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Sustainable Mud Crab Aquaculture Using Individual Battery Cage Systems in Silvofishery Ponds

Moh. Zainal Arifin[1], Agus Widodo[1], Catur Pramono Adi[2], I Nyoman Sudiarsa[3], Zainal Usman[4], Putri Nurhanida Rizky[1]*, Dafin Alfa Fatahillah[1], Moch. Lutvin Vana[1]

[1]Department of Aquaculture, Politeknik Kelautan dan Perikanan Sidoarjo 61254, East Java, Indonesia
[2]Department of Aquaculture, Politeknik Kelautan dan Perikanan Karawang 41315, Weast Java, Indonesia
[3]Department of Aquaculture, Politeknik Kelautan dan Perikanan Jembrana 82218, Bali, Indonesia
[4]Department of Aquaculture, Politeknik Kelautan dan Perikanan Kupang 85351, East Nusa Tenggara, Indonesia

*Corresponding Author: putrimarine92@gmail.com

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ABSTRACT

Silvofishery systems integrate aquaculture with mangrove forestry, offering ecological and economic benefits. This study investigated the effectiveness of individual cell cage battery systems for fattening mud crabs (*Scylla* spp.*)* in silvofishery ponds. Ninety male mud crabs were individually housed in battery cages and assigned to three feeding treatments: commercial feed (Treatment 1), trash fish (Treatment 2), and salted fish (Treatment 3). Growth performance indicators, including absolute growth (AG), specific growth rate (SGR), and survival rate (SR), were measured over a 21-day culture period. Crabs fed with trash fish showed significantly higher AG (45.93 ± 3.7g) and SGR (1.4 ± 0.1%) compared to those fed commercial feed (30.43 ± 3.9g AG; 0.81 ± 0.09% SGR) and salted fish (18.3 ± 4.07 g AG; 0.5 ± 0.1% SGR) (P<0.05). All treatments achieved a 100% survival rate. Water quality parameters remained within or near optimal ranges throughout the study, with temperature at 27.29 ± 0.68°C, pH at 7.72 ± 0.25, salinity at 27.54 ± 1.25ppt, and ammonia at 0mg/ L. Dissolved oxygen was slightly below the optimal threshold at 4 ± 0.78ppm, while other nutrients such as nitrate (0.014 ± 0.3mg/ L), nitrite (0.012 ± 0.2mg/ L), and phosphate (0.65 ± 1.1mg/ L) were within acceptable limits. Individual cell cage systems significantly improved mud crab growth and survival by mitigating cannibalism and optimizing feed intake. This study highlights the potential of combining silvofishery systems with battery cage technology to enhance sustainable aquaculture productivity.

INTRODUCTION

Despite their presence in over 120 tropical and subtropical countries and territories, mangroves are relatively rare on a global scale, occupying less than one percent of all tropical forests. Indonesia, Brazil, Nigeria, Mexico, and Australia together represent 47 percent of the global mangrove area **(Leal *et al.*, 2024)**. Mangrove ecosystems are vital coastal habitats that support a diverse range of aquatic and semi-aquatic organisms **(Islamy & Hasan, 2020; Hasan *et al.*, 2022; Dabalà *et al.*, 2023; Hasan *et al.*, 2023; Isroni *et al.*, 2023)**. The FAO's report highlights that these ecosystems are not only crucial for local biodiversity but also serve as critical resources for communities that depend on them for food and livelihoods **(FAO, 2023)**. Despite their importance, mangroves face significant threats primarily from coastal development, agriculture, and climate change **(Susanto *et al.*, 2018; Asadi *et al.*, 2019; Akram *et al.*, 2023; Wirabuana *et al.*, 2025)**.

Silvofishery represents a promising conservation strategy aimed at protecting and restoring mangrove ecosystems while simultaneously supporting local livelihoods through sustainable aquaculture practices **(Susetya *et al.*, 2023)**. This integrated approach combines the cultivation of aquatic species, such as shrimp and fish, with the preservation of mangrove forests, creating a mutually beneficial environment **(Harefa *et al.*, 2022; Sumarga *et al.*, 2024)**.

Mud crabs, particularly species from the genus *Scylla*, are among the most economically significant marine commodities, widely sought after for their culinary value and high market demand **(Yulianto *et al.*, 2019; Maulianawati *et al.*, 2020; Apine *et al.*, 2023)**. The increasing global demand for mud crabs has prompted aquaculture practitioners to explore various methods to enhance their production efficiency **(Pati *et al.*, 2023)**. Traditional fattening practices often face challenges related to growth rates, survival rates, and environmental sustainability, necessitating innovative approaches to improve output **(Apine *et al.*, 2023; Liew *et al.*, 2023)**.

One promising method is the implementation of individual battery cell cage system in silvofishery environments, which integrate aquaculture with mangrove forestry. This approach not only optimizes space but also utilizes the natural benefits provided by mangrove ecosystems, such as habitat complexity and nutrient cycling. Mud crab cultivation with individual battery cell cage is performed with each crab placed in a separate chamber within the battery systems. This setup minimizes stress among the crabs and prevents cannibalism, common issues in communal caging methods. The individualized space also facilitates easier monitoring and management of each crab's well-being **(Wohlford *et al.*, 2004; Mirera, 2013; Yulianto *et al.*, 2019)**.

This research aimed to fill this gap by investigating how these mud crab culture systems can enhance productivity while ensuring environmental sustainability. By focusing on the interaction between mud crab biology and the unique characteristics of silvofishery ecosystems, this study seeked to provide valuable insights that can inform best practices for mud crab aquaculture. This background sets the stage for understanding the significance of enhancing productivity in mud crab fattening through innovative aquaculture practices, emphasizing both economic and ecological perspectives.

MATERIALS AND METHODS

1. Study area

The research was conducted directly in the silvofishery pond located in the Brackish Water Laboratory of the Polytechnic Marine and Fisheries in Sidoarjo, at mangrove center of Pasuruan, East Java, Indonesia, from 1 - 21 October, 2024. The silvofishery system was utilized in the aquaculture process for effective water treatment.

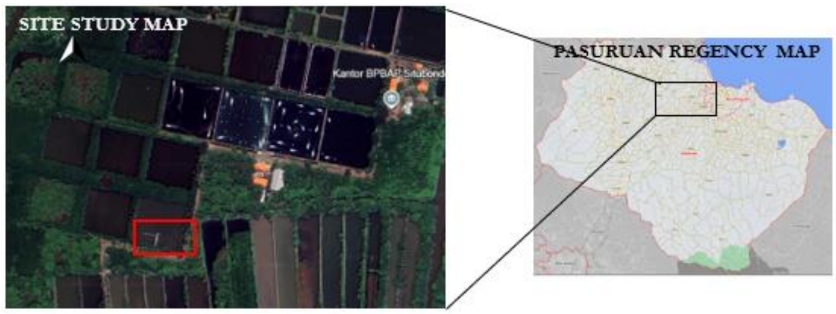

Fig. 1. Maps showing the location (red square) of Brackish Water Laboratory, mangrove center of Pasuruan

2. Experimental design

This study aimed to investigate the effects of different types of feed on the growth and health of mud crabs cultivated in individual battery cell cages systems in silfovishery pond. A completely randomized design (CRD) was employed. The mud crabs were divided into three treatment groups, with each group consisting of thirty replications. This resulted in a total of ninety individual mud crab cages being utilized for the experiment. Each treatment group received a distinct type of feed, allowing for a comprehensive analysis of how varying nutritional inputs influenced the crabs' growth performance and overall well-being.

3. Battery cell cage preparation

The preparation of the mud crab cages was conducted at the institution's Brackish Water Laboratory. Following the experimental design, ten pairs of PVC pipes, each measuring 4.8 meters in length, were prepared to serve as a support structure for the cages. A total of ninety black polypropylene (PP) mud crab cages, each with dimensions of 22cm in length, 16cm in width, and 9.5cm in height, were securely attached to these pipes using cable ties. Cages were spaced 0.3 meters apart to ensure adequate water circulation and access. The water depth in the setup was maintained at approximately 80 to 100cm, providing an optimal environment for the crabs. Each cage was equipped with a lid to prevent the crabs from escaping, ensuring better management of the stock. Along the cell cage culture, the 70% net blocks of paranet was equipped to prevent the excessive of sunlight.

The cage design featured twelve holes at the top and small holes along the sides to facilitate the free movement of water and air, promoting a healthy environment for the crabs. However, no openings were included at the bottom of the cages to prevent the crabs from easily moving out. Additionally, each experimental unit contained a fishing net placed inside the cage to further prevent any escape through the holes while allowing for water circulation. This comprehensive preparation ensured that the mud crab culture system was both functional and conducive to the growth and health of the crabs throughout the experiment.

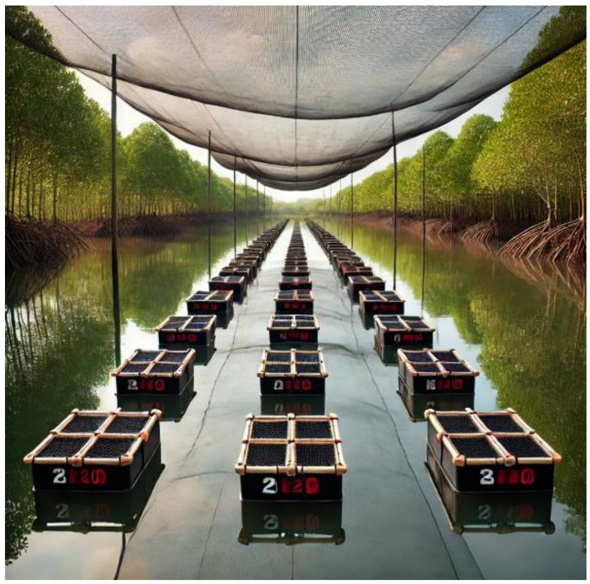

Fig. 1. Mud crab individual battery cell cage systems culture

4. Mud crab preparation

Ninety male mud crabs with body weight of 150 – 175 grams were collected from local farm in Pasuruan. For the experimental setup, each cage was stocked with a single lean crab, ensuring a controlled environment that minimizes competition and stress. During this acclimatization phase, the crabs' body weights were measured using an electric scale with an accuracy of 0.1 grams, while their lengths were recorded with a fish measuring board that offers precision up to 0.1 millimeters.

5. Experimental feed preparation

In treatments, types of different mud crab feed were used; in Treatment 1, mud crab was fed with commercial feed, in Treatment 2, they were fed on trash feed, and in Treatment 3, salted fish was fed for the crab. Feeding is done twice a day (08.00 and 17,00). The daily dose of feeding is given at 10% of the mud crab body weight. The commercial diet used in this study was purchased from a local market. Commonly used trash fish includes species such as tilapia (*Oreochromis mossambicus*) and longfin herring (*Ilisha elongata*) based on local availability. The selected trash fish should be fresh and free from spoilage. The fish was washed thoroughly to remove any impurities, blood, or contaminants. In additional, commonly used salt fish includes bycatch species or less commercially valuable fish such as anchovies (*Thryssa mystax*). The salt fish was soaked in fresh water for a few hours to reduce salinity levels, making it more palatable and digestible for the crabs. The trash fish and salt fish were cut into pieces that are appropriate for the size of the mud crab's mouth.

6. Mud crab growth performance

The evaluation of the mud crab weight was done every seven days. The growth performance was measured by the following indicators: absolute growth (AG), specific growth rate (SGR), and survival rate (SR). The parameters of growth performance was measured using the formula outlined by **Yulianto *et al.* (2019)** :

Absolute growth (AG)

$$AG = Wt - Wo \quad (1)$$

Where :
AG = Absolute growth (g)
Wt = Final weight (g)
Wo = Initial Weight (g)

Specific growth rate (SGR)

$$SGR = 100\, x \ln \frac{\left(\frac{Wo\ (g)}{Wt\ (g)}\right)}{days} \quad (2)$$

Where :
SGR = Specific growth rate (g)
Wt = Final weight (g)
Wo = Initial Weight (g)
Days = Day of treatment

Survival rate (SR) **(Hannan *et al*., 2024)**:

$$SR = 100\ x\ \frac{Nt}{No} \quad (3)$$

Where :
SR = Survival rate of the crab (%)
Nt = Number of live crabs at the end of study
No = Number of crabs at the beginning

7. Water quality measurement

Water temperature (°C), dissolved oxygen (ppm), water transparency (cm), salinity (ppt), and pH (ppm), were carried out *in situ*; while measurements of ammonia (mg/L), nitrite (mg/L), nitrate (mg/L), phosphate (mg/L), and TOM (mg/L) were carried out in laboratory to determine water quality. The water samples were taken at a depth of 50cm and analyzed at the Technical Implementation Unit, Fish and Environmental Health Laboratory, Pasuruan, East Java.

8. Data analysis

After 21 days of fattening, all the mud crabs were harvested by carefully removing them from their cages. For data analysis, the means for each treatment group were calculated for all measured variables. A one-way analysis of variance (ANOVA) was employed to assess the significance of the differences among the three treatment groups. Water quality data were displayed in tabular form. All data collected were described descriptively.

RESULTS

1. Silvofishery pond

The study site features the mangrove species *Rhizophora apiculata*, which has an average diameter of approximately 6 meters and is spaced about 5 meters apart. This species plays a crucial role in the silvofishery system, which integrates aquaculture with mangrove ecosystems. Additionally, the silvofishery pond is utilized for culturing milkfish (*Chanos chanos*), with an estimated population of 1,500 individuals present in the pond. The combination of *R. apiculata*, milkfish and mud crab cultivation not only enhances biodiversity but also supports sustainable fish production within the ecosystem.

The milkfish cultivated in the silvofishery pond, when combined with mud crab culture, demonstrates significantly improved growth performance compared to the growth rates observed prior to the initiation of mud crab cultivation.

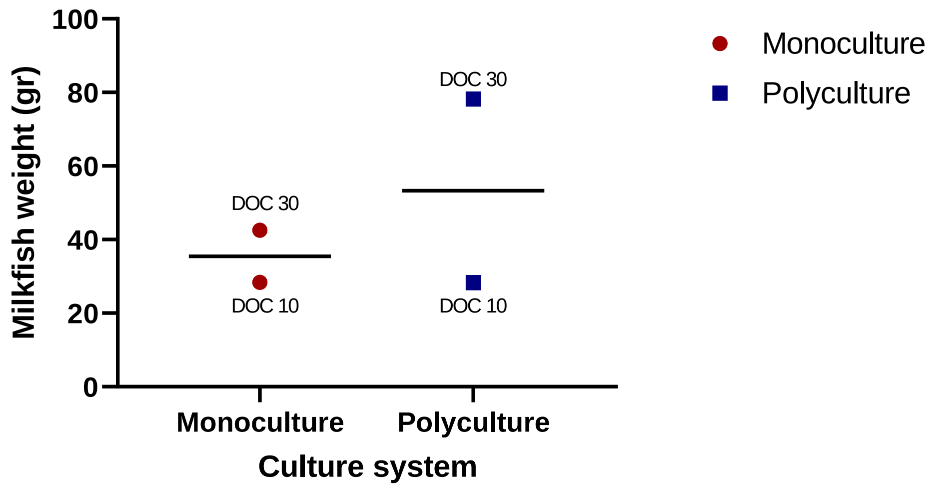

Fig. 3. The growth performance of milkfish in sylvofihery pond combined with mud crab culture

The growth of the milkfish in a monoculture system was measured before the commencement of the mud crab fattening study, with water quality and environmental conditions assumed to be identical. After the milkfish in the silvofishery pond were harvested, milkfish farming was resumed in conjunction with mud crab cultivation. Fig. (3) shows that both systems showed an increase in fish weight as the DOC progresses, indicating growth over time. However, the mean of milkfish weight in the polyculture system (blue squares) appears consistently higher than that in the monoculture system (red circles) across the observed days of culture.

2. Water quality

Water quality obtained from this study is presented in Table (1). The analysis of water quality parameters in the silvofishery pond indicates generally favorable conditions for mud crab (*Scylla* spp.) aquaculture. The temperature (27.29 ± 0.68°C), transparency (27.94 ± 2.75 cm), and pH (7.72 ± 0.25) were all within the optimal ranges defined by SNI 01-7246-2006, supporting the metabolic activity and overall health of mud crabs. Ammonia levels were undetectable (0mg/ L), and total organic matter (TOM) was low (11.23 ± 1.2mg/ L), indicating minimal organic pollution and a stable pond environment. Nutrient levels such as nitrate (0.014 ± 0.3mg/ L), nitrite (0.012 ± 0.2mg/ L), and phosphate (0.65 ± 1.1mg/ L) exceeded the minimum thresholds required for productive aquaculture systems, contributing to nutrient availability and supporting plankton growth.

Table 1. Water quality parameter of mud crab culture in sylvofishery pond

Parameter	Measurement	Optimal range (SNI 01-7246-2006)	Status
Tempt (ºC)	27,29±0,68	25 - 35	Within range
DO (ppm)	4±0,78	>5 ppm	Slightly low
Transparency (cm)	27,94±2,75	20 – 30	Within range

Salinity (ppt)	27,54±1,25	10 – 25	Slightly high
pH	7,72±0,25	7.5 – 9	Within range
Amonia (mg/L)	0±0,0	max. 0.01	excellent
Nitrite (mg/L)	0,012 ± 0,2	min. 0.01	acceptable
Nitrate (mg/L)	0,014 ± 0.3	min. 0.01	Acceptable
Phosphate (mg/L)	0.65 ± 1.1	min. 0.1	High and favorable
TOM (mg/L)	11,23 ± 1,2	max.55	Safe

However, dissolved oxygen (DO) was slightly below the optimal level (>5ppm), averaging 4 ± 0.78ppm, which may affect crab respiration if not addressed; supplemental aeration is recommended to improve oxygen availability. Salinity was also slightly above the optimal range at 27.54 ± 1.25ppt, though still within tolerance limits for mud crabs, which are known to be euryhaline. Overall, the pond environment was suitable for mud crab cultivation and contributed to the high survival rate and satisfactory growth performance observed in the study.

3. Mud crabs growth performance

The growth performance was determined through the following measured indicators: absolute growth (AG), specific growth performance (SGR), and survival rate (SR). In addition, Table (2) presents the proximate composition of the diets provided to mud crabs. The crude protein content for commercial feed was 38.14%, 39.23% for trash fish, which primarily consisted of tilapia and longfin herring, and 21.8% for salted fish, mainly composed of anchovy. This difference in protein content explains the significantly higher absolute growth performance of mud crabs in Treatment 2 compared to treatments 1 and 3 (Fig. 4).

Tabel 2. Proximate composition of the feeds given to mud crabs

Composition (% wet weight)	Com. Feed (T1)	Trash fish (T2)	Salted fish (T3)
Crude protein	38.14	39.23	21.8
Crude fat	18.91	15.43	12.28
Water	42.68	45,34	65,92

The mean initial weight of the mud crab was 150 to 175 grams and resulted in a mean final weight of 194 grams in Treatment 1; 216.7 grams in Treatment 2, and 182.83 grams in Treatment 3. Moreover, all treatments had a 100% survival. Results showed that the highest average absolute growth performance of mud crabs was found in Treatment 2 (trash fish) was 45.93 ± 3.7g, followed Treatment 1 (commercial feed) at 30.43 ± 3.9g, and Treatment 3 (salted fish) at 18.3 ± 4.07 g (Fig. 4).

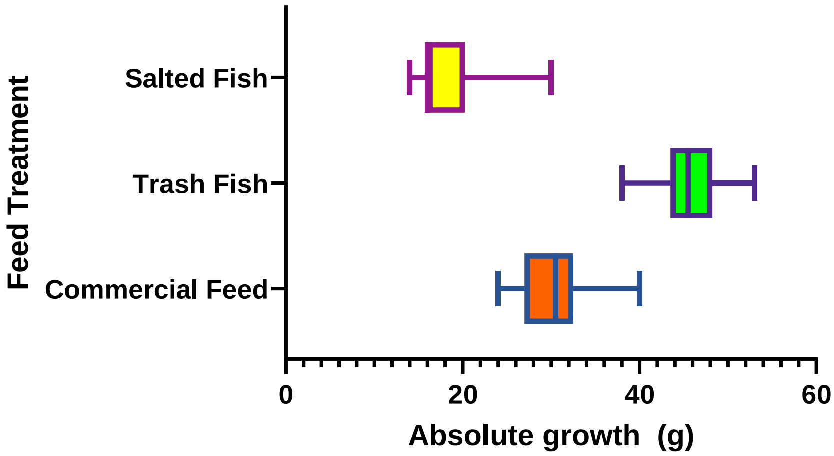

Fig. 4. The average weight growth of mud crabs over a 21-day period of fattening in individual cage battery system

The specific growth performance of mud crab indicates how quickly the crab grows relative to its initial weight. Mud crab in Treatment 2 recorded higher SGR compared to Treatment 1 and Treatment 2 (Fig. 5). The SGR of mud crabs after 21 days of experiment in Treatment 2 started from 1.13±0,32% to 1.4±0.1%. while, the SGR in Treatment 1 started from 0.69±0.76% 0.81±0.09% and Treatment 3 started from 0.46±0.06% to 0.5±0.1 %. The difference in SGR values among the treatments was significant (P<0.05).

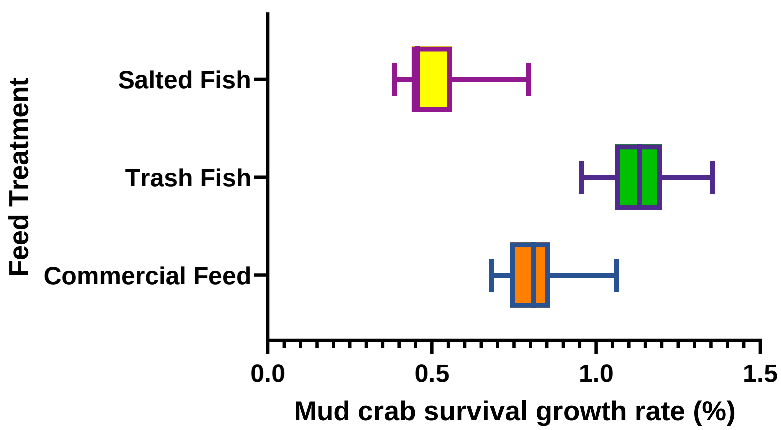

Fig. 5. The specifc growth rate of mud crabs over a 21-day period of fattening in individual cage battery system

DISCUSSION

Rhizophora apiculata is one of the mangrove species commonly utilized in silvofishery systems **(Delvian *et al.*, 2019)**. This species, along with other *Rhizophora* species, is classified as a facultative halophyte, meaning it can thrive in saline water or environments with high salinity. A distinctive characteristic of *R. apiculata* is its complex root system, which features low branching that effectively protects pond areas from soil erosion caused by storms and tidal fluctuations **(Wulandari *et al.*, 2022; Nursinar *et al.*, 2023)**, thereby forming a dense structural habitat.

The integration of mangrove ecosystems, particularly the *Rhizophora* species, with aquaculture practices involving the milkfish (*Chanos chanos*) and mud crab (*Scylla* spp.) presents a promising model for sustainable fishery practices. Research has shown that the combination of the milkfish and mud crab in polyculture systems can lead to enhanced growth performance for both species. For instance, a study highlighted that polyculture significantly affects the abundance of phytoplankton, which is vital for the food web within these ecosystems.

Moreover, the previous study on polyculture showed that, integrating multiple species in aquaculture systems, including fish, crustaceans, and mollusks, can enhance overall productivity and efficiency. For instance, the integration of the milkfish, tiger shrimp, and mussels in an IMTA system demonstrated an improved feed utilization and economic viability **(Samidjan *et al.*, 2022; Heriansah *et al.*, 2023)**.

The integration of *Rhizophora* mangroves in silvofishery systems has been shown to enhance water quality for mud crab (*Scylla* spp.) Most water quality parameters in this study were within the optimal ranges, except for DO, which was slightly below the recommended threshold, and salinity, which slightly exceeded the optimal range. While the water temperature and transparency parameters are favorable for mud crab cultivation, the slightly low dissolved oxygen levels warrant immediate attention to ensure optimal growth conditions.

The water temperature averaged 27.29 ± 0.68°C, which falls within the optimal range of 25–35°C as recommended by **Shelley and Lovatelli (2013)**. This temperature range supports the metabolic activities and growth of mud crabs. The dissolved oxygen (DO) concentration, however, averaged 4 ± 0.78 ppm, which is slightly below the optimal level of >5ppm. Low DO levels may indicate suboptimal conditions for respiration, requiring additional aeration to improve oxygen availability. Water transparency averaged 27.94 ± 2.75cm, which lies within the optimal range of 20–30cm, indicating sufficient clarity to support natural plankton growth for food sources.

Salinity averaged 27.54 ± 1.25ppt, slightly exceeding the optimal range of 10–25ppt, though mud crabs are generally tolerant of higher salinity levels, making this variation unlikely to cause significant adverse effects. The pH averaged 7.72 ± 0.25, which is well within the optimal range of 7.5–9, ensuring a stable chemical and biological environment for mud crabs. Mangroves are well-adapted to fluctuating salinity levels and can help stabilize salinity conditions in adjacent aquaculture systems. This stabilization is particularly important for mud crabs, which thrive within specific salinity ranges **(Dai *et al.*, 2020)**. The ability of *Rhizophora* to tolerate higher salinity while providing a more stable environment supports optimal conditions for crab growth **(Toriman *et al.*, 2013)**.

Rhizophora mangroves act as natural filters, reducing turbidity and improving water clarity. This filtration process helps maintain optimal light levels for phytoplankton growth, which serves as a primary food source for many aquatic species, including mud crabs **(Dai *et al.*, 2020)**. The ammonia concentration in this study was 0ppm, well below the maximum allowable level of <3ppm, indicating excellent water quality with minimal toxicity risk.

Rhizophora mangroves have been identified as microbiological buffers that can reduce pathogen loads in the water. This capability helps create a healthier environment for mud crabs, potentially decreasing disease outbreaks and improving survival rates **(McSherry *et al.*, 2023)**. The alteration of microbial communities in the water due to mangrove presence can enhance the gut microbiota of mud crabs, further supporting their health and growth.

The use of a battery system for individual cell cage culture of mud crabs (*Scylla* spp.) in sylvofihsery system has shown promising results in enhancing the fattening process of these crustaceans. Individual cages facilitate controlled feeding practices, allowing for precise management of diet and feeding frequency. Moreover, individual cell cages prevent physical contact between crabs, minimizing stress and energy expenditure associated with territorial disputes and self-defense. This allows crabs to allocate more energy to growth rather than survival.

For instance, a study reported a survival rate ranging from 63 to 79% over 48 days, with significantly higher weights gained by crabs housed in closed-cage setups **(Mirera, 2013; Yulianto *et al.*, 2019)**. Additionally, the specific growth rate varied from 0.67 to 1.36% daily, indicating robust growth under controlled conditions **(Yulianto *et al.*, 2019)**.

Properly formulated diets can lead to enhanced growth rates and better feed conversion ratios. For instance, studies have shown that mud crabs fed with trash fish exhibit superior growth performance (45.93g of absolute growth rate with the specific growth rate varied from 1.13 to 1.4% daily) compared to those receiving commercial diets (30.43g of absolute growth rate with the specific growth rate varied from 0.69 to 0.81% daily) or salted fish (18,3g of absolute growth rate with the specific growth rate varied from 0.46 to 0.5% daily) after 21 days of fattening. Other studies have suggested that diets rich in protein, such as chicken intestines, also enhance growth rates and economic viability in crab farming **(Nivas *et al*., 2024)**. For instance, mud crabs fed with African land snails exhibited the highest growth performance and feed conversion ratio (FCR) of 1.38, indicating effective feed utilization **(Gabito & Baltar, 2023)**.

Trash fish often contains higher levels of essential nutrients, particularly protein and lipids, which are crucial for the growth and development of mud crabs **(Iromo *et al.*, 2020)**. The higher crude protein contain on trash fish promoting better growth performance compared to salted fish that may not fully meet the nutritional requirements of mud crabs. Moreover, feeding mud crabs with trash fish aligns more closely with their natural foraging behavior **(Gabito & Baltar, 2023)**. This natural diet can stimulate their feeding instincts and promote more active feeding, which is beneficial for their overall growth and health. In contrast, formulated feeds and salted fish may not be as readily accepted by mud crabs, potentially leading to reduced consumption and lower growth rates.

Mud crabs in individual cell cages with battery systems mitigates the natural limitations of communal farming, resulting in faster growth, higher survival rates, and more predictable outcomes. The battery cage system allows for the individual housing of mud crabs, which can significantly reduce competition and aggression among them. This study showed that the survival rate among all the treatments was 100%. It was reported that survival rates can be as high as 87% in such systems, compared to lower survival rates in more crowded environments **(Yulianto *et al.*, 2019)**. This high survival rate is crucial for successful fattening, as it ensures that a greater number of crabs reach market size.

To support the advancement of sustainable mud crab aquaculture in salvofishery systems, future studies should consider incorporating well-established health indicator parameters as outlined in earlier works, including molecular diagnostics **(Valen *et al.*, 2023, 2024; Syarif *et al.*, 2025)**, histopathological examination of the hepatopancreas and intestines **(Kilawati *et al.*, 2024)**, and hemocyanin gene (HMC) expression analysis **(Kilawati *et al.*, 2025)**. These parameters can provide comprehensive insights into the physiological state of mud crabs under varying environmental and management conditions.

Furthermore, enhancing feed efficiency through the incorporation of nutrient-rich natural ingredients should be explored to improve the feed conversion ratio (FCR) and sustainability of mud crab farming. Several promising natural feed resources include seaweeds **(Islamy *et al.*, 2024a; Islamy *et al.*, 2024b; Islamy *et al.*, 2025)**, neem leaves **(Islamy *et al.*, 2024c)**, Ipomoea pes-caprae **(Islamy *et al.*, 2024d)**, and alligator weed **(Serdiati *et al.*, 2024)**. They have shown potential as alternative ingredients **(Islamy *et al.*, 2024e)**. However, further investigation is needed to determine their optimal inclusion levels, long-term physiological effects, and overall impact on production efficiency and ecological sustainability within integrated salvofishery systems.

CONCLUSION

This study demonstrates the effectiveness of individual cell cage battery systems in silvofishery ponds for enhancing the growth and survival rates of mud crabs (*Scylla* spp.). The isolation of crabs in individual cages minimizes cannibalism and stress, achieving a 100% survival rate across all feeding treatments. Trash fish emerged as the most effective feed, yielding significantly higher growth performance than commercial feed and salted fish. The integration of silvofishery systems with battery cage technology leverages the ecological benefits of mangrove ecosystems, maintaining optimal water quality and supporting sustainable aquaculture practices. These findings provide a viable framework for improving mud crab productivity while ensuring environmental sustainability, with potential applications in other aquaculture settings.

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