A review of maturation diets for mud crab genus Scylla broodstock: Present research, problems and future perspective

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Abstract Study of broodstock maturation diets is important in order to increase the quality of berried females, which indirectly improve the larval quantity in the hatchery production of cultured species. This paper reviewed the studies on the maturation diets for mud crab broodstock, genus Scylla and compared independently to identify their effect on reproductive performance and larval quality. The broodstock is usually caught from the wild and held in the spawning or maturation tank for further use of hatchery seed production. Mud crab broodstock was fed either natural diet, artificial diet or mixed diet. Trash fishes were commonly used as a natural feed for mud crab broodstock; meanwhile artificial diets are from formulated fish meal and various kinds of feed. The results indicated that mud crab broodstock has a high dietary requirement for lipids, fatty acids and protein which are to be used during the maturation and breeding processes. However, the natural diet produce better larval quality compared to the artificial diet. The mixed diet is the better diet which resulted in better reproductive performances such as growth, survival, fecundity and maturation processes. This review also discusses the problems in the previous studies for the potential future research to develop very high quality and cost-effective formulated diet for the enhancement of...
broodstock and seed production technology. Information from this review can be useful in developing a better quality of crustacean broodstock's diet for commercial hatchery production. © 2015 The Authors. Production and hosting by Elsevier B.V. on behalf of King Saud University. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

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1. Introduction

The mud crab, genus Scylla is considered a new species in aquaculture with high expectation to continue to grow in the future. However, the hatchery technology of the mud crab's culture is in the developmental stage with a small number of breeding programs in a few countries. Due to rising market value of this product and its high demand, most crab farmers target the seed from the wild for stocking in the ponds (Noorbaiduri et al., 2014). The mud crab, especially the genus Scylla is commercially important because it is fished and cultured in various Asian countries such as Philippines, Indonesia, Vietnam, China, Taiwan, India, Sri Lanka and Malaysia. Currently, the mud crab aquaculture in Malaysia is associated with the mud crab fisheries and is likely to lead in changes to the enhancement of the ecological system, socioeconomic and livelihood. Although some information is fundamental to the development of mud crab's seed production such as rearing techniques (Rabbani and Zeng, 2005) and culture systems (Quintito et al., 2001), the status of broodstock nutrition should firstly be known before further breeding or restocking program. For mud crab hatchery culture, broodstock has never been an issue as generally female mud crabs spawn readily and has high hatching rates. However, the development of hatchery seed productions currently relies on the wild caught broodstock. In addition, the consistent production of Scylla seed has never been successful anywhere in the world due to limited berried females produced in captivity. Furthermore, the wild ovigerous mud crab female especially the genus Scylla is difficult to obtain due to its migratory spawning behavior, especially in Scylla serrata which spawns in offshore water (Hill, 1994). They are also exploited by local individuals for immediate consumption (Ikhwanuddin et al., 2011). In order to obtain reliable ovigerous females, an appropriate diet should be analyzed to improve their reproductive performance without copulatory molting (changes of new exoskeleton for sexual mating) or further mating. In addition, the broodstock management technology is a critically important procedure that should be further improved, and dietary nutrition is an important issue for successful hatchery production.

Nutrition plays a critical role in the development of the ovary in mud crabs. Scientific studies on mud crab, Scylla broodstock nutrition have been conducted in the last three decades by several authors (Marichamy et al., 1986; Samarasinghe et al., 1991; Marichamy, 1996; Fortes, 1999a;
2. Broodstock management

2.1. Sources of broodstock

Majority of broodstock comes from captive wild-caught, on-growing in earthen-ponds or domesticated improved broodstock (Shelley and Lovatelli, 2011). The mud crabs were usually collected from their natural habitat using trawl net, baited traps, hoop-and-bag traps, gill nets, hand-collected and hand-scoop or bought from the local fisherman. The broodstock’s size used for breeding is important because it will affect the feeding ratio in the diet under the study. Commonly, for breeding purpose, the broodstock’s eyestalk was ablated in order to increase their molting frequency and to accelerate the spawning and development of their gonads (Mann et al., 1999a). There are different procedures in the eyestalk ablation method such as constriction of eyestalk with catgut or removal using sterile surgical blades which reduced mortality to the minimum level (Allayie et al., 2011). There are two different management methods generally adopted between before and after spawning.

2.2. Before spawning

Usually, the broodstock may be dipped in antiseptic baths such as formalin and/or formaldehyde (Mann et al., 1999b; Millamena and Quinitio, 2000; Quinitio et al., 2011), potassium permanganate (Pattiasina et al., 2012), malachite green (Davis et al., 2004) or treflan (Shelley and Lovatelli, 2011) to eliminate microbial infection of the embryos and the eggs in broodstock.

The broodstocks were typically held in a maturation or spawning tank or pond for a period of a few months or more (1–3 months) and stocked with various stocking densities between 1 to 5 crab m⁻², depending on the broodstock size.

Once the broodstocks were in captivity, they were provided with gravel (Alava et al., 2007a) or pebble substrate (Millamena and Quinitio, 2000) and topped with around 12–15 cm thick sand (Hamasaki, 2003; Millamena and Quinitio, 2000) for broodstocks to bury and extrude their eggs successfully. They were also supplied with sand-filtered seawater (Millamena and Quinitio, 2000) with good water quality (Ali et al., 2011) and adequate aeration (Quinitio et al., 2001; Millamena and Quinitio, 2000) to avoid stress to the brood and eggs. To prevent the attack by the other broodstock, each spawning tank was supplied with a wooden shelter (Alava et al., 2007a), half-cut vinyl chloride pipes (Hamasaki, 2003) or black nylon (Millamena and Quinitio, 2000). After an extensive care, they were fed with different types of diets including natural diet, artificial diet or mixed diet until they spawned.

2.3. After spawning

After the broodstocks spawned, they are reared in individual spawning tanks with sand-filtered seawater and flow through water system. During the incubation period, the broodstocks were not fed and one day before hatching, they were transferred in hatching tank with still water and gentle aeration (Hamasaki, 2003). After the broodstocks hatched, they were returned to experimental tanks and observed for re-maturation (Millamena and Quinitio, 2000). Usually, the broodstocks take a few weeks and they do not have to further mate for re-maturation.

3. Types of maturation diet

During the last 10 years, many attentions have been focused on the broodstock nutrition as well as the role and effect of various components of broodstock diet, such as lipid, cholesteryl, protein especially on their maturation status (Anderson et al., 2004). Broodstock nutrition is without doubt one of the most outstanding reasons that affects the reproductive performance of most crustacean (Chung et al., 2011; Alava et al., 2007a). Broodstock nutrition affected directly the maturation of the ovary where the restriction of food can seriously inhibit the ovarian maturation in several Scylla species (Alava et al., 2007a; Djunaidah et al., 2003). In this review, three main diets were considered: natural diet (fresh feed), formulated feed (artificial diet), and mixed feed (combination of natural and artificial diet).

3.1. Natural feed

Generally, mud crabs were fed with the traditional food, which is natural feeds (or fresh feed) such as mussel meat, Perna sp., squid, Loligo sp., trash fish, Leiognathus sp. or Oreochromis sp., small bivalves, Potamocorbula sp., shrimp, Fenneropenaeus sp. because these food can potentially reduce operational costs and can be recycled for daily use. However, frequent uses of the natural feed can also decline water quality in the cultural environment which indirectly influences the broodstock growth and maturation. The study by Millamena and Quinitio (2000) found that lack of essential dietary fatty acids in natural diets can reduce the reproductive performance of broodstock compared to the formulated diets or mixed diets.
3.2. Artificial feed alone (formulated feed)

The formulated feed data of mud crab broodstock are important for the development of nutritionally balanced and cost-effective commercial feeds. Millamena and Bangcaya (2001) suggested that future artificial diets are needed as a supplement to natural diet in order to promote more broodstock spawning with good quality eggs and larval production. Before the use of artificial diet alone, the broodstock was usually fed with natural diet for a few days and weaned till the end of the experiment. To develop suitable artificial feed for the mud crab broodstock, few studies refer to the modification of prawn broodstock diet (Millamena and Quinitio, 2000; Djunaidah et al., 2003). Majority of the artificial diets are from the fish, shrimp or squid meal with the addition of other ingredients such as fish or squid oil, wheat and binder (Djunaidah et al., 2003; Alava et al., 2007b).

3.3. Mixed feed (combination of natural and artificial feed)

The mixed diets are the combination of various natural diets and artificial feed for better effect of the reproduction and larval quality of cultured species. The study of mixed diet on the reproductive performance and larval quality of mud crab has been done by various authors (Millamena and Quinitio, 2000; Millamena and Bangcaya, 2001; Djunaidah et al., 2003; Rodriguez et al., 2003; Alava et al., 2007b). The proximate composition of crude protein, crude fat, crude fiber, ash and nitrogen free extract was calculated as percentage on a dry matter basis with mean percentage of natural diet and addition of formulated diet or artificial diet for each group.

4. Reproductive performance and larval quality

4.1. Natural feed

Table 1 shows the reproductive performance and larval quality of mud crab broodstock, genus Scylla fed with various natural diets. In general, the natural feed affected broodstock performances and larval quality of mud crab, genus Scylla. It’s suggested that the natural diets can improve the broodstock’s fecundity which indirectly increases the number of eggs produced from a single broodstock.

4.1.1. Broodstock growth and survival

The study by Millamena and Quinitio (2000) showed that S. serrata broodstock fed with mussel meat, squid and trash fish produced better broodstock survival compared to the mixed diet or formulated diet. The broodstock growth also decreased when they fed with the natural diet as well as the total days taken from crab spawning to hatching (Alava et al., 2007b; Ali et al., 2011). Study by Millamena and Bangcaya (2001) indicated that broodstock fed with the natural fed showed lower survival compared to other diets.

4.1.2. Broodstock spawned, time to matured and re-spawned

Studies on the effects of natural diet on mud crab broodstock also suggested that fresh natural food can be fed to the broodstock to accelerate the broodstock to mature, re-spawn and mating success (Alava et al., 2007b; Misieng, 2007; Ali et al., 2011; Pattiasina et al., 2012). The study by Millamena and Quinitio (2000) showed that S. serrata broodstock fed with mussel meat, squid and trash fish produced more spawns compared to the other diets (mixed diet or formulated diet).

4.1.3. Fecundity, egg production and fertilization

Both studies by Millamena and Bangcaya (2001) and Djunaidah et al. (2003) found that natural diet can enhance the fecundity of the broodstock. On the other hand, the studies by Millamena and Quinitio (2000) and Millamena and Bangcaya (2001) resulted in the decrease of egg production and egg fertilization. The summary from the Table 1 of broodstock reproductive performance fed with natural food illustrates that fecundity, egg fertilization, hatching rate and survival of mud crab broodstock were affected by various kinds of natural diet (Millamena and Quinitio, 2000; Millamena and Bangcaya, 2001; Djunaidah et al., 2003).

4.1.4. Larval quality

The natural feeds resulted in higher total zoea production according to Djunaidah et al. (2003) and Alava et al. (2007b). Djunaidah et al. (2003) also demonstrated that a combination of natural diet (shrimp, squid, trash fish and Artemia sp.) resulted in a higher survival and the strongest larval production as determined by the starvation test with up to 120 h starvation compared to the artificial food which is as low as 60 h. In addition, Pattiasina et al. (2012) proved that broodstock fed with natural foods (fish and small bivalve) resulted in good larval quality with higher zoea survival compared to the artificial diet alone. On the other hand, both studies by Millamena and Quinitio (2000) and Millamena and Bangcaya (2001) showed that the natural foods could decrease the growth of larvae mud crab which was measured by the larval stage index (LSI).

4.2. Artificial feed alone

Table 2 shows different types of artificial diet which affect the reproductive performance and larval quality of mud crab broodstock. The use of artificial feed is suggested to increase the water quality and increase the reproductive performance of the mud crab broodstock (Ali et al., 2011; Pattiasina et al., 2012). In terms of the commercial hatchery production, the use of fish meal in the artificial diet could increase the total production cost which indirectly increases the price of the species cultured. However, a new approach has been done to overcome the usage of fish meal (see Section 6).

4.2.1. Reproductive performance

Most of the formulated feeds consist of various protein types (Millamena and Quinitio, 2000; Millamena and Bangcaya, 2001), lipid classes (Djunaidah et al., 2003; Alava et al., 2007b) and essentials amino acids (Djunaidah et al., 2003; Ali et al., 2011) which are important to the ovarian maturation in mud crab broodstock. Artificial feed with higher protein percentage resulted in a better egg fertilization rate (Millamena and Quinitio, 2000; Millamena and Bangcaya, 2001) while on the other hand, broodstock fed with higher lipid had shown a shorter latency period and incubation time (Djunaidah et al., 2003). The preparations of the formulated
| Species (country) | Eyestalk ablated – Study duration | Body weight – BW (g) | Types of mixture of natural feed | Summary | Broodstock reproductive performance | Offspring quality performances | References |
|------------------|-----------------------------------|----------------------|----------------------------------|---------|-------------------------------------|-------------------------------|------------|
| *Scylla serrata* (Philippines) | Yes – 3 months | 300–400 | Mussel meat, squid and trash fish | Fecundity, egg produced, egg fertilization rate and crab hatched | Crab spawned and broodstock survival | Lower total number of zoea and larval stage index | Millamena and Quintio (2000) |
| *Scylla serrata* (Philippines) | Yes – 90 days | 350–400 | Brown mussel meat and fish by-catch | Egg fertilization rate and broodstock survival | Fecundity | Lower total zoea production and zoea growth index | Millamena and Bangcaya (2001) |
| *Scylla paramamosain* (Indonesia) | Yes – 2 months | 200–300 | Shrimp, squid, trash fish and *Artemia* sp. | Hatching rate, egg fertilization rate and egg hatching rate | Fecundity | Higher zoea production, phototaxis larvae and survival (> 120 h starvation test) | Djunaidah et al. (2003) |
| *Scylla serrata* (Philippines) | Yes – 112 days | 625 ± 6.4 | Fish and small bivalves | Longest incubation period* | Re-spawning (2 times) and shorter total days from ablation to spawned | Better zoea production | Alava et al. (2007b) |
| *Scylla olivacea* (Malaysia) | Yes – 84 days | n/a | Trash fish, cuttlefish and shelled prawn | n/a | Mating success and shortest period of ovarian development | n/a | Misieng (2007) |
| *Scylla serrata* (India) | No – 30 days | 151 ± 5.3 | Fresh fish meat | Weight gain (growth) and survival | Maturity stages | n/a | Ali et al. (2011) |
| *Scylla serrata* (Indonesia) | No – 34 days | 500 ± 103 | Fresh fish meat, squid and shrimp | Fecundity | Fast maturation | Higher zoea survival | Pattiasina et al. (2012) |

* Incubation time means the duration (day(s)) taken by broodstock from spawning to hatching.
feeds are usually from moist or dry feed forms. The study by Ali et al. (2011) indicated that crabs fed with dry form showed better performance compared to the semi-moist feed. They also found that the use of artificial diet resulted in a faster weight gain, the lowest feed gain ratio and a higher molting frequency compared to the broodstock fed with fresh natural diet. However, the formulated feed with a higher percentage of fish meal produced the worst result of total number of crab spawned, and fecundity (Millamena and Quinitio, 2000; Millamena and Bangcaya, 2001). In addition, the results from the studies by Alava et al. (2007b) and Pattiasina et al. (2012) found that artificial diets affected the maturation and survival of the mud crab broodstock with the longest duration to mature and the lowest broodstock survival till the end of the experiment.

### 4.2.2. Larval quality

The study revealed that broodstock fed with a higher protein and lipid content of artificial feed caused the lowest larval quality (zoea production and starvation test) compared to the broodstock fed with natural feed (Millamena and Quinitio, 2000; Millamena and Bangcaya, 2001; Djunaidah et al., 2003; Alava et al., 2007b). The study on artificial diet showed that performance of broodstock can be increased by various artificial diets, but not the offspring quality of the mud crab. Thus, further analysis should be done to the mixed diet (combination of natural diet and artificial diet) in order to increase the larval quality of the mud crab.

### 4.3. Mixed feed

Table 3 shows the reproductive performance and larval quality of mud crab broodstock fed with different mixed diets. The use of higher protein is obligatory in the formulation of the formulated diet. The higher protein level could enhance the reproduction of mud crab broodstock. In addition, the previous study showed that the protein has higher levels (>43%) in the diet composition of formulated feed compared to other diet composition (Fig. 1). In addition, a previous review on the mud crab, <i>S. serrata</i> showed that crabs grew well on diets containing 32–40% protein and 6–12% lipid, at dietary energies from 14.7 to 17.6 MJ/kg (Anderson et al., 2004). On the other hand, this review also discovered that the mixed diet results in a better larval quality especially in the number of zoea production (the number of larvae produced).

#### 4.3.1. Reproductive performance

The results from most studies showed that the mixed diet offered better reproductive performance of mud crab compared to other diets such as natural diet and artificial diet alone (Millamena and Quinitio, 2000; Millamena and Bangcaya, 2001; Djunaidah et al., 2003; Rodriguez et al., 2003; Alava et al., 2007b). The results from both studies by Millamena and Quinitio (2000) and Millamena and Bangcaya (2001) demonstrated that mixed diet achieved better number of crab spawned, crab hatched (the successful number of broodstock hatched) and the number of eggs produced. The studies by Millamena and Quinitio (2000), Millamena and Bangcaya (2001), Rodriguez et al. (2003) and Alava et al. (2007b) also found that mixed diet affects the survival of mud crab broodstock. The results from the reproductive performance also indicated that broodstock fed with mixed diet resulted in the highest egg fertilization rate compared to the broodstock fed with natural diet (Millamena and Quinitio, 2000; Millamena and Bangcaya, 2001; Djunaidah et al., 2003). The result from Rodriguez et al. (2003) found that the combination of natural diet, brown mussels and artificial feed, cooked cracked corn showed an increase of final body weight and specific growth rate compared to natural diet alone. The mixed diet also shortened the latency period and duration from spawning to hatching of the mud crab broodstock (Djunaidah et al., 2003; Alava et al., 2007b). The result of mixed diet only affected the period from ablation to spawning of the mud crab broodstock (Alava et al., 2007b).

#### 4.3.2. Larval quality

The results of the previous study revealed that the mixed diet resulted in the highest zoea production of mud crab (Millamena and Quinitio, 2000; Millamena and Bangcaya, 2001; Djunaidah et al., 2003; Rodriguez et al., 2003; Alava et al., 2007b). All results from the study showed that the crab fed with mixed diet resulted in highest total zoea production except from the study by Rodriguez et al. (2003) because no data were available for larval quality performance. The LSI value also increased when the broodstock fed with the combination of natural and formulated diet (Millamena and Quinitio, 2000; Millamena and Bangcaya, 2001).

### 5. Problems associated with mud crab broodstock

Poor nutrition on the broodstock also resulted in reduced fecundity, fertilization and larval starvation of Portunud crab (Oniam et al., 2012; Djunaidah et al., 2003). During embryonic development, the normal development is influenced by the availability of essential nutrients which are supplied via the broodstock diets (Izquierdo et al., 2001). These nutrients such as amino acids, vitamins and essential fatty acids are important during embryonic development which in turn affect the egg morphology, hatching rates as well as vitellogenin synthesis (Izquierdo et al., 2001). Moreover, the reliance of the embryo and newly hatched larvae on the egg yolk nutrition is essential in understanding the nutrient requirements of broodstock (Alava et al., 2007b). Other problems associated with the <i>Scylla</i> broodstock were also been done by the Lavilla-Pitogo et al. (2001) and they stated that shell disease, bacterial contamination of the hemolymph, parasitic infestation are the main factors to develop better broodstock for hatchery seed production. In addition, the preliminary study also showed that the fungus infections were also the main problem in the maintenance of the broodstock in the hatchery culture of the mud crab, genus <i>Scylla</i> (Ikhwanuddin, unpublished data). The lack of information on the changes in the ovary during reproductive cycle is one of the important factors that limits the expansion and development of the mud crab seed hatchery technology.

### 6. Future research development

Improvements in mud crab broodstock maturation diets should involve the development of alternative natural feed
| Species (country) | Feeding ratio (% of body weight) | Types of artificial feed | Conclusion | Offspring quality performances | References |
|------------------|----------------------------------|-------------------------|------------|-------------------------------|------------|
| Scylla serrata (Philippines) | 2–3 | Modified from prawn broodstock diet (Majority: fish meal, shrimp meal, squid meal and wheat) | Total number of spawning, fecundity and survival rate | Egg fertilization rate | Lower total number of zoea | Millamena and Quinitio (2000) |
| Scylla serrata (Philippines) | 2–3 | Based on FA and AA* profile of matured crab ovaries (Majority: fish meal, shrimp meal, squid meal and wheat) | Total number of spawning with and without hatching, fecundity, broodstock survival rate | Egg fertilization rate | Lowest total number of zoea | Millamena and Bangcaya (2001) |
| Scylla paramamosain (Indonesia) | 3–5 | Majority: squid meal, minced meat mussel and calf liver | Fecundity | Latency period** and incubation time *** | Lowest zoea production and phototaxis larvae | Djunaidah et al. (2003) |
| Scylla serrata (Philippines) | 1–2 | Based on different percentages of lipid – squid oil and soybean lecithin (Majority: fish and squid meal and bread flour) | Survival rate and re-spawn. | Lowest days from spawned to hatched | Lowest zoea production | Alava et al. (2007b) |
| Scylla serrata (India) | 10 | Majority: fish meal, soya cake, wheat flour and squilla | n/a | Weight gain, feed gain ratio and molting frequency | n/a | Ali et al. (2011) |
| Scylla serrata (Indonesia) | 10 | Based on protein and fat (Majority: –) | Days to matured and egg diameter | Not effected | Not effected | Pattiasina et al. (2012) |

* %, percentage; FA, fatty acids; AA, amino acids.
** Latency period means the duration (day(s)) of broodstock taken from eyestalk ablation to spawning.
*** Incubation time means the duration (day(s)) taken by broodstock from spawning to hatching.
Table 3  Reproductive performance and larval quality of mud crab broodstock, genus *Scylla* fed with different mixed diets.

| Species (country)  | Mixed diet and proximate composition | Mean percentage of dry matter basis (%) | Conclusion | References |
|-------------------|--------------------------------------|----------------------------------------|------------|------------|
|                   | Types of mixed diet                  | Protein  Fat  Fiber  Ash  N*-free extract | Broodstock reproductive performance | Offspring quality performances |
|                   |                                      | Lower     Higher/Better                 |            |            |
| *Scylla serrata*  (Philippines) | Squid, fish, mussel with formulated diet | 58 10 3 14 16 | None | Crab spawned, crab hatched, fecundity, egg fertilization rate and broodstock survival | Highest total zoea produced and highest mean larval stage index |
|                   | Mussel meat, fish with formulated feed | 45 12 5 15 23 | None | Crab spawned, crab hatched, fecundity and broodstock survival | Highest zoea produced and growth index |
| *Scylla paramamosain*  (Indonesia) | Brine shrimp with formulated feed | 43 16 9 19 13 | None | Shortest latency period, ** egg fertilization rate and egg hatching rate | Highest zoea production |
| *Scylla olivacea*  (Filipina) | Brown mussel flesh and cooked cracked corn | 48 7 8 7 30 | None | Final body weight, weight gain, specific growth rate and broodstock survival | n/a |
| *Scylla serrata*  (Philippines) | Squid, fish, mussel with artificial diet | 58 18 3 12 16 | Longest days from ablation to spawning | Shortest days from spawning to hatching and broodstock survival | Highest zoea produced |

* N, nitrogen.

** Latency period means the duration (day(s)) taken from eyestalk ablation to spawning.

References:
- Millamena and Quinitio (2000)
- Millamena and Bangcaya (2001)
- Djunaidah et al. (2003)
- Rodriguez et al. (2003)
- Alava et al. (2007b)
and identify the important sources for gonad maturation which was one of the bottlenecks to the mud crabs’ industry expansion. The hatchery production of mud crab is mainly focused on the better quality of seed production. Dietary lipid plays an important role as potential supplier of energy and essential fatty acids and fat soluble vitamins for the ovarian maturation. Thus, special diets are needed for future development of mud crab broodstock with more focus on various dietary compositions which will increase the quantity of berried females as well as the seed quality of mud crab production. Natural diet was also recommended in order to enhance the quality of the berried females such as polychaetes which were identified to have some steroid hormones for crustacean reproductive performance (Meunpol et al., 2007) which indirectly can reduce the production cost of formulated diet. Recently, the development of alternative sources of fish meal protein with gamma-irradiated soybean meal (Zhang et al., 2014) will also be suggested to replace more fish meal in the diet of mud crab broodstock. In addition, other than manipulation of diet requirement, other techniques such as using probiotic and antibiotic (Wu et al., 2014), alternative design of culture systems such as Re-circulating Marine Aquaculture Systems – RMAS (Ikhwanuddin, unpublished data) and genetic selection of broodstock (He et al., 2014) could increase the reproductive performance and larval quality of mud crab. Our future research will be focused on the development of high quality and cost-effective formulated diet such as development of alternative protein using single cell organism, enzymatic study, formulation of micro-bound diet with inclusion of natural ingredients and development of appropriate food type and feeding schedule to develop high quality of berried females either for restocking or breeding program.

7. Conclusion

The sufficient amount of diets such as protein (Millamena and Quinitio, 2000; How-Cheong et al., 1991), lipids (Alava et al., 2007b), cholesterol (Pattiasina et al., 2010), omega 3 and 6 (Millamena and Quinitio, 2000; Djunaidah et al., 2003), carbohydrates (Pavasovic, 2004), vitamins and minerals (Trino et al., 2001) and other amino acids (Millamena and Bangcaya, 2001; Ali et al., 2011) should be provided in the broodstock diet to permit successful development of the mud crabs’ ovaries and quality of eggs produced. The higher level of protein in the formulated diet of mud crab broodstock showed that protein must be included in the diet formulation for better reproductive performance. For lipid, it has been found that an artificial diet with a total lipid content of 10% composition (6–12%) can lead to improvement of larval production and quality (Shelley and Lovatelli, 2011). However, in-depth study should be done to identify the appropriate percentage of nutrition to enhance the broodstock maturation as well as larval performance. In conclusion, the combination of natural food and artificial feed can achieve more consistency in broodstock reproductive performance and enhance the quality of seed production in the hatchery (Table 3). Further study on the mud crab broodstock maturation diet should analyze the biochemical composition and enzyme profile of the diet in the wild first before using it the future hatchery seed production.

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