommended levels, the water quality conditions supported successful molting and development of *S. paramamosain* to the first-crablet stage.

CONCLUSION

The present study demonstrates that seaweed shelters can improve survival and molting success of *Scylla paramamosain* during the megalopa-to-first-crablet transition. Among the tested treatments, *Gracilaria fisheri* at 0.32 kg/tank resulted in the highest survival and molting rates. These findings indicate that seaweed shelters, particularly *Gracilaria fisheri* at the tested density, may provide an effective natural refuge during this vulnerable developmental stage and have potential for improving nursery performance of mud crab seed production.

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