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REVIEW

An Overview of the Major Constraints in *Scylla* Mud Crabs Grow-out Culture and Its Mitigation Methods

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Abstract

Scylla mud crabs are economically important portunid species for aquaculture in many countries. However, mass production of mud crabs as a supply of seafood is still difficult up-to-date. This review aimed to provide an overview of the major constraints faced in the grow-out farming of mud crabs, and the potential solutions were discussed. The major constraints in the *Scylla* mud crabs' grow-out culture are (1) inadequate seed supply, (2) cannibalism, (3) disease outbreaks, and (4) no commercial formulated feed that is specifically designed for mud crabs. The inadequate wild mud crabs seed supply can be solved through artificial seed production seed in the hatcheries, but the knowledge of mud crab requirements at early life stages is needed to improve the rearing techniques and production. Cannibalism in the grow-out culture of mud crabs is manageable, provided that the farmers are knowledgeable about the basic prevention methods (shelter provision, size grading, monosex culture) and they are practicing it. On the disease outbreaks, research into discovering new alternatives to antibiotics and prevention methods should be prioritized. Finally, the commercial formulated grow-out diet that is specific for the *Scylla* mud crabs should be developed to replace the use of natural products for feeding.

Introduction

The *Scylla* mud crabs can be found throughout the Indo-Pacific region, from Southeast and East Africa to Southeast Asia (Fuseya & Watanabe, 1996). They can be classified into four species, which are the *Scylla serrata*, *S. tranquebarica*, *S. olivacea*, and *S. paramamosain* (Keenan et al., 1998). Among them, *S. serrata* has the widest distribution in the Indo-Pacific region (Keenan et al., 1998; Le Vay, 2001; Shelley & Lovatelli, 2011; Alberts-Hubatsch et al., 2016). Due to its high tolerance to salinity, *S. serrata* can adapt and survive in oceanic waters and mangrove areas where the water surface salinity is greater than 34 ppt (Keenan et al., 1998). While for another three species, their distribution is mainly centered in the South China Sea and the Bay of Bengal, where the water salinities are lesser than 33 ppt during the northern hemisphere summer (Keenan et al., 1998).

The *Scylla* mud crabs are economically important portunid species; especially in the small-scale coastal fisheries and aquaculture. According to Ikhwanuddin et al. (2013), aquaculture of the *Scylla* mud crab has a long history in the world, which is more than 100 years in China, and 30 years throughout the Asian countries. Nevertheless, mass aquaculture production of the *Scylla*

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mud crabs is still difficult, although all four species of the *Scylla* mud crabs, share very similar requirements for their aquaculture, and their full-cycle aquaculture has already been made possible (Shelley & Lovatelli, 2011).

Full cycle aquaculture of the *Scylla* mud crabs begins with the broodstock management, eggs incubation and hatching, larval rearing, nursery culture of the post-larvae, grow-out of the crablets to juvenile and adult, and crop harvesting (Shelley & Lovatelli, 2011). Recently, Azra & Ikhwanuddin (2016) has reviewed the maturation diets for the *Scylla* mud crabs broodstock, while the progress and advancement in larval rearing and nursery culture of the *Scylla* mud crabs have been reviewed by Waiho et al. (2018) and Syafaat et al. (2021), respectively. However, there is still no review done to provide a comprehensive overview of the progress and current advancement in the *Scylla* mud crabs' grow-out culture, especially the major constraints that are remaining to be solved in this culture phase. This effort is necessary to determine the knowledge gap, potential solutions, and future research topics to improve the rearing technique in this culture phase. Therefore, this overview highlights the major constraints that are facing in the *Scylla* mud crabs' grow-out culture, and the potential solutions to these constraints were discussed.

Grow-out Culture of the *Scylla* Mud Crabs

The life cycle of the *Scylla* mud crabs has been reported earlier by Quinitio & Parado-Estepa (2008). In brief, after hatching, larvae of the mud crabs will go through 5 zoea stages, followed by the megalopa stage. Then, it metamorphoses into the first crab instar and finally becomes the crablets that possess similar morphology to the juveniles. Grow-out culture of the *Scylla* mud crabs is referring to the culture period where the crablets are taken care of until it becomes juvenile or adult. Generally, crablets with a carapace width of at least 1.0 - 2.5 cm are suitable enough to be transferred from the larval rearing tanks to the grow-out systems (Shelley & Lovatelli, 2011; Ganesh et al., 2015).

Grow-out culture of the *Scylla* mud crabs is usually operated in earthen ponds, mangrove pens, canals, and so forth. Within about 1 - 2 months, the mud crabs can achieve a body weight of 60 - 100 g (Quinitio & Parado-Estepa, 2017). At this size, the mud crabs can either be harvested for stocking to produce the soft shell crabs, a fast turnover product, or continue cultured for another 4 - 5 months in the grow-out systems, until it becomes adult and reaches the marketable size at about 400 - 500 g (Marichamy & Rajapackiam, 2001; Ganesh et al., 2015; Quinitio & Parado-Estepa, 2017). The crop is typically harvested selectively. The healthy and intact mud crabs that qualify for their body size and weight will be firstly harvested, whereas those with damaged chelipeds, limb-loss, undersized, or newly-moulted will be released back to the pond for 'recuperate'.

Constraints in Grow-out Culture of the S*cylla* Mud Crab and the Mitigation Methods

Inadequate Seed Supply

Inadequate seed supply has always been the first problem for most mud crab farmers (Keenan, 1999; Lavilla-Pitogo et al., 2001; Rodriguez et al., 2001; Sathiadhas & Najmudeen, 2004; Mia & Alam, 2006; Ut et al., 2007; Rahman et al*.,* 2017). In the traditional grow-out farming of mud crabs, the farmers are relying heavily on the seeds that have been collected from the wild, and fattening them in the grow-out systems. However, such practice is not sustainable as it could degrade the natural habitat, and threaten the wild mud crabs population (Le Vay, 2001; Quinitio et al., 2002; Sathiadhas & Najmudeen, 2004; Shelley, 2008; Quinitio & Parado-Estepa, 2017). Indeed, Rahman et al. (2017) reported that the seed harvesters in the coastal area of Bangladesh were able to collect 4 - 5 kg of mud crabs daily in 2012. However, this amount has decreased to 2 - 3 kg in 2017; while the sizes of the collected mud crabs have dropped significantly from 250 - 350 g to 100 - 150 g. Also, Suman et al. (2018) have reported that the wild population of *S. serrata* in the Kendari Bay of Indonesia has attained a negative allometric growth pattern due to overfishing. To fulfill the expanding market demand for mud crabs as seafood, the hatchery-produced seed is critically needed to replace the wild-collected seed as the supply to the mud crabs' grow-out farming (Gunarto et al., 2016).

The *Scylla* mud crabs seed production techniques have been successfully established in the hatcheries in many countries, including Australia (Shelley, 2008), Philippines (Quinitio & Parado-Estepa, 2008, 2017), and Vietnam (Nghia et al., 2007; Ut et al., 2007). Nevertheless, the achievement of mass seed production relies on the high quality and survival of the hatchery-produced mud crabs larvae, which is still very challenging to achieve and maintain up-to-date (Waiho et al., 2018; Syafaat et al., 2021). The challenges to producing high quality and maintaining high larval survival in the *Scylla* mud crabs production have been reviewed and discussed by Waiho et al. (2018) and Syafaat et al. (2021); therefore, this overview does not further describe those challenges.

Cannibalism

Cannibalism refers to predation among the same species; while some animals used it as a tactic to establish their dominance in a population (Fox, 1975; Polis, 1981; Smith & Reay, 1991; Laranja et al., 2010). Agonistic behaviour usually occurs before cannibalism (Laranja et al., 2010). In crustaceans, agonistic behaviour can be triggered by both intrinsic (*e.g.*, sex, body and chelae size, reproductive state, and past social experience) and extrinsic (*e.g*., shelters, food availability, mating territory, and environmental communication) factors (Moore, 2007).

In the *Scylla* mud crab aquaculture, cannibalism has always been reported as a serious issue, especially during the nursery and the communal grow-out phases. The occurrence of cannibalism has significantly decreased crop survival and production (Triño et al. 1999a, b; Shelley, 2008; Waiho et al., 2015; Rahman et al., 2017; Islam et al., 2018). The high occurrence of cannibalism in mud crabs farming can be triggered mainly due to several reasons. One of the reasons is the mixed-sex culture (Cholik & Hanafi, 1992) and indeed, it was evident that practicing the monosex culture can yield a higher production than the mixed-sex culture (Triño & Rodriguez, 2001). Another reason is keeping variable size ranges of stocks in the culture system, while this issue can be solved by practicing size-grading (Mirera & Moksnes, 2013). Recently, Sanda et al. (2021) recommended that maintaining the size differences below the relative size difference [RSD=1 − (size of small crab) / (size of large crab)] threshold at 0.34 would be an effective strategy to contain the cannibalism occurrence in the culture of the *S. serrata* juveniles.

Over-crowded stocking density in the grow-out systems is also another main cause triggering cannibalism among the mud crabs (Baliao et al., 1981; Suprapto, 2001; Mia & Alam, 2006). It was suggested that shelter provision can ease the over-crowed stocking density problem by providing more hiding spaces and subsequently, reduce cannibalism occurrence and increase the mud crabs' survival (Triño et al., 1999a, b; Catacutan, 2002; Ye et al., 2011; Rahman et al., 2017). However, the survival of the cultured mud crabs can be varied when different materials or designs of shelters were provided. Table 1 shows the farming conditions and survival of the *Scylla* mud crabs juveniles cultured under different stocking densities, provided with various types of material as shelters. Although it is not possible to compare the shelters' efficiency in reducing the cannibalism occurrence across these studies, Chakraborty (2018) has reported that the plastic pipes are quite efficient as a shelter as the survival percentage of the mud crab juveniles did not drop drastically when the stocking density was increased. On the other hand, Triño et al. (1999a) and Venugopal et al. (2012) have reported that the seaweed, *Gracilariopsis bailinae*, and concrete pipes were not effective shelters for the mud crab juveniles for maintaining their survival in the higher stocking densities, respectively. Under the laboratory culture conditions with sand bottom, Mirera & Moknes (2013) reported that the bamboo tubes were more efficient than the plastic strings and the seaweed (*Eucheuma denticulatum*) to function as a shelter for the *S. serrata* juveniles, with a trend of less cannibalism occurrence in this treatment. However, Fatihah et al. (2017) found that the survival of the *S. tranquebarica* juveniles, provided with soft sand as the substrate, was significantly higher than those provided with the black agricultural mesh net or the polymer high-density polyethylene (mesh size 15 mm x 15 mm) made rod shape-shelter. Nevertheless, in these reports, how the *S. tranquebarica* reacts to the substrate and these shelters, and how these shelters contribute to reducing the cannibalism occurrence to enhance the mud crab's survival were not observed. Recently, Kawamura et al. (2020a, b) have reported that the *S. tranquebarica* juveniles can discriminate colour, and show their preference for blue over green, red, black, or white shelter. These findings indicated that the *Scylla* mud crabs may have a preference for different types of shelter. Therefore, future studies on the mud crabs' preference for shelters with different types of materials and designs, and how the mud crabs utilize these shelters are highly recommended.

Other than monosex culture, size grading, and shelter provision, Laranja et al. (2010) have demonstrated that aggression in the *S. serrata* juveniles can be suppressed through feeding by supplementing tryptophan into the diet. Dietary supplementation of tryptophan was effective to increase the brain serotonin, 5- hydroxytryptamine (5-HT) concentration in the mud crab hemolymph and suppressed its agonistic behaviour; the survival of the mud crabs was enhanced consequently.

Table 1. Grow-out farming conditions and production of the *Scylla* mud crabs juveniles from the previous studies

Size of the Mud Crabs	Rearing duration	Rearing systems	Stocking density/ Treatments	Shelter provision	Feeding	Survival (%)	Growth/ Production	References
BW: 7.3-11.0 g CW: 3.50-4.26 cm	120 days	150 m^2 earthen ponds	(a) 0.5 ind/m^2 (b) 1.5 ind/m^2 (c) 3.0 ind/m^2	Seaweed, *Gracilariopsis bailinae*	Fish bycatch + mussel flesh	(a) 98.22 (b) 56.72 (c) 30.56	Production (kg) (a) 29.69 (b) 48.54 (c) 50.45	Triño et al. (1999a)
BW: 45.80 g	135 days	0.121 ha earthen ponds with pens deployed	(a) 0.025 mil/ha (b) 0.035 mil/ha (c) 0.045 mil/ha	Plastic pipes	Trash fish	(a) 64.10 (b) 51.44 (c) 40.52	Production (kg / ha) (a) 4783.44 (b) 4324.72 (c) 3506.76	Chakraborty (2018)
BW: 40-60 g CW: 5.2-6.8 cm	4 months	810 m^2 earthen ponds	(a) 0.50 ind/m^2 (b) 0.75 ind/m^2 (c) 1.00 ind/m^2	Concrete pipes	Chopped low value marine fish	(a) 46.60 (b) 33.30 (c) 27.30	Production (kg / ha) (a) 663 (b) 592 (c) 489	Venugopal et al. (2012)

Disease Outbreaks

Disease outbreaks have been reported as one of the major constraints in mud crab farming as they can cause mass mortality to the animal (Tendencia & Cabilitasan, 2017). Mud crab is susceptible to many types of pathogens and diseases, including bacterial and viral infections, an infestation of parasitic organisms (*e.g.*, protozoan, metazoan), fungus, ciliate, and many others. For instance, fungal (*e.g.*, *Lagenidium* spp., *Haliphthoros* spp.) and ciliate (*e.g.*, *Zoothamnium* spp.) infestations are some of the common causative agents of mortality in the *Scylla* mud crab larvae and eggs (Hatai et al., 2000; Quinitio et al., 2001; Jithendran et al., 2010; Lee et al., 2016a, b, 2017a, b; Linh et al., 2017). Virus (*e.g.*, white spot syndrome virus) has always been reported in many Asian countries, found in both wild-caught and farmed mud crabs at different life stages (Norizan et al., 2019). Bacterial infection (*e.g.*, Vibriosis that is caused by the *Vibrio* spp.) also contributes to mass mortality of the mud crabs (Gunasekaran et al., 2019). Comprehensive information on the diseases that are commonly reported in the *Scylla* mud crabs at the grow-out phase has been reported by Lavilla-Pitogo & de la Peña (2004) with the respective prevention and management measures. On the other hand, many other reviews on the diseases of the *Scylla* mud crabs (regardless of their life stage) are also available (Jithendran et al., 2010; de Souza Valente & Wan, 2021; Coates & Rowley, 2022). Therefore, the present study skips the explanation on this topic.

Treating diseases with chemicals, especially antibiotics, is commonly used in aquaculture (Chelossi et al., 2003; Lulijwa et al., 2019; Thiang et al., 2021). However, antibiotic treatment was not recommended as it will cause pollution to the environment and contribute to the arising of antibiotic resistance pathogens (Poornima et al., 2012; Coates & Rowley, 2022), and it can be harmful to the mud crabs. Indeed, Pates Jr et al. (2017) have reported that the *S. serrata* juveniles attained morphological deformities when they were exposed to oxytetracycline and furazolidone during the zoeae stage, and suggested that the use of antibiotics should be eliminated. Recently, Saito & Tamrin (2019) has successfully utilized the extracts of seaweeds (*Caulerpa lentillifera* and *Eucheuma cottonii*) as an alternative to the antibiotic to treat the marine oomycetes, *Lagenidium* spp. and *Haliphthoros* spp. Yang et al. (2020) also demonstrated a novel antimicrobial peptide, scyreprocin, produced from the *S. paramamosain* as a promising alternative to antibiotics used in mud crab farming. Nevertheless, these research were all working for the treatments of the mud crabs' eggs and larvae; there is a very limited report on the treatments for the mud crabs' juvenile. In the near future, research to discover new alternatives to antibiotics for the treatment of the mud crabs juvenile is highly recommended to enhance the disease control in the *Scylla* mud crabs grow-out farming.

Commercial Formulated Feeds

To date, the natural products, such as the low-value fish, molluscs, crustaceans, animal viscera, or by-products are still the major items for feeding in the *Scylla* mud crabs farming (Quinitio et al., 2001; Triño et al., 2001; Catacutan, 2002; Catacutan et al., 2003; Tuan et al., 2006; Truong et al., 2008; Mirera & Mtile, 2009; Unnikrishnan & Paulraj, 2010; Ali et al., 2011; Shelley & Lovatelli, 2011; Rabia, 2015; Zhao et al., 2015). The use of these products for feeding is not sustainable as their availability and quality can vary greatly, and it requires adequate refrigeration to maintain their freshness. Besides, the quality of the rearing water can deteriorate rapidly when these items were left uneaten by the mud crabs in the culture facilities. This happening will eventually cause disease outbreaks and mortality to the mud crabs (Sheen & Wu, 1999; Ali et al., 2011). To solve this problem, formulated feed is recommended to replace the natural products for feeding in the *Scylla* mud crabs farming. In fact, through a bio-economy analysis on mud crabs farming (fattening) in Vietnam, Petersen et al. (2013) have reported that feeding formulated feed in mud crabs farming can significantly increase the animals' survival, and help the farmers to generate higher profit to cover the expensive cost of the formulated feed. However, there is still no formulated feed available commercially for the *Scylla* mud crabs up-to-date (Fielder & Allan, 2003; Pavasovic et al., 2004; Azra & Ikhwanuddin, 2016; Genodepa & Failaman, 2016; Zheng et al., 2020), despite much research that has already been conducted on its nutritional requirement for formulated feed development (*e.g.* Sheen & Wu, 1999; Catacutan et al., 2003; Truong, 2008; Unnikrishnan & Paulraj, 2010; Ali et al., 2011; Zhao et al., 2015; Dong et al., 2017; Kader et al., 2017; Zheng et al., 2020).

Commercial formulated diet plays a very important role in aquaculture as the diet is designed based on the nutritional requirements of the targeted species. Commercial formulated diets designed for single fish species are very common (*e.g.* for tilapia, catfish, groupers, and others). However, in crustaceans, research related to the nutritional requirements and commercial feed development is focusing on the whiteleg shrimp, *Litopenaeus vannamei, which* is also the most widely farmed crustacean species in the world, up-to-date (FAO, 2020). In a situation when formulated feed is recommended for feeding but there is no commercial formulated diet available for the *Scylla* mud crabs, Genodepa & Failaman (2016) have conducted a trial to determine the suitability of the commercially available fish or penaeid shrimp diets for feeding the mud crabs in the grow-out farm. It was reported that a significantly high mortality rate was observed in the fish diet treatment as the feed was poorly accepted by the mud crab. The mud crab survival in the shrimp feed treatment was not significantly different from that of the natural food (control) treatment in the first half of the culture period (11 days), but it significantly dropped at the end of the experiment (20 days). Although the shrimp feed is more suitable than the fish feed for feeding the mud crab, it is expensive (maybe not cost-effective) and the suitability of its ingredients nutrition for mud crabs is not confirmed. Apparently, to expand the *Scylla* mud crabs farming sustainably, it is inevitable to establish commercial practical diets that are specifically for mud crabs.

According to Catacutan et al. (2003) and Pavasovic et al. (2004), high amylase, cellulase, and xylanase activities were found in the soluble extracts from the midgut gland of mud crabs, indicating that mud crabs can digest plant-based nutrients, including fibre and ash. Indeed, the feeding experiments conducted by Tuan et al. (2006), Truong et al. (2008, 2009), and Nguyen et al. (2014) have evident that mud crabs can digest and utilize the crude protein from soybean meal. There is no doubt that fish meal is still considered an indispensable or essential protein source in aquafeeds due to its high nutritive value, excellent palatability, digestibility, and acceptability to all fishes (Kaushik et al., 2008; FAO, 2018). However, considering the increasing price of fish meal, plant-based protein sources, especially soybean meal that contains high protein levels, a well-balanced amino acid profile, stable market supply with reasonable cost (Davis & Arnold, 2000; Amaya et al., 2007a, b) can be a good alternative to fish meal in the diet developed for mud crabs.

Conclusion

Inadequate wild seed supply, cannibalism, disease outbreaks, and no commercial species-specific designated formulated feed are the 4 major constraints faced in the *Scylla* mud crabs grow-out culture. Although artificial seed production in the hatcheries can solve the wild seed supply issue, knowledge of the mud crab requirements at early life stages is needed to improve the rearing techniques and production. The cannibalism issue is still manageable, as long as the farmers are knowledgeable about the basic prevention methods (shelter provision, size grading, monosex culture) and they are practicing them. Meanwhile, continuous research to discover new alternatives to antibiotic and disease prevention methods should be prioritized to minimize disease outbreaks. Finally, the commercial formulated grow-out diet that is specific for the *Scylla* mud crabs should be developed to replace the use of natural products for feeding.

Ethical Statement

No ethical statement is required.

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Author Contribution

KSL: Conceived the study, and drafted the original manuscript. FKBY: Conceived the study, commented and edited the manuscript. LSL: Conceived the study, funding acquisition, supervised the work, commented and edited the manuscript.

Conflict of Interest

The authors declared that they have no conflict of interest.

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