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A Review of Broodstock Improvement to Brachyuran Crab: Reproductive Performance

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Abstract An improvement in adult brachyuran crabs performance is vital in order to produce better captive broodstock of commercially seed productions. Many factors can control the broodstock performance in brachyuran crabs but of particular importance in aquaculture will be the enhancement of female broodstock that indirectly improve the reproductive performance because of high quality berried females can be used to increase hatchery seed production. This review gives a recent overview on methods to enhance the female's broodstock performance and many of the most important factors affecting female's reproduction, including environmental conditions, nutritional requirements, genetic management, physiological effects and etc. and advise on the future research directions. Eyestalk ablation was the basic procedure to enhance the reproductive performance in most brachyuran crabs. Environmental factors such as temperature, salinity and oxygen affect most brachyuran crab's reproduction such as carapace width, ovarian development and spawning success. For maximal berried female production of brachyuran crabs, a fine balance must be maintained between two distinct nutrient classes (macronutrient and micronutrient) and fresh feed items. The identification of functional gene such as molt-inhibiting hormone, extracellular signal-regulated kinase 2, cyclin B or vasa gene in controlling of gonadal development is a preliminary attempt to boost the broodstock performance of brachyuran crabs. On the other hand, most chemical used in the acceleration of ovarian maturation are from hormone supplementation or direct injection such as thyroxine hormone, androgenic hormone, steroid hormone and serotonin hormones and was used to exert their effects on target tissue in crabs.

Keywords Reproduction; Brachyuran crab; Broodstock; Breeding technology; Seed production; Reproductive performance.

1 Background

The true crabs, the Brachyura (Linnaeus 1758) is one of the most diverse animal groups consists of two major group, Podotremata or primitive crabs and Eubrachyura or advanced crabs. They are includes various delicates, commercially and/or important aquaculture crabs such as the blue crab, *Callinectessapidus*, Dungeness crab, *Metacarcinus magister*, mud crab, *Scylla serrata*, blueswimmer crab, *Portunuspelagicus*, Chinese mitten crab, *Eriocheirsinensis* and fiddler crab, *Ucaterpsichores*. The recent Fishery and Aquaculture Statistic's report showed that the total marine crab landings increased (FAO, 2014) with development of fishing industry. Thus, to avoid overfishing of commercially brachyuran crabs in the wild, development of crabs' culture in the hatchery should be considered. Producing high quality of female crab broodstock is essential to successful hatchery production. It is also being considered as a first step in hatchery of cultured species. By obtaining broodstock from the wild, it is vulnerable for the improvements of better broodstock into the hatchery. Recent review has pointed to improve reproductive performance and larval quality of captive brachyuran broodstock, as a future alternative for more independent and reliable seed production (Azra and Ikhwanuddin, 2015; Azra and Ikhwanuddin, 2016). However, in the hatchery seed production, the status of the broodstock used and others important criteria such as mating behavior (Waiho et al., 2015; Baiduri et al., 2014; Ikhwanuddin et al., 2014a), size at maturity and fecundity (Ikhwanuddin et al., 2012; Ikhwanuddin et al., 2010), artificial production (Noorbaiduri and Ikhwanuddin, 2015), gonad development (Ikhwanuddin et al., 2014b) as well as natural diet (Ikhwanuddin et al., 2014c) should be firstly known before further culture practices can be taken. Such information on improvement of broodstock performance as well as thevetellogenin production is crucial to produce better seed with a mass production.

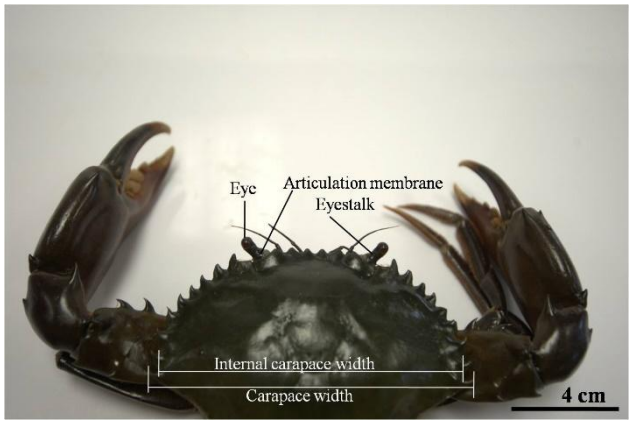

Figure 1 An example of brachyuran crab (genus Scylla) eye, eyestalk, articulation membrane, carapace width and internal carapace width measurement

A suitable method for induction and enhancement of ovarian maturation or reproduction is needed to reduce the wild caught broodstock in the natural habitat.

Several methods or techniques on the induction of brachyuran crab's reproduction were focused on the induction of gonad or hepatopancreas because of this is a crucial organ in the production of embryonic or egg development and it's has proven to be the most important organ synthesizing vetellogenin outside of the ovary (Subramoniam,2011) under controlled conditions. It is well known that the eyestalk ablation is an easier method to improve and accelerated the reproduction in crustacean as well as brachyuran crabs' species (Khazraeenia and Khazraiinia, 2009). As demonstrated for others crustacean species (reviewed by Green et al., 2014), environmental conditions play a key role in the changes of the brachyuran crab's reproduction and development (Rotllant et al., 2015; Brylawski and Miller, 2006). Studies on food and feeding behavior of brachyuran crabs indicated that nutritional content of food and feeding activities could affecting the reproductive performance of most brachyuran crabs (Sui et al., 2009; Woll and Berge, 2007). It is important to identify the genes that are differently expressed in crab's reproductive performance for better novel methods of reproduction control in selected culture species (Zou et al., 2011). Meanwhile, most recent studies of improvement on brachyuran crab's broodstock were intrigued on their physiological effects of chemicals reaction (Khornchatri et al., 2015; Medesani et al., 2015; Gong et al., 2015) because of their significant effects oncrab's reproduction. On the other hand, few attempts have been made on the culture practices of brachyuran crabs' broodstock as well as by new reproductive strategy (Paterson et al., 2007). In order to improve the efficiency of the crab culture industry as well as other crustacean, appropriate method and techniques on enhancement of the broodstock's performance should be reported in particular for easy application to the culture practices. To our knowledge, the details of this work have not been compiled, organize, and analyzed for brachyuran crab's species.

Thus, this article reviewed recent developments(within 21st century of English full text information) of discussion and/or methods for broodstock improvements at selected species in brachyuran crabs through application and manipulation in environmental conditions, nutritional requirements, genetic selection, physiological effects and others such as culture practices or new reproductive strategy. In addition, the key indicators of reproductive performance will also been discussed in order to give an overview to the future broodstock management. Furthermore, the suitability of such methods was evaluated as tools to improve the female's broodstock for future sustainable of hatchery seed production as well as for mass crab culture.

2 Broodstock Eyestalk Ablation

In the past few years, the broodstock which used either in the research or hatchery culture basically were wild-caught broodstock. Usually, hatchery reared broodstockare sources from the wild is at early ovarian maturation stage or with fully develop ovaries and an improvement in their performance should be a top priority

Table 1Various effects of eyestalk ablation on brachyuran crabs

Common English name (Species)	Technique(s) and procedure of ESA	Benefit of procedure	Results	Reference
Swimming brachyuran crab (*Charybdis lucifera*)	• Unilateral • Cut the right eyestalk with scissors and wound was cauterized with hot blunt needle	Prevent loss of haemolymph and mortality	• Significant effects on biochemical composition except body ash • Effectively influence saturated and unsaturated fatty acids	Murugesan et al. 2008
Chinese mitten crab (*Eriocheirsinensis*)	• Unilateral & bilateral – cut the left (unilateral) or both eyestalk (s) and applied burn to the wound	Minimize haemolymph loss and help coagulation	• Not significantly affected digestive enzyme activity of female's hepatopancreas • Significantly on serum of lipid	Wu et al. 2013
Freshwater crab (*Potamonpersicum*)	• Bilateral – anesthetized (cooling in ice) and excised the eyestalk with scissors and wound was cauterized with hot needle	n/a	• Significantly effects level of glucose and total hemocytes count • Accelerated ovarian development and times of molting in females	Khazraeenia and Khazraiinia, 2009
Freshwater crab (*Sartorianaspinigea*)	• Unilateral & bilateral – cut the right (unilateral) or both eyestalk (s) with sterile hot scissor and wound was cauterized with hot blunt needle	Prevent loss of haemolymph and mortality with 2h for next eyestalk	• Mortality occurred after few days of bilateral • Significant increase of female gonads by unilateral procedure	Prasad and Besra, 2012
Freshwater field crab (*Oziotelphusasenex senex*)	• Unilateral – cut the right eyestalk at its far end and wound was cauterized with hot blunt needle	Prevent loss of haemolymphand mortality	• Affected ovarian growth within 25 days • Significantly reduced content of various lipids	Samyappan et al. 2015
Chinese mitten crab (*Eriocheirsinensis*)	• Bilateral – clipped the eyestalk using sterile scissors and wound was cauterized	Minimize haemolymph loss and avoid infection	• Strongly induced sex-lethal gene expression in female ovary at day 7 after ESA	Shen et al. 2014
Shore crab (*Metopograpsusmessor*)	• Bilateral – excised the base of eyestalk with scissors	n/a	• Effects crab hyperphagia (unsatisfied drive to consume food) at post-ablation • Simultaneous enhance the ovarian growth significantly	Sudha and Anilkumar, 2007
Blue swimmer crab (*Portunuspelagicus*)	• Unilateral – cut the base of eyestalk (left) at its far end and wound was cauterized with hot blunt needle	Prevent haemolymph loss and mortality	• Decrease the percentage of glucose level	Velmurugan et al. 2008

Note: ESA; Eyestalk ablation, n/a; not available

for further used in seed production. The role of eyestalk ablation has been frequently adopted procedure for induced maturation of gonads and spawning of the crabs (Allayie et al., 2011). The eyestalk ablation (ESA) was a removal procedure of the sources of gonad and/or molt inhibiting hormones (GIH and MIH) secreted by the X-organ/ sinus gland complex located in the base of eyestalk or known as a articulation membrane (Figure 1) through bi (both/full) or unilateral (left or right/partial) methods.

Table 2: Examples of calculation formula of some reproductive indicators on selected brachyuran crab species

	Reproductive performance parameter	Calculation formula	Reference
Freshwater crab (*Potamonpersicum*)	Body mass index	Total weight of crab(including eggs) / carapace width	Akpaniteaku, 2015
	Weight of egg mass	(weight of sample ×number of eggs in the ovary) / number of sample	
	Egg mass index (%)	(Weight of egg mass / weight of crab) ×100	
Mud crab (*Scylla serrata*)	Relative fecundity	Number of eggs extruded / female / batch	Davis et al. 2004
	Total egg mass	Mass of crab at extrusion – mass of crab after hatch	
	Hatching success (%)	(Number of larvae hatched / number of eggs extruded) ×100	
Gazami crab (*Portunustrituberculatus*)	Berried female successfully hatched (%)	(Number of females successfully hatched / total number of surviving berried females) ×100	Wu et al. 2010
	Female spawned rate (%)	(Number of berried females / total number of surviving females or berried + un-berried females) ×100	
Patagonian stone crab (*Platyxanthisdaepatagonicus*)	Gonadosomatic indices	Wet weight of the ovary / whole crab wet weight	Dima et al. 2009
	Hepatosomatic indices	Wet weight of the digestive gland / whole crab wet weight	
Chinese mitten crab (*Eriocheirsinensis*)	Weight gain (crab size – body weight) (%)	((Final weight – initial weight) / initial weight) ×100	Chen et al. 2014
(*E. sinensis*)	Reproductive effort	(Percentage of egg weight / body weight) ×100	Wu et al. 2009
Blue swimmer crab (*Portunuspelagicus*)	Fecundity	Total number of the newly hatched larvae (zoea) + total number of un-hatched eggs	Oniam et al. 2012
Blue swimmer crab (*P. pelagicus*)	Fertilization rate (%)	((Fertilized eggs) / (fertilized eggs + un-fertilized eggs)) ×100	Efrizal et al. 2006

Previous studies showed that this procedure could affects physiological and biochemical metabolism of brachyuran crabs species (Table 1). Multiplication in shellfish is controlled by different neurohormones that are integrated and discharged from the X-organ sinus organ complex situated in the eyestalk of the species (Pervaiz et al., 2011). Meanwhile, the eyestalks of crustacean contain neurosecretory cells that involve in the regulation of molting (Meade and Watts, 2001). In most cases of crustacean especially brachyuran crab, the eyestalk ablation technique showed significant effects on amount of vetellogenin and haemolymphecdysteroids (molting) level (Sudha and Anilkumar, 2007; Tamone et al., 2005). However, this technique is not an appropriate method for enhancing the growth and maturation in certain crustacean's culture due to a failure in recovery of molting and mortality (Venkitraman et al., 2010; Prasad and Besra, 2012). In addition, this technique is traumatic procedure that is performed as part of crustacean aquaculture (Diarte-Plata et al., 2012). Thus, there is a need to induce the gonad development through various methods and techniques for better broodstock production in the future hatcheries seed production. Many factors can control the broodstock performance in brachyuran crabs but of particular importance in aquaculture will be the enhancement of female broodstock that indirectly improve their reproductive performance for further hatchery production.

3 Key Indicator of Reproductive Performance

Based on the previous study, an eyestalk ablation technique were not enough to induce the gonad maturation of brachyuran crab (Kim et al., 2010), thus, an induction of environmental stimuli should be consider for better reproductive output. As described by the study of Wu et al. (2010a), indicators of reproductive performance in brachyuran crab includes of embryonic development (stage), spawning frequency (time), female spawned (percentage), berried female hatched successfully (percentage), carapace width (CW) (crab size), internal carapace width (ICW) (carapace width), wet weights of female without eggs (crab size - body weight), fecundity (total number of eggs per female). In addition, the spawning parameter of brachyuran crabs could also been measured as a time to spawning (days), total eggs mass (g of eggs/female), calculated mass of individual eggs (μg), egg diameter at extrusion (mm), egg diameter prior to hatch (mm), incubation time (hour or days) and percentage of hatching (Davis et al. 2004). Other than studies by Wu et al. (2010) and Davis et al. (2004), the study by Quinitio et al. (2011) also indicated that the reproductive performance of brachyuran crabs can also been indicated asinterval between spawning to hatching (days), number of zoea per crab size (wet weight), number of days from zoea (larval stage) to crab stage and the final survival rate from zoea (larval stage) to crab stage.

Most of the brachyuran have ten embryonic stages which often used which are based on the relative proportion of yolk (Ates et al., 2012; Zeng, 2007). Previous study indicated that crustacean embryos are wrapped in two kinds of layers; thick outer layer and a very thin inner layer, and these structures are distinguishable until hatching occurs (Saigusa et al., 2000). However, the differentiation of embryonic stages was depends on various factors such as environmental conditions or breeding technology of cultured species. Spawning of brachyuran occur between 10-119 days depends on the species and the induction methods used for crabs spawn. The measurement of CW and ICW were shown in Figure. 1. Examples of calculation on key indicator of reproductive performance were shown in Table 2.

4Induction on Reproductive Performance

4.1 Environmental conditions

A significant research effort has been directed towards the identifying of improvement on the reproductive performance for several crustacean species especially crabs. Many studies were conducted to determine the effects of different environmental stimuli on broodstock reproduction of crustacean (reviewed by Green et al., 2014). However, the importance of the environmental effects such as temperature (Brylawski and Miller, 2006; Burmeister and Sainte-Marie, 2010; Fischer and Thatje, 2008; Litulo, 2005; Wu et al., 2010a; Zeng, 2007), salinity (reviewed by Bianchini et al., 2008; Rotllant et al., 2015), oxygen (reviewed by Green et al., 2014), photoperiod (Bembe, 2009), has been only study for some brachyuran crab especially for broodstock which can be use in hatchery culture. The study by Wu et al. (2013), environmental conditions was the main factor affecting the accumulation of energy by hepatopancreas. Thus, the nutrition and energy which stored in hepatopancreas were often consumed soon for gonadal development as well as reproductive performance. In addition, the study by Darnell et al. (2009) also initiated that environmental factors play a major role in determining brachyuran crab size.

4.2 Nutritional Requirements

Nutrient availability is one of the most important factors influencing the broodstock maturation of crabs (Azra and Ikhwanuddin, 2016). Previous review showed that nutrition in aquaculture viewpoint are divided into two distinct classes which are macronutrients, those required in high dietary concentration such as protein and lipids and micronutrients, those required in trace elements (Francis et al., 2014). It is well established that the nutritional content of crustacean crab's broodstock generally reflect the maturation process and the overall viability of seed, through early growth and survival (Oniam et al., 2012). However, the effects of different diets on brachyuran crab reproduction, genus *Scylla* have been done by the previous study (Azra and Ikhwanuddin, 2016); thus, it will be excluded in this present review. Investigations into nutritional classes and ratios have concurrently generated a few of published data corresponding to the nutritional maintenance of broodstock. The nutritional content of diets

showed different effects on reproductive performance of brachyuran crabs such as *P. pelagicus*and *E. sinensis* (Chaiyawat et al., 2008; Sui et al., 2009; Wu et al., 2007).

4.3 Genetic selection

It is important to understand the regulatory mechanism associated with crab reproduction at the molecular and genomic level in more detail. Identifying significant functional genes involved in the gonadal development of crabs indirectly improved the broodstock selection for hatchery used. Genetically induced of oviposition in the brachyuran crabs are not well studied. There are several studies related to the genetic selection such as by Han et al. (2012) and Li et al. (2013) on cyclin B, Ma et al. (2012) on Erk2 and Wang et al. (2012) on vasa gene during ovarian development of brachyuran crabs as our knowledge. These genes usually play different roles in brachyuran ovary such as act as a maturation promotion in the ovarian cycle of brachyuran crabs. More details study should be done on the development of genetic selection especially in the improvement of the brachyuran crab reproductive performance. In additions, the methods of ease-to-obtain of the certain genes were also needed in the future research especially commercial brachyuran crabs culture.

4.4 Physiological Effects (chemical)

To increase viable seed production techniques, better understanding of broodstock selection through chemical effects is considerable new in the future hatchery management. The limited understanding of the physiological effects of several chemical in brachyuran crabs reproduction only allows a much generalized picture of certain broodstock reproduction aspects. Most of the chemicals used in brachyuran crabs cultures areused in the laboratory trials as well as being very expensive. However, several chemicals have been tested as reproduction promotes in aquaculture but they cannot be endorsed for commercial processes due to their residual effects in the body of crabs. The reproductive condition of brachyuran crabs is usually determined by inspection of the gonad. Thus, several methods and techniques are directed to affect the gonad maturation as well as vetellogenin production. Previous studies showed that several chemicals could be used to induce the ovarian maturation and accelerate the reproductive performance of brachyuran crab species such as thyroxine hormone (Iromo et al., 2015), methyl farnesoate (Medesani et al., 2015), steroid hormone, 17-hydroxypregnenolone (Muhd-Farouk et al., 2014) and 17-hydroxyprogesterone (Reddy et al., 2006).

4.5 Others

Research on the culture practices and system is limited and has not been adequately investigated in crab models. In recent years, in-tank and ponds investigation, where the response of broodstock to produced higher female production have been done by the study of Paterson et al. (2007), Oniam et al.(2010) and Wu et al. (2010b). These studies showed that brachyuran crabs reproductive performance can be improved by crab reared in indoor shedding system and in earthen pond culture. Others than that, the improvement in management practices of wild-caught edible crab, *Cancer pagurus* showed acceleration in the spawning of the crab. On the other hand, an interested study by Simeo et al. (2015) indicated that female of spider crab, *Maja brachydactyla* reared without male in the captivity produced four consecutive broods per breeding compared to only three times in the wild. The study by Wu et al. (2010a) showed the different between the first and second female broodstock (same individual with two times spawned) used for hatchery culture. There is no significant different between them, but they found that offspring quality were higher from the first brood compared to the second brood.

5 Future Research Directions and Conclusion

In brachyuran crabs, embryos which develop in broodstock that are carried by the females, they experienced the parental conditions includes environment and nutrition content. The seed produce by the brachyuran crab broodstock usually depend on the broodstock performance. The enhancement of the broodstock is important to the successful of mass rearing of selected crab's species. The development of techniques for the production of improved female's broodstock especially brachyuran crabs could benefit the hatchery seed production. The demand for female's broodstock by crab's hatchery culture, particularly for free-wild caught broodstock, will at some point increasing in the future. Research efforts to enhance the broodstock quality of these delicious

crustaceans in captivity represent the most reasonable way forward in this regard. The present review showed that broodstock reproductive's performance widely differs between crab's species and individually, depending on broodstock spatial and latitudinal aspects, nutritional content and culture system and practices. Generally, external factors such as temperature, salinity, photoperiod and availability of food can determine the length of the reproductive period. The significant induction of ovarian maturation as well as reproductive performance could also been done by the chemicals reaction such as hormone manipulation. It is concluded that the reproductive performance of brachyuran crabs especially female broodstock can be induced by the selected techniques and methods for further used in hatchery seed production.

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References

Akpaniteaku R.C., 2015, Aspects of reproduction and the condition of gravid mud crab (Crustacea: Brachyura: Potamon) in Ebonyi State, Nigeria, International Journal of Research Studies in Biosciences, 3: 104-109

Allayie S.A., Ravichandran S., and Bhat B.A., 2011, Hormonal regulatory role of eyestalk factors on growth of heart in mud crab, Scylla serrata, Saudi Journal of Biological Sciences, 18: 283-286
http://dx.doi.org/10.1016/j.sjbs.2011.02.003

Ates M.C.D., Quinitio G.F., Quinitio E.T., and Sanares R.C., 2012, Comparative study on the embryonic development of three mud crabs Scyllaspp, Aquaculture Research, 43: 215–225
http://dx.doi.org/10.1111/j.1365-2109.2011.02818.x

Azra M.N., and Ikhwanuddin M., 2015, Larval culture and rearing techniques of commercially important crab, Portunuspelagicus (Linnaeus, 1758): Present status and future prospects, Songklanakarin Journal of Science and Technology, 37: 135-145

Azra M.N., and Ikhwanuddin M., 2016, A review of maturation diets for mud crab genus Scylla broodstock: Present research, problems and future perspective, Saudi Journal of Biological Sciences, 23: 257-267
http://dx.doi.org/10.1016/j.sjbs.2015.03.011

Baiduri S.N., Akmal S.N., and Ikhwanuddin M., 2014, Mating success of hybrid trials between two mud crab species, Scylla tranquebaricaand Scylla olivacea, Journal of Fisheries and Aquatic Science, 9: 85-91
http://dx.doi.org/10.3923/jfas.2014.85.91

Bembe S.E., 2009, Reproductive physiology of the female blue crab, Callinectessapidus: spawning induction and vitellogenesis, Thesis for M.S., Faculty of the Graduate School, University of Maryland, Supervisor: Chung, J.S., pp.78-79

Bianchini A., Lauer M.M., Nery L.E.M., Colares E.P., Monserrat J.M., and Filho E.A.D.S., 2008, Biochemical and physiological adaptations in the estuarine crab Neohelicegranulata during salinity acclimation, Comparative Biochemistry and Physiology-Part A, 151:423-436
http://dx.doi.org/10.1016/j.cbpa.2007.12.001

Brylawski B.J., and Miller T.J., 2006, Temperature-dependent growth of the blue crab (Callinectessapidus): a molt process approach, Canadian Journal of Fisheries and Aquatic Sciences, 63: 1298-1308
http://dx.doi.org/10.1139/f06-011

Burmeister A.D., and Sainte-Marie B., 2010, Pattern and causes of a temperature-dependent gradient of size at terminal moult in snow crab (Chionoecetesopilio) along West Greenland, Polar Biology, 33: 775-788
http://dx.doi.org/10.1007/s00300-009-0755-6

Chaiyawat M., Eungrasamee I., and Raksakulthai N., 2008, Quality characteristics of blue swimming crab (Portunuspelagicus, Linnaeus 1758) meat fed Gracilaria edulis (Gmelin) Silva,Kasetsart Journal-Natural Science, 42: 522-530

Chen Y., Chen L., Qin J.G., Ding Z., Li M., Jiang H., Sun S., Kong Y., and Li E., 2014, Growth and immune response of Chinese mitten crab (Eriocheirsinensis) fed diets containing different lipid sources, Aquaculture Research, 1-12

Darnell M.Z., Rittschof D., Darnell K.M., and McDowell R.E., 2009, Lifetime reproductive potential of female blue crabs Callinectessapidus in North Carolina, USA, Marine Ecology Progress Series, 394: 153-163
http://dx.doi.org/10.3354/meps08295

Davis J.A., Churchill G.J., Hecht T., and Sorgeloos P., 2004, Spawning characteristic of the South African mudcrab Scylla serrata (Forskal) in captivity, Journal of the World Aquaculture Society, 35: 121-133

http://dx.doi.org/10.1111/j.1749-7345.2004.tb01068.x

Diarte-Plata G., Sainz-Hernandez J.C., Aguinaga-Cruz J.A., Fierro-Coronado J.A., Polanco-Torres A., and Puente-Palazuelos C., 2012, Eyestalk ablation procedures to minimize pain in the freshwater prawn Macrobrachiumamericanum, Applied Animal Behaviour Science, 140: 172-178
http://dx.doi.org/10.1016/j.applanim.2012.06.002

Dima J.B., Vido N.A.D., Leal G.A., and Baron P.J., 2009, Fluctuations in the biochemical composition of the Patagonian stone crab PlatyxanthuspatagonicusA. Milne Edwards, 1879 (Platyxanthidae: Brachyura) throughout its reproductive cycle, Scientia Marina, 73: 423-430
http://dx.doi.org/10.3989/scimar.2009.73n3423

Efrizal, Arshad A., Kamarudin M.S., and Saad C.R., 2006, Effects of temperature on the incubation period and reproductive performance of berried female blue swimming crab, Portunuspelagicus (Linnaeus, 1758) under cultured conditions, Research Journal of Fisheries and Hydrobiology, 1: 23-27

Fischer S., and Thatje S., 2008, Temperature-induced oviposition in the brachyuran crab Cancer setosus along a latitudinal cline: Aquaria experiments and analysis of field-data, Journal of Experimental Marine Biology and Ecology, 357: 157-164
http://dx.doi.org/10.1016/j.jembe.2008.01.007

Food and Agriculture Organization of the United Nations – FAO yearbook, 2014, Fishery and Aquaculture Statistics, 2012.Statistics and Information Branch of the Fisheries and Aquaculture Department, VialedelleTerme di Caracalla, Rome, Italy.76 pp

Francis D.S., Salmon M.L., Kenway M.J., and Hall M.R., 2014, Palinurid lobster aquaculture: nutritional progress and considerations for successful larval rearing, Reviews in Aquaculture, 6: 180-203
http://dx.doi.org/10.1111/raq.12040

Green B.S., Gardner C., Hochmuth J.D., and Linnane A., 2014, Environmental effects on fished lobsters and crabs, Reviews in Fish Biology and Fisheries, 24: 613-638
http://dx.doi.org/10.1007/s11160-014-9350-1

Han K., Dai Y., Zou Z., Fu M., Wang Y., and Zhang Z.,2012, Molecular characterization and expression profiles of cdc2 and cyclin B during oogenesis and spermatogenesis in green mud crab (Scylla paramamosain), Comparative Biochemistry and Physiology-Part B, 163: 292-302
http://dx.doi.org/10.1016/j.cbpb.2012.07.001

Ikhwanuddin M., Bachok Z., Mohd-Faizal W.W.Y., Azmie G., and Abol-Munafi A.B., 2010. Size of maturity of mud crab Scylla olivacea (Herbst, 1796) from mangrove areas of Terengganu coastal waters, Journal of Sustainability Science and Management, 5: 134-147

Ikhwanuddin M., Azra M.N., Siti-Aimuni H., and Abol-Munafi A.B.,2012, Fecundity, embryonic and ovarian development of blue swimming crab, Portunuspelagicus (Linnaeus, 1758) in coastal water of Johor, Malaysia, Pakistan Journal of Biological Sciences, 15: 720-728

Ikhwanuddin M., Baiduri S.N., Norfaizza W.I.W., and Abol-Munafi A.B., 2014a.Effect of water salinity on mating success of orange mud crab, Scylla olivacea (Herbst, 1796) in captivity, Journal of Fisheries and Aquatic Science, 9: 134-140
http://dx.doi.org/10.3923/jfas.2014.134.140

Ikhwanuddin M., Nur-Atika J., Abol-Munafi A.B., and Muhd-Farouk H., 2014b,Reproductive biology on the gonad of female orange mud crab, Scylla olivacea (Herbst, 1796) from the west coastal water of peninsular Malaysia, Asian Journal of Cell Biology, 9: 14-22
http://dx.doi.org/10.3923/ajcb.2014.14.22

Ikhwanuddin M., Liyana A.N., Azra M.N., Bachok Z., and Abol-Munafi A.B., 2014c, Natural diet of blue swimming crab, Portunuspelagicus at strait of Tebrau, Johor, Malaysia, SainsMalaysiana, 43: 37-44

Iromo H., Zairin J.M., Agus S.M., and Manalu W., 2015,The optimum dose of thyroxine hormone supplementation in broodstock mud crab (Scylla serrata) to accelerate ovarian maturation, Journal of Aquaculture Research and Development, 6: 317

Khazraeenia S., and Khazraiinia P., 2009, Effects of bilateral eyestalk ablation on gonadal maturity, moulting and biochemical changes in the hemolymph of female Potamonpersicumcrabs (Decapoda, Brachyura, Potamidae), International Journal of Veterinary Research, 3: 143-150

Kim D.H., Kim S.K., Choi J.H., Kim B.R., Seo H.C., and Jang I.K., 2010, The effects of manipulating water temperature, photoperiod, and eyestalk ablation on gonad maturation of the swimming crab, Portunustrituberculatus, Crustaceana, 83: 129-141
http://dx.doi.org/10.1163/001121609X12591347509248

Li W.X., Huang H.Y., Huang J.R., Yu J.J., Ma J., and Ye H.H., 2013, Molecular cloning, expression profiles and subcellular localization of cyclin B in ovary of the mud crab, Scylla paramamosain, Genes and Genomics, 35: 185-195
http://dx.doi.org/10.1007/s13258-013-0077-5

Litulo C., 2005, External factors determining the reproductive periodicity in a tropical population of the hairy crab Pilumnusvespertilio(Decapoda: Brachyura: Pilumnidae), The Raffles Bulletin of Zoology, 53: 115-118

Ma A., Wang Y., Zou Z., Fu M., Lin P., and Zhang Z., 2012, Erk2 in Ovarian Development of Green Mud Crab Scylla paramamosain, DNA and Cell Biology, 31: 1233-1244
http://dx.doi.org/10.1089/dna.2011.1458

Meade M., and Watts S., 2001, Physiological compensation in unilateral eyestalk ablated crayfish, Cheraxquadricarinatus, Journal of Experimental Zoology, 289: 184-189
http://dx.doi.org/10.1002/1097-010X(20010215)289:3<184::AID-JEZ5>3.0.CO;2-6

Medesani D.A., Ferre L.E., Canosa I.S., Silveyra G.R., and Rodriguez EM., 2015, Induction of vitellogenesis by 17-hydroxyprogesterone and methyl farnesoate during post-reproductive period, in the estuarine crab Neohelicegranulate, Invertebrate Reproduction and Development, 59: 104-110
http://dx.doi.org/10.1080/07924259.2015.1019014

Muhd-Farouk H., Abol-Munafi A.B., Jasmani S., and Ikhwanuddin M., 2014, Effect of steroid hormones, 17α-hydroxyprogestrone and 17α-hydroxypregnelone on ovary external morphology of orange mud crab, Scylla olivacea, Asian Journal of Cell Biology, 9: 23-28
http://dx.doi.org/10.3923/ajcb.2014.23.28

Murugesan R., Soundarapandian P., and Manivannan K., 2008, Effect of unilateral eyestalk ablation on the biochemical changes of edible Portunid crab Charybdis lucifera(Fabricius), Journal of Fisheries and Aquatic Science, 3: 82-86
http://dx.doi.org/10.3923/jfas.2008.82.86

Noorbaiduri S., and Ikhwanuddin M., 2015.Artificial crablets production of orange mud crab, Scylla olivacea (Herbst, 1796) through in-vitro fertilization technique, Journal of Fisheries and Aquatic Science, 10: 102-110
http://dx.doi.org/10.3923/jfas.2015.102.110

Oniam V., Buathee U., Chuchit L., and Wechakama T., 2010, Growth and sexual maturity of blue swimming crab (Portunuspelagicus Linnaeus, 1758) reared in earthen ponds,Kasetsart University Fisheries Research Bulletin, 34: 20-27

Oniam V., Chuchit L., and Arkronrat W., 2012, Reproductive performance and larval quality of blue swimming crab (Portunuspelagicus) broodstock, fed with different feeds,Songklanakarin Journal of Science and Technology, 34: 381-386

Paterson B., Mann D., Kelly B., and Barchiesi M., 2007. Limb-loss in pond-reared blue swimmer crabs Portunuspelagicus (L.): effect on growth in an indoor shedding system, Aquaculture Research, 38: 1569-1579
http://dx.doi.org/10.1111/j.1365-2109.2006.01625.x

Pervaiz P.A., Jhon S.M., Sikdar-Bar M., Khan H.A., and Wani A.A., 2011, Studies on the effect of unilateral eyestalk ablation in maturation of gonads of a freshwater prawn Macrobrachiumdayanum, World Journal of Zoology, 6: 159-163

Prasad R.N., and Besra S., 2012, Effect of eyestalk ablation on ovarian development in freshwater crab, Sartorianaspinigera (Wood mason, 1871),Ecoscan, 1: 357-360

Quinitio E.T., de la Cruz J.J., Eguia M.R.R., Parado-Estepa F.D., Pates G., and Lavilla-Pitogo C.R., 2011, Domestication of the mud crab Scylla serrata, Aquaculture International, 19: 237-250
http://dx.doi.org/10.1007/s10499-010-9381-0

Reddy P.R., Kiranmayi P.,Kumari K.T., and Reddy P.S., 2006, 17α-hydroxyprogestrone induced ovarian growth and vitellogenesis in the freshwater rice field crab Oziotelphusasenexsenex, Aquaculture, 254: 768-775
http://dx.doi.org/10.1016/j.aquaculture.2005.11.023

Rotllant G., Simeo C.G., Macia G., and Estevez A., 2015, High environmental salinity reduces the reproductive potential of the spider crab Maja brachydactyla(Decapoda, Majidae), Marine Ecology, 36: 496-505
http://dx.doi.org/10.1111/maec.12157

Saigusa M., 2000,Hatching of an estuarine crab, Sesarmahaematocheir: factors affecting the timing of hatching in detached embryos, and enhancement of hatching synchrony by the female, Journal of Oceanography, 56: 93-102
http://dx.doi.org/10.1023/A:1011118726283

Samyappan K., Saravanan R., Vijayakanth T., and Prabakaran D., 2015, Impact of unilateral eyestalk ablation on lipid profiles in freshwater female crab Oziotelphusasenexsenex, Asian Journal of Science and Technology, 6: 1474-1478

Shen H., Hu Y., and Zhou X., 2014,Sez-lethal gene of the Chinese mitten crab Eriocheirsinensis: cDNA cloning, induction by eyestalk ablation, and expression of two splice variants in males and females, Development of Genes and Evolution, 224: 97-105
http://dx.doi.org/10.1007/s00427-014-0467-y

Simeo C.G., Andres M., Estevez A., and Rotllant G., 2015, The effect of male absence on the larval production of the spider crab Maja brachydactyla Balss, 1922, Aquaculture Research, 46: 937-944
http://dx.doi.org/10.1111/are.12250

Subramoniam T., 2011, Mechanisms and control of vetellogenesis in crustaceans, Fisheries Science, 77: 1-21
http://dx.doi.org/10.1007/s12562-010-0301-z

Sudha K., and Anilkumar G., 2007, Elevated ecdysteroid titer and precocious molt and vitellogenesis induced by eyestalk ablation in the estuarine crab, Metopograpsusmessor (Brachyura: Decapoda), Journal of Crustacean Biology, 27: 304-308
http://dx.doi.org/10.1651/S-2750.1

Sui L.Y., Wu W.G., Mille M., Cheng Y.X., and Sorgeloos P., 2009, Effect of dietary soybean lecithin on reproductive performance of Chinese mitten crab Eriocheirsinensis (H. Milne-Edwards) broodstock, Aquaculture International, 17: 45-56
http://dx.doi.org/10.1007/s10499-008-9178-6

Tamone S.L., Adams M.M., and Dutton J.M., 2005, Effect of eyestalk-ablation on circulating ecdysteroids in hemolymph of snow crabs, Chionoecetesopilio: Physio-logical evidence for a terminal molt, Integrative and Comparative Biology, 45: 166-171
http://dx.doi.org/10.1093/icb/45.1.166

Velmurugan S., Soundarapandian P., Samuel N.J., and Rajagopal S., 2008, Activity of hyperglycemic hormone in the eyestalk of commercially important crab Portunuspelagicus (Linnaeus), Journal of Fisheries and Aquatic Science, 3: 77-81
http://dx.doi.org/10.3923/jfas.2008.77.81

Venkitraman P.R., Jayalakshmy K.V., Balasubramanian T., 2010, Effect of eyestalk ablation on moulting and growth in penaeid prawns: Metapenaeusmonoceros, Indian Journal of Fisheries, 57: 25–32

Woll A.K., and Berge G.M., 2007, Feeding and management practices affect quality improvement in wild-caught edible crab (Cancer pagurus), Aquaculture, 269: 328-338
http://dx.doi.org/10.1016/j.aquaculture.2007.04.022

Waiho K., Mustaqim M., Fazhan H., Norfaizza W.I.W., Megat F.H., and Ikhwanuddin M., 2015,Matingbehaviour of the orange mud crab, Scylla olivacea: The effect of sex ratio and stocking density on mating success, Aquaculture Reports, 2: 50-57

Wu X., Cheng Y., Sui L., Zeng C., Southgate P.C., and Yang X., 2007, Effect of dietary supplementation of phospholipids and highly unsaturated fatty acids on reproductive performance and offspring quality of Chinese mitten crab, Eriocheirsinensis (H. Milne-Edwards), female broodstock, Aquaculture, 273: 602-613
http://dx.doi.org/10.1016/j.aquaculture.2007.09.030

Wu X., Cheng Y., Zeng C., Southgate P.C., Zhou G., and Bian W., 2009, Reproductive performance and offspring quality of Chinese mitten crab Eriocheirsinensis (H. Milne-Edwards) females fed an optimized formulated diet and the razor clam Sinonovaculaconstricta, Aquaculture Research, 40: 1335-1349
http://dx.doi.org/10.1111/j.1365-2109.2008.02121.x

Wu X., Cheng Y., Zeng C., Wang C., and Cui Z., 2010a, Reproductive performance and offspring quality of the first and the second brood of female swimming crab, Portunustrituberculatus, Aquaculture, 303: 94-100
http://dx.doi.org/10.1016/j.aquaculture.2010.03.006

Wu X., Cheng Y., Zeng C., Wang C., and Yang X., 2010b, Reproductive performance and offspring quality of wild-caught and pond-reared swimming crab Portunu strituberculatus broodstock, Aquaculture, 301: 78-84
http://dx.doi.org/10.1016/j.aquaculture.2010.01.016

Wu J., Kang X., Mu S., and Tian Z., 2013, Effect of eyestalk ablation in Eriocheirsinensis on physiological and biochemical metabolism, Agricultural Sciences, 4: 25-29
http://dx.doi.org/10.4236/as.2013.46A004

Zeng C., 2007, Induced out-of-season spawning of the mud crab, Scylla paramamosain (Estampador) and effects of temperature on embryo development, Aquaculture Research, 38: 1478-1485
http://dx.doi.org/10.1111/j.1365-2109.2007.01826.x

Zou Z., Zhang Z., Wang Y., Han K., Fu M., Lin P., and Xiwei J., 2011, EST analysis on the gonad development related organs and microarray screen for differentially expressed genes in mature ovary and testis of Scylla paramamosain, Comparative Biochemistry and Physiology-Part D, 6: 150-157
http://dx.doi.org/10.1016/j.cbd.2010.12.003

Sun W.T, 2009, Life cycle assessment of indoor recirculating shrimp aquaculture system.Master's thesis, School of Natural Resources and Environment, University of Michigan, AnnArbor, MI

Thrane, 2004, Environmental impacts from Danish fish products – hot spots and environmental policies.PhD Dissertation, Department of Development and Planning, Aalborg University, Denmark

Ziegler F., Nilsson P., Mattsson B., Walther Y., 2003, Life cycle assessment of frozen cod fillets including fishery-specific environmental impacts, International Journal of Life Cycle Assessment, 8: 39–47