Effects of Artificial Shelters on Survival Rates and Growth Performances of Scalloped Spiny Lobster, *Panulirus homarus* (Linnaeus, 1758), Reared in Floating-Net Cages

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Abstract

Cannibalism causes severe losses and has been considered one of the most important challenges in lobster aquaculture. The present study aimed to assess the effects of artificial shelters on the survival rate and growth performances of the scalloped spiny lobster, *Panulirus homarus* (Linnaeus, 1758). Wild-caught 600 puerulus stage scalloped spiny lobsters (~0.18 g wet-weight and 7.16 cm total length) were randomly allocated into floating cages provided with four different shelters; i) polyvinyl chloride (PVC), ii) nylon net, iii) cement sack and iv) no shelter as a control and cultured for 10 weeks to measure mortality and growth. The result of the experiment done in triplicate indicated that artificial shelters significantly affected scalloped spiny lobsters' survival rate and growth performances. The survival rate of scalloped spiny lobster in the control group observed on week 2 was only 62 %, while the survival rate in all treatments (with shelter) was 76 to 82 %. After 10 weeks culture period, the mean survival rate was only 28 % in control, which was significantly lower than all treatments (53 %, 54 %, and 59 % for nylon net, cement sack, and PVC, respectively). Similarly, the absolute growth and specific growth rate of the spiny lobsters reared with the artificial shelters were significantly better than that of lobsters in the control group. The best growth was obtained from lobster reared with a nylon net, followed by cement sack and PVC pipe. This research finding can be used to select suitable shelters for cultivating spiny lobsters.

Keywords: cannibalism, life below water, puerulus, shelter types

Introduction

The scalloped spiny lobster, *Panulirus homarus* (Linnaeus, 1758), is considered one of the world's most economically important marine commodities due to its high demand and high economic value. Among the available markets, the USA was recorded as the largest lobster importing country worth USD1.29 billion, followed by China with USD576.7 million and Canada with USD334.5 million (Radhakrishnan et al., 2019). While Indonesia is the 27th exporting country that contributes to the world lobster supply. According to the Indonesia Ministry of Fisheries and Marine Affairs, Indonesia's lobster export volume in 2021 reached 1.374 tonnes with a total value of more than USD17,468,241 (https://statistik.kkp.go.id/home.php). On the other hand, the increasing world lobster demand has led to intensive fishing activities, put more pressure, and threatened the sustainability of wild lobster stocks (Amin et al., 2022a).

After more than 30 years of stable catches, spiny lobster fisheries in many parts of the world are declining due to decreased recruitment (Fitzgibbon et al., 2014). There are also reports that there has been increasing pressure on the wild stock due to overfishing, indicated by the decrease of the total catch in several fishing locations such as West Java, Central Java, and West Nusa Tenggara (Wardiatno, 2020; Hilyana et al., 2021; Amin et al., 2022b). Consequently, recent data indicated that wild lobster capture remains static even though more catching efforts were operated. Thus, lobster aquaculture development is of special interest in many countries,

including Vietnam and Indonesia.

However, lobster farmers face several challenges, including a high level of cannibalism (Ma et al., 2021). The cannibalism begins in the grow-out of juveniles (~5–15 g of total wet weight) as the moulting process at this stage is relatively high (one every 10 days). Cannibalism occurs because when the lobster moults and leaves out the old shell, the new cover is still very soft, thus leaving the lobster without almost no protection against predators (Su et al., 2020; Ma et al., 2021). Some studies suggest cannibalism in lobsters can be reduced by decreasing interaction among lobsters using shelters. Fatihah et al. (2017), for instance, used sand substrate shelter to reduce cannibalism in mud crab juveniles, *Scylla transquebarica* (Fabricius, 1798). Similarly, Kawamura et al. (2020) reported that using shelter reared in tanks and ponds decreased aggressive behaviour and resulted in low cannibalism in *Scylla* spp.

Other studies have also documented that more shelters showed more protection leading to a higher survival rate. There are several types of artificial shelters, such as PVC pipe, brick, cement sacks, or nets (Zaky et al., 2020; Ma et al., 2021; Slamet et al., 2021), and few authors have described that the shelters have been used in culturing baby lobsters (Johnston et al., 2006). Each type of shelter has been described giving more advantages. For instance, PVC pipes are considered more durable, do not affect water quality, are easier to move and place in aquaculture containers. The size of the pipe can be adjusted to the size of the lobster's body. However, other authors argued that PVC pipe is also more expensive, thus, cheaper material such as cement sack is economically more suitable. Therefore, researchers are interested in observing the survival and growth of scalloped spiny lobsters against the provision of different shelters.

This study aimed to investigate the effects of artificial shelter types on the survival rate and growth performances of scalloped spiny lobsters reared in floating net cages. The result of the present study is expected to give additional information on the best substrate for growing spiny lobster.

Materials and Methods

Ethical approval

Research procedures followed the "Animals in research: Reporting in vivo experiments" (ARRIVE) guidelines as outlined in Kilkenny et al. (2010) and approved by the Institutional Animal Care and Use Committee (IACUC) of Universitas Airlangga, Indonesia.

Experimental design

A total of 700 scalloped spiny lobster puerulus (0.18 ± 0.01 g wet weight and 7.16 ± 0.35 cm) collected by fishermen in Gerupuk Bay, West Nusa Tenggara, Indonesia, were first acclimatised by culturing in a floating-net cage for 7 days according to shelter types used in the experiment and fed with chopped trash fish. Thereafter, healthy lobster puerulus showing no disease symptoms were selected and assigned into four groups of floating-net cages with four different shelters and three replicates; T1: 2-inch-wide PVC pipe, T2: cement sack, T3: black nylon net formed like a fan, and T4: control or without shelter. As presented in Figure 1, each floating-net cage was constructed in a circular with a diameter of 80 cm and 70 cm high. In each treatment, the surface area provided by these shelters was ~0.5 m^2. Each rearing unit was stocked with 50 puerulus stage lobsters and cultured for 90 days. During the culture period, lobster puerulus were fed with trash fish (mainly *Sardinella longiceps* Valenciennes, 1847) at 100 % wet weight once a day.

Observed parameters

The present experiment was conducted in Sekotong Bay, West Nusa Tenggara, Indonesia. During the experimental period, growth performance was monitored by measuring total wet weight using a weighing scale (Kern, Germany) and carapace length using a digital calliper (Kristeel, India) every 2 weeks. While mortality was monitored daily, and dead animals were removed from the rearing tank. In addition, water quality parameters (temperature, dissolved oxygen (YSI PRO20I, USA), pH (Senz, Trans Instrument, USA),

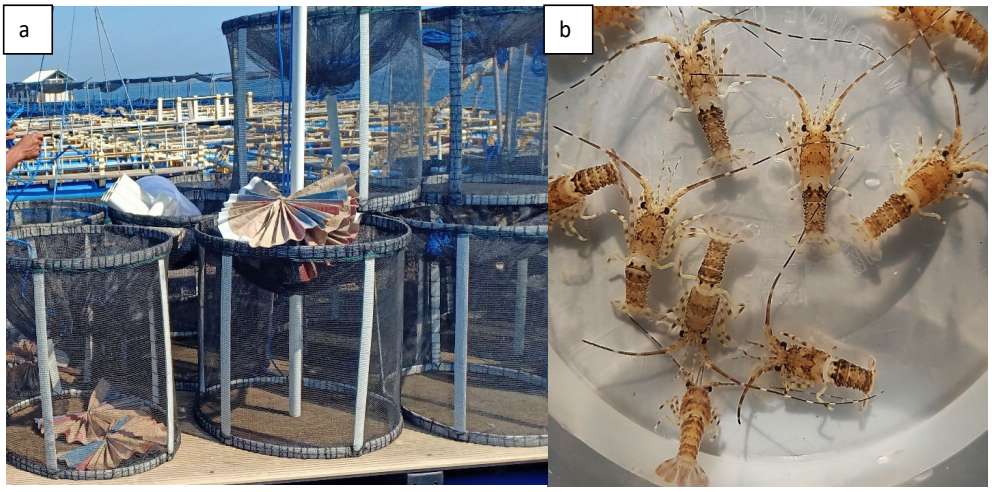

Fig. 1. a. Rearing unit and artificial shelter (cement sack) fan-like formation, b. Post-puerulus stage scalloped spiny lobster, *Panulirus homarus*.

salinity (Atago refractometer, Japan), ammonia, and nitrite levels (Hach DR900, USA)) were continuously monitored once a week during the experiment to make sure that the lobsters were reared under optimal conditions. Total gain, average daily growth, specific growth rate, feed conversion ratio, and survival rate were calculated according to the following formula described by Amin et al. (2020).

Absolute growth (AG):

$AG\,(g \text{ or } cm) = Mf - Mi$

Specific growth rate (SGR):

$$SGR\,(\%\ day^{-1}) = \frac{LnMf - LnMi}{t} \times 100$$

Survival rate (SR):

$$SR\,(\%) = \frac{Nt}{No} \times 100$$

Where: *Mi* and *Mf* are the mean initial and final individual masses, *t* = duration of the periods in days, *Ln* = Napierian logarithm, *No* = initial number of fish, and *Nt* = number of spiny lobster in each group remaining after the 10-week feeding period.

Data analysis

Data required in all measurements were expressed as a mean ± standard deviation (SD). All data were first verified for normal distribution and equal variance. After that, all data were analysed using an analysis of variance (ANOVA) test using SPSS Version 23 for Windows (SPSS Inc., USA) to determine the effects of different artificial shelters on growth performance, survival rate, body composition, and water quality. Values were considered significantly different when $P < 0.05$. Post-hoc Tukey's test was used to determine differences among means.

Results

Survival rate

The percentage of the surviving scalloped spiny lobsters was significantly affected by the presence of shelter in the rearing system, $P < 0.05$. As presented in Figure 2, the survival rate of spiny lobsters without shelter (control) was significantly lower from week 2 onward. The survival rate of spiny lobsters measured on week 2 was 62 %, while in all treatments with shelter was 76 to 82 %. The SR value continuously decreased over time. After a culture period of 10 weeks, the mean SR was 28 % in control (without shelter) and was significantly lower compared to all treatments with shelter; 53 %, 54 %, and 59 % for T3, T2 and T1, respectively.

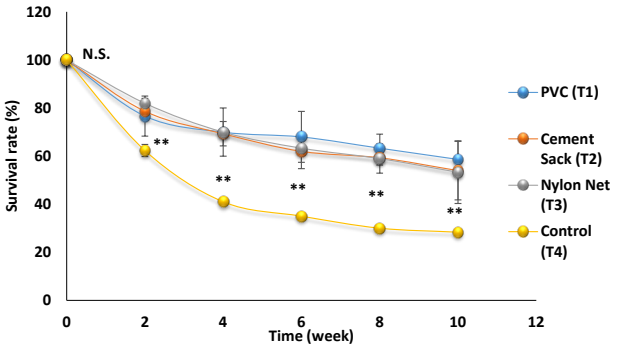

Fig. 2. The survival rate of scalloped spiny lobster *Panulirus homarus* of puerulus stage reared in floating net cages with different artificial shelter types. Values are means of three replicates, and each replicates had 50 lobsters. T1: PVC pipe, T2: cement sack, T3: nylon net, T4: no shelter or control. N.S. means the average values were not significantly different. ** means the average values were significantly different at $P < 0.05$.

Total body weight and length

The artificial shelter types significantly affected the absolute growth of scalloped spiny lobster puerulus, indicated by the difference in final body weight and length after 10 weeks of culture in the floating net cages with the different artificial shelter. Starting from statistically similar body weight, the spiny lobster puerulii appeared to grow at the same rate until week 6 ($P > 0.05$) (Fig. 3). However, the spiny lobsters reared with the artificial shelter of T2 and T3 grew significantly faster than the lobster with PVC shelter (T1) or without shelter (T4 or control), indicated by the higher ($P < 0.05$) total body weight on week 8 and week 10. The final weight of lobsters measured after 10 weeks was 3.36 g and 3.63 g for sheltered in cement sack and nylon net, respectively. At the same time, the PVC shelter gave the smallest body mass, which was 1.95 g (Fig. 3).

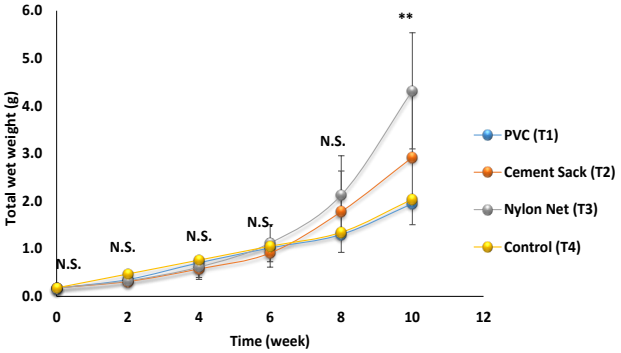

Fig. 3. Total wet weight of scalloped spiny lobster *Panulirus homarus* puerulus stage reared in floating net cages with different artificial shelter types. Values are means of three replicates, and each replicates had 50 lobsters. T1: PVC pipe, T2: cement sack, T3: nylon net, T4: no shelter or control. N.S. means the average values were not significantly different. ** means the average values were significantly different at $P < 0.05$.

In terms of length, the artificial shelter significantly affected the growth of spiny lobsters, $P < 0.05$. Starting from a statistically similar initial carapace length, the lobsters appeared to grow at the same rate for the first week, $P > 0.05$. However, carapace lengths of the spiny lobsters measured at weeks 8 and 10 were significantly different among the different shelter types. As presented in Figure 4, spiny lobsters reared in shelter using a nylon net, and cement sack were significantly higher than the control. However, there was no significant difference among the three shelter types, although the lobster in nylon net shelter was the highest (16.07 cm), followed by cement sack (14.45 cm) and PVC pipe (13.45 cm). While the lowest growth was obtained from those spiny lobsters reared in the floating net cages without artificial shelter (Fig. 4).

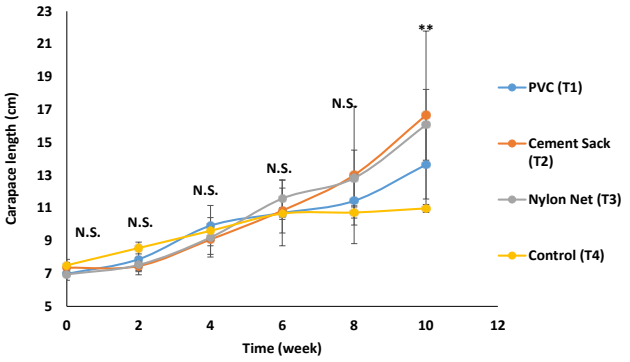

Fig. 4. Total carapace length of scalloped spiny lobster *Panulirus homarus* reared in floating net cages with different artificial shelter types. Values are means of three replicates, and each replicates had 50 lobsters. T1: PVC pipe, T2: cement sack, T3: nylon net, T4: no shelter or control. N.S. means the average was not significantly different. ** means the average values were significantly different at $P < 0.05$.

Specific growth rate

Types of artificial shelters significantly affected the specific growth rate (SGR) of spiny lobster puerulus reared in the floating net cages ($F = 5.701$, df 3, 10, $P = 0.015$). As presented in Figure 5, the highest SGR was observed in those spiny lobsters grown with nylon net as artificial shelter (4.37 ± 0.59 % BW.d^{-1}), followed by those with cement sack (3.64 ± 0.71 % BW.d^{-1}), and PVC (3.17 ± 0.94 % BW.d^{-1}). While the lowest SGR was obtained from the control or the spiny lobsters cultured without artificial shelters, 3.44 % BW.d^{-1}.

Water quality

Seven water quality parameters, measured weekly during the experiment, were similar among treatments since the lobsters were cultured in floating net cages using the same water body. The averages of each water quality parameter are presented in Table 1.

Discussion

A low survival rate, mainly due to cannibalism, is one of

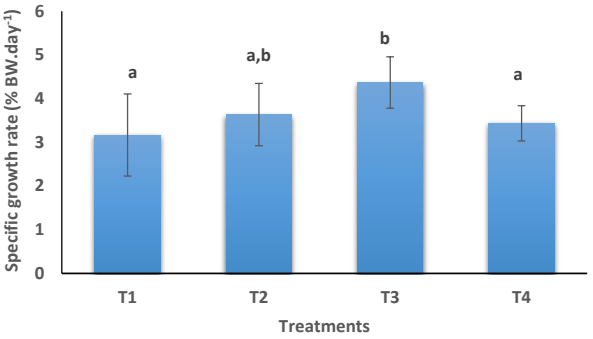

Fig. 5. The specific growth rate of scalloped spiny *lobster Panulirus homarus* reared in floating net cages with different artificial shelters. Values are means, and bars are the standard deviation of three replicates, and each replicates had 50 lobsters. Different superscripts (a, b) indicate significant difference at $P < 0.05$. T1: PVC pipe, T2: cement sack, T3: nylon net, T4: no shelter or control.

Table 1. The average values of water quality parameters of lobster, *Panulirus homarus* rearing water in the floating-net cages.

Water quality parameters	Average ± SD
Temperature (°C)	28.33 ± 0.52
pH	7.73 ± 0.06
DO (mg.L^{-1})	7.12 ± 0.79
Salinity (psu)	30.75 ± 0.61
NO_2 (mg.L^{-1})	0.005 ± 0.004
NO_3 (mg.L^{-1})	0.005 ± 0.001
NH_4 (mg.L^{-1})	0.05 ±0.015

SD is standard deviation, and each parameter is an average of 10 measurements.

the most common problems faced in lobster aquaculture. Few studies suggest that shelter installed inside the rearing system may reduce aggressiveness and cannibalism in lobster aquaculture (Su et al., 2020; Ma et al., 2021). Thus, the present study reported the effects of three artificial shelters (PVC pipe, nylon net, and cement sack) on the growth and survival rate of scalloped spiny lobster, *P. homarus*, reared in floating net cages. The result, in general, indicated that artificial shelter types significantly affected scalloped spiny lobster's survival rate and growth performances.

The survival rate of scalloped spiny lobsters with all artificial shelters was significantly higher compared to the control (with no shelter) from week 2 onward. The survival rate of scalloped spiny lobsters in control (T4) measured on week 2 was 62 %, while the survival rate in all treatments with shelter was 76 % to 82 %. The SR value continuously decreased over time, and after 10 weeks of culture, the mean SR was 28 % in control, which was significantly lower compared to all treatments (53 %, 54 %, and 59 % for nylon net, cement sack, and PVC, respectively). The same result was reported by Lesmana and Mumpuni (2022), where

using brick with holes as artificial shelters could reduce cannibalism among lobsters because the shelters were used for hiding during the moulting process. According to Slamet et al. (2021), scalloped spiny lobsters, *P. homarus,* reared with nylon-net shelter, reduced cannibalism significantly among lobsters.

Possible mechanisms are that the addition of the nylon net shelter reduced their physical contact with the lobsters and reduced cannibalism during the moulting process (Adiyana et al., 2020), increasing the survival rate. According to Su et al. (2020) and Atema (2018), moulted lobster releases a specific aroma that attracts other lobsters to attack and is vulnerable to cannibalism. The reduction in mortalities can be attributed to the shelter used primarily by subordinate animals to avoid interactions with dominant lobsters during vulnerable stages such as moulting, reducing the likelihood of cannibalism. The presence of shelter can be used to hide and protect them from other aggressive lobsters.

Another study by Ma et al. (2021) confirmed that providing shelter reduced agonistic behaviour due to intense interaction among lobsters and increased the survival rate of lobsters. The same response was reported by Zhang et al. (2021) in crabs, where shelter addition reduced the aggressiveness of swimming crab, *Portunus trituberculatus* (Miers, 1876). In addition, Adiyana et al. (2020) also revealed that the addition of shelter reduced the stress response in lobsters, indicated by lower glucose levels in the blood. All this evidence suggests that shelter can be used to reduce cannibalism and increase the survival rate of spiny lobsters.

However, the results also showed no significant difference in the survival rate of scalloped spiny lobster reared in the three shelter types using nylon net, PVC, and cement sack. Similarly, Mamuaya et al. (2019) reported no significant difference in the survival rate of lobsters reared with dried coconut leaves, bamboo, and *Hydrilla*. These results may suggest that the tested shelters have similar quality in terms of function. However, the present result was also contradictory to previous studies where plastic mesh shelters had a significantly higher survival rate than brick, in postpueruli of western rock lobster *Panulirus cygnus* George, 1962 (Johnston et al., 2006).

The artificial shelters also significantly affected scalloped spiny lobster's absolute growth rate and SGR. During the first six-week, the absolute growth and specific growth rate of scalloped spiny lobsters reared in floating-net cages with different shelters appeared to be the same. However, calculated on week 8 onward, lobster with shelters of nylon net and cement sack showed significantly better absolute growth. Similarly, the highest SGR was observed in those scalloped spiny lobsters grown with nylon net (4.37 ± 0.59 % $BW.d^{-1}$), followed by those scalloped spiny lobsters with cement sacks ($3,64 \pm 0.71$ % $BW.d^{-1}$), and PVC (3.17 ± 0.94 % $BW.d^{-1}$). In contrast, the lowest SGR was obtained from the control or those scalloped spiny lobsters cultured without artificial shelters, 3.44 % $BW.d^{-1}$. A similar result was reported by Slamet et al. (2021), where scalloped spiny lobster reared with nylon net shelter had better growth in terms of both body weight and total length. According to Adiyana et al. (2020), the possible mechanism for better growth performance is probably the spiny lobster felt more secure in the shelter. Therefore, the consumed nutrients are directed more toward growth instead of maintenance.

The positive responses of spiny lobsters to the shelter should be further studied to determine the number, structures, shapes, and colour preferences for spiny lobsters. Optimising these factors may contribute to better survival and growth rates of scalloped spiny lobster in the future, as previously reported from purple mud crab, *Scylla tranquebarica* (Fabricius, 1798) (Kawamura et al., 2020) and redclaw crayfish, *Cherax quadricarinatus* (von Martens, 1868) (Hermawati, 2018).

Conclusion

Scalloped spiny lobsters, *Panulirus homarus* reared in a floating net cage with artificial shelter had better survival rates and growth performances than those cultured without shelter. The survival rate of scalloped spiny lobster measured in the control group observed on week 2 was only 62 %, while the survival rate in all treatments (with shelter) was 76 % to 82 %. The accumulative survival rate continuously decreased over time, and after being cultured for 10 weeks, the mean survival rate was 28 % in control (without shelter), which was significantly lower compared to all treatments; 53 %, 54 %, and 59 % for nylon net, cement sack, and PVC respectively. However, the results also showed that different shelter types had no significant effect on the survival rate. Furthermore, the absolute growth and specific growth rate of the scalloped spiny lobsters reared with the artificial shelters were significantly better than that of lobsters in the control group. The best growth was obtained from lobster reared with nylon net as shelter, followed by fan-like constructed cement sack, and PVC pipe. Other factors, including the shelter area, structures, shapes, and colour preferences, should be further investigated to optimise the environmental condition of the growth and survival rates of spiny lobsters.

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Conflict of interest: The authors declare that they have no conflict of interest.

Author contributions: Mochamad Amiri: Experimental design, data collection, data analysis, writing draft. Laila Musdalifah: Experimental design, data collection, data analysis, writing draft. Muhamad Amin: Experimental design, data collection, data analysis, writing draft, data validation, supervision.

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