Thesis for the Degree of Master of Fisheries Science

Review on Global Crab Production and Its Potential to Aquaculture in Africa

by

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Division of Fisheries Science

The Graduate School of World Fisheries University,

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전 세계 게 양식과 아프리카 게 양식의 잠재력에 대한 검토

Advisor: Prof. Christopher L Brown

by

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Abstract

More than 5000 species exist but about 4500 species are true crabs while the others are called hermit crabs that uses other animal shell for protection. The culture is the processes involved in acquiring crablets from the hatchery and rearing in grow out ponds till it gets to table size. This is mostly done in south east Asia countries because of the inability to meet the demand only from the wild. Fattening of captured wild juvenile crabs is also a good culture method, mostly done because of low hatchery success in crab culture. Overexploitation of natural crab stock without considering the age, size and status (gravid) has led to declining wild populations. The interest of many hatchery scientists and private fish farmers on crabs and provision of crablets has been influenced by growing market demands of crab meat all over the world. Crab culture technology lags behind because of species-dependent challenges in the rearing and reliable production of healthy seedstock. In this paper, the status of crab (*Eriocheir sinensis*, *Callinectes sapidus*, *Scylla serrata*, *Portunus trituberculatus* and *Portunus pelagicus*) aquaculture globally is examined together with technological development and problems hindering the industry. The potential for development of the crab aquaculture industry in Africa is discussed.

DEDICATION

To my lovely dad and my beloved guardians (Dr and Dr. Mrs. Ikeogu) who was by my side, praying and advising often for me to achieve my goal of making this thesis a success.

To my family members:

and

To all my friends who supported me all these years

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I am grateful to almighty God for giving me the knowledge, strength and courage to complete my thesis writing within the stipulated time frame. Christopher L. Brown, to whom I am eternally grateful happened to be my supervisor, who worked tirelessly together with me in giving me advice and guidance throughout the period of the thesis. Without his counsel and close follow up, this thesis would not be able to achieve its objective. I pray God to repay him of his deeds and give him more years to reap the rewards of his years of labour.

I would not forget the advice and corrections of my thesis committee members, S. Charles Bai and Chang-Ik Zhang. Their efforts as well contributed to the success and completion of this work.

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I. INTRODUCTION

This thesis examines the status of crab aquaculture worldwide, considering its technological development and constraints to aquaculture industry growth. Special attention is focused on the suitability of crab culture and its potential for commercial establishment in Africa. Possibilities for the establishment of commercial crab culture in Africa are evaluated in terms of the availability and prospects for transfer and development of suitable technology, and the potential economic and nutritional contributions of cultured crabs to the development of African communities.

Crabs, according to FAO (2006) contribute about 20% of all crustaceans caught, farmed, and consumed worldwide both from marine and freshwater sources, which amounts to about 1.5 million tonnes annually. The species *Portunus trituberculatus* contributes one-fifth of that total. *Cancer pagurus*, the Dungeness crab (*Metacarcinus magister*), and the mud crab *Scylla serrata* each contribute yields of more than 20,000 tonnes every year. Worldwide production of both wild-captured and cultured crabs has increased. Crab culture technology lags the culture of other crustaceans because of species-dependent challenges in the rearing and reliable production of healthy seedstock. Until recently, crab farming was reliant on the collection of wild megalopae and juveniles, but habitat degradation and patterns of overharvesting have reduced the available wild seedstock supplies among many species of crustaceans. Crab fattening – the captive maturation of wild juveniles – and the production of soft-shell crabs have emerged as hatchery-independent crab production operations, but the absence of abundant hatchery-reared juveniles has delayed the arrival of large-scale farming of most crab species. When available, hatchery-reared juveniles have also supported stock enhancement, replenishment, and sea ranching efforts.

Numerous and complicated larval phases and a propensity for cannibalism have been problematic to larviculturists. Larval rearing involves transitions through multiple zoeal stages followed by metamorphosis into megalopae, and megalopae and juvenile crabs show species-dependent degrees of aggressiveness and cannibalistic tendencies. Crabs are especially vulnerable to cannibalism after each molt. Survival of late larval and early juvenile phases rank at the top of obstacles to establishing reliable crab hatchery technology.

The U.N. Food and Agriculture Organization (FAO) compiles annual records of crab harvests, and the latest available data reveal several trends. Between 2008 and 2018, the harvest of wild crabs increased to total production of about 1.7 million metric tonnes in 2015 - the highest landing in the last ten years. Aquaculture produced crab has also been on the increase over the last ten years with a series of efforts made to overcome the problem of unavailability of crablets for aquaculture. Total production in 2018 of about 1.1 million metric tonnes was the highest amount between 2008 and 2018. Three specific harvests account for about 86.6% of this increase, they include: mitten crab (*Ereocheir sinensis*) production in China and the capture harvest of Gazami crab (*Portunus trituberculatus*); both more than doubled during this 10-year period. These two species collectively account for 67% of the FAO-reported crab harvest. The mitten crab is extensively farmed in China with hatchery-reared juveniles, and the harvest of wild Gazami crabs in Japan and elsewhere has been supported by hatchery production for stock enhancement or sea-ranching purposes; that practice began in 1963 (Hamasaki et al., 2011). The increase in mitten crab production in China between 2004 and 2018 far exceeds the 5.8% per annum growth rate of the aquaculture industry (FAO, 2016). Another sharply increased harvest reported over this eleven-year period was for the mud crab, *Scylla serrata*, largely resulting from the availability of hatchery technology. *S. serrata* is preferred by farmers because it is larger and less aggressive than the other 3 mud crab species (Quinitio et al., 2009) and *S. serrata*, together with *S. tranquebarica, S. paramamosain* and *S. olivacea* can be commercially produced from the wild and as well produced through aquaculture throughout their distribution (Shelley & Lovatelli, 2011).

In addition to the long-established hatchery program for *P. trituberculatus* stock enhancement, the most recently reported FAO totals for eight harvested crabs indicate the sharpest increases in production for two other crab species (*E. sinensis* and *S. serrata*), both supported with hatchery technology. An additional five species of commercial importance are at present only captured and have negligible rates of aquaculture. The lack of hatchery technology is widely recognized as the primary constraint to crab aquaculture industry development (Williams and Primavera, 2001). Larval rearing methods were first developed in the 1960's for *Portunus pelagicus* and *Portunus trituberculatus* (Hamasaki et al., 2011), methods development was initiated in the 1970's for *E. sinensis* (Cheng et al., 2008), and has been actively under development more recently for *Scylla spp*. (Quinitio, 2003; Shelley and Lovatelli, 2011). Mud crab (*Scylla spp.*) aquaculture production is currently expanding which is attributed to the high market demand/price, high flesh content, and rapid growth rates in captivity. In addition, they have the ability to tolerate nitrate (Romano & Zeng, 2007B) and ammonia, which is beneficial because Ammonia-N is the main bottleneck on closed aquaculture systems (Romano & Zeng, 2007A). Hatchery technology for the production of juvenile *Scylla spp*. crabs is being refined and applied in the Philippines, Bangladesh, India, Vietnam, and elsewhere. There have been successful development programs intended to make crablets readily and easily accessible for aquaculture, especially for commercial purposes. One example is the initiative by World Fish and Bangladesh Fisheries Research Institute (BFRI) for producing crablets in laboratory conditions, which according to Molla et al., (2009) was successful as a first attempt in Bangladesh. This initiative provides hope that Bangladesh and countries depending on them for crablets are on their way to gaining the needed expertise for development of a viable crab hatchery. A large-scale expansion of commercial *Scylla sp*. production in Vietnam has been announced recently (Shrimp News, 2018), with ambitious production and economic targets. These new mud crab hatchery initiatives could provide a useful model for the launch of crab farming in Africa.

Aquaculture was first introduced in Africa in the early 20th century mainly to satisfy the earlier recreational fishing needs (Hecht et al. 2006). African aquaculture is growing and will continue to grow if the species cultured are diversified to include not only finfish but also crustaceans and mollusks. African aquaculture centers on finfish especially north African catfish and Nile tilapia have been successfully cultured in ponds in Kenya, starting in the 1920s (FAO, 2005). Finfish culture has not met the demand for food fish in the growing African population, so diversification to include other species like crabs could add to food security, increasing employment opportunities and income to the farmers.

Impediments to African crab farming are the lack of seedstock for the growing industry, lack of technical know-how on hatchery technology and the grow-out farming operations, expertise on the prevention of diseases in both hatchery (bacterial and fungal infections, and protozoan infestation) and grow-out, reduction of cannibalism from nursery to grow-out phase and reduction in the dependence on low-value fish for feeding.

Addressing the above-mentioned problems will help improve both the crab farming sector and aquaculture in general in Africa, thereby helping to obtain the potential nutritional and economic benefits of crab farming in Africa.

II. STATUS OF GLOBAL CRAB AQUACULTURE

1. Mitten Crabs

Mitten crabs (*Eriocheir sinensis* and related species) are native to coastal waters extending from Russia to China, spending a majority of their life in freshwater rivers but returning to the ocean to breed. Their life cycle includes spawning in the ocean, a free-swimming larval phase, an anadromous migration, adult life and maturation in fresh water rivers or lakes, and a later catadromous reproductive migration. Consequently, brackish water or seawater culture systems are required to rear larvae to the megalopa stage, and for hatchery production of juvenile mitten crabs. Mitten crabs are omnivorous and euryhaline, and adults exhibit tolerance of a broad range of temperatures and other water quality conditions. After reproducing, mitten crabs have depleted energy reserves and begin to experience mortality. Their dietary preferences shift throughout development, with an early reliance on algae and detritus but becoming voracious and considerably more carnivorous eaters as they grow (Veilleux and de Lafontaine, 2007; CABI, 2018). Dense patches of dark setae on their claws distinguish mitten crabs from other species. Adult mitten crabs are tolerant of exposure to pollutants such as heavy metals (e.g. mercury and cadmium) and can endure extended periods of time out of the water and without food (see Veilleux and de Lafontaine, 2007;

Zeng et al., 2012). The robustness of mitten crabs contributes both to their suitability as aquaculture farm subjects and to their tenacity as invasive species. Fecundity can be very high - around a million eggs per spawn (Sui et al, 2011), leading to rapid recovery after overexploitation and to explosive population growth during invasions of areas lacking natural predators (CABI, 2018). Mitten crabs are a costly and environmentally damaging invader that can out-compete, out breed, and quickly displace endemic crab species, and control measures that have been implemented in Europe and North America are frustratingly ineffective. These trends reflect the species high degree of competitiveness, high fecundity and reproduction rate coupled with their tolerance of a wide range of environmental changes. In United States of America for instance, the law forbids the importation, transportation and possession of live Chinese mitten crabs (Elizabeth et al., 2006) in a bid to curb the invasiveness of the crab. According to Stephen (2006) some efforts/measures such as "catch as many as you can", migration barriers, trapping, creation of awareness, the use of electrical screens and pulses used earlier proved to be ineffective.

Acceptable larval water quality parameters are much more moderate than those of adults: temperature 15-25°C and acceptable salinities range from brackish to full strength seawater (15 – 32 PSU; Veilleux and de LaFontaine, 2007), which makes the megalopae form within 24 days. The optimal temperature and salinity for the proper development of megalopae is temperature between 18–25 °C and

20–25 $^{o}/_{oo}$ salinity (Steven et al., 2012). Moreover, suboptimal temperature and salinity range affects the survival rate of megalopae. Environmental tolerance limits of larvae are thought to define the range for establishment of *Erocheir sinensis* as a non-endemic nuisance, as exemplified in Northern California, USA (Blumenshine et al., 2012) and in western Europe (Herborg et al., 2007). Zoeael survival has been found experimentally to be contingent on water with at least 16 PPT (or $^{o}/_{oo}$, ~ 16 PSU) salinity and a minimum temperature of 11.7ºC (Tsukimura, 2008). Unlike adults, larval mitten crabs are vulnerable to predation (CABI, 2018). Water parameters for captive mitten crabs are kept in check by combinations of ecosystem services and by aquaculture efforts.

Mitten crabs are considered a delicacy in China, with a 1000-year tradition of human consumption (Sui, 2008). Persistent efforts in recent decades to improve culture technology have established *E. sinensis* as the most abundantly cultured of crab species; the total harvest of mitten crabs exceeds that of all other cultured crabs combined (Cheng et al., 2008). The history and incentives for farming Mitten crab follow a classic paradigm: overfishing and habitat destruction caused a collapse of wild populations in China in the early 1980's, and unmet demand was followed by the accelerated development of hatchery methods beginning in the 1970's. As with other crabs, the availability of adequate and reliable hatchery technology has been rate-limiting in the emergence of mitten crab farming. The need for dependable, on-demand production of healthy seed-stock is a major obstacle throughout crustacean culture, and progress with mitten crabs in China has required persistent scientific attention. Initial hatchery work focused on the generation of healthy juveniles for rebuilding, replacing or enhancing wild populations, followed by their use in semi-intensive stocking for rearing in cages and pens, and eventually for commercial farming. Most recently the record of progress in hatchery technology reached a prestigious benchmark with the October, 2017 approval of Zhejiang Aoling Aquatic Seeding Technology mitten crab farm in Huzhou, China for Global Aquaculture Alliance (GAA) Best Aquaculture Practice Certification (GAA, 2018). *Erocheir sinensis* shares the dual distinctions of being a revered cultural favorite that is also listed among the world's 100 Worst Invasive Species (Global Invasive Species Database, 2018).

The steady advancement of mitten crab propagation technology has been recommended as a model for the development of hatchery technology for other species of crabs (Cheng et al., 2008). Of all cultured crabs, mitten crab larvae are considered to be technically easiest to rear (Qi et al., 2013). An overview of the sequence of steps in hatchery technology development for *E. sinensis* crablet production may provide useful insight into appropriate refinements to emerging crustacean hatchery technology. A forecast of technical obstacles likely to be faced and acceptable approaches to them may help to provide a sense of what can be anticipated in the development of technology for other decapod aquaculture candidates.

Chinese mitten crab populations were severely impacted in the 1960s by overfishing and environmental disruptions/degradation maybe as a result of pollution (e.g influx of chemicals, plastics, oil spillage, etc.) and the construction of dams (Zeng et al., 2012). Hatchery research was launched in the 1970s following the decline of wild stocks, which collapsed in 1982. Diminished supplies of wild megalopae conventionally collected for captive grow-out operations raised interest in improving larviculture, and various live, frozen, and formulated larval feeds were tested. Several events coincided to accelerate the pace of the advancement of mitten crab farming technology. Unprecedented larval rearing success was reported by Zhao (1980), using synthetic seawater for larviculture with a diet of *Artemia sp.* nauplii. Larval nutrition is not especially challenging in this species; *E. sinensis* can be reared on nothing more than algae, chicken egg yolk and beer yeast, although these were often supplemented with rotifers and *Artemia sp.* (Qi et al., 2013). During the early 1980's, China adopted new official policies favoring openness to international scientific exchange (Gao, 2015). This was a pivotal time for building momentum in the aquaculture industry, as produciton by capture fisheries was beginning to level off (FAO, 2016). Marine hatchery technology in particular reached a notable turning point, becoming more widely accepted as a legitimate scientific pursuit (see FAO manuals by Tacon,1988; Baluyut, 1989). Innumerable larval diets were under development with live or natural planktonic organisms, cultured, frozen, HUFAenriched, and synthetic formulated feeds, all being evaluated in various sequences and combinations to meet the nutritional needs of developing marine larvae (Tacon, 1988), and many of the more difficult species were offered *Branchionus plicatus* or *Artemia sp*. embellished with nutrient enrichments tailored to meet their specific requirements (Leger et al., 1986).

The harvest of wild mitten crab megalopae declined abruptly almost to zero, in early 1982, and has not recovered (Cheng et al., 2008). This occurred just before a series of viral outbreaks in the late 1980's and 1990's that devastated Penaeid shrimp farms, in many cases resulting in their closure (Sui et al., 2011). Chinese shrimp hatcheries and farms were frequently reconfigured for conversion into mitten crab production facilities, resulting in an unprecedented expansion of mitten crab larviculture and farming in the 1990s (Sui et al., 2011).

Annual megalopae hatchery production increased at a brisk and steady rate (Cheng et al., 2008; Zeng et al., 2012), and the resultant availability of large quantities of juvenile crabs in the 1990's contributed to rapid, sustained growth of mitten crab production on farms, as depicted in Figure 1., below.

Figure 1: Growth in total harvests in the mitten crab aquaculture industry, redrawn from FAO data.

This increase in mitten crab aquaculture production also led to the increase in value of harvests in USD and has contributed meaningfully to the world economy, especially that of China where it is massively produced. According to FAO (2010) the total value of mitten crab aquaculture was about 4.9 million USD and in 2018 it was about 9.6 million USD showing the corresponding increase in value with increase in total tonnes of yearly productions. So prominent success in the hatchery technology or procurement of larvae and juveniles will further increase the harvest and at the same time increase the value of total production. This increase in value over the years is shown in the figure below.

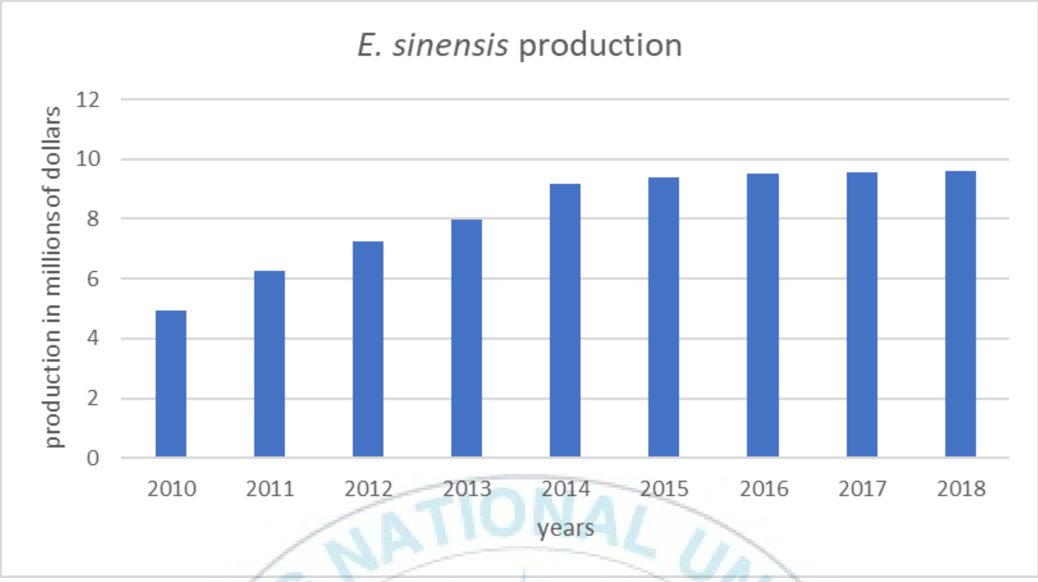

Figure 2: Increase in total harvests value in USD of the mitten crab aquaculture industry, redrawn from FAO data

E. sinensis larvae are reared in brackish or salt water, progressing through a series of five stages of zoea, followed by a metamorphosis into megalopae. Megalopae are final-stage, morphologically crablike larvae that are suitable for distribution and stocking elsewhere for nursery care and growout. Hatchery managers emphasize the critical importance of brood-stock quality and nutrition, conditioning pre-spawning brood-stock with natural foods like razor clams (*Sinonovacula constricta*), and more recently with highly effective formulated diets (Wu et al., 2009), trash fish (*Chaeturichthys stigmatias*) and sandworms (*Nereis japonicus;* a sea cucumber) can be used as natural foods also. Female brood-stock crabs should be about 125-150 grams and males should be larger than or 150 grams

(Bob, 2018). Reproductive output and larval performance were statistically indistinguishable in comparisons of those two conditioning diets, although larvae from females fed the formulated diet had larger carapaces with shorter inter-molt durations (Wu et al., 2009). Synchronized molts among larvae within a cohort have remained a target of hatchery operators, since they can result in reduced rates of cannibalism associated with molting. Fecundity is very high in mitten crabs; females produce up to a million eggs per spawn, and females are capable of a second spawn after carrying eggs after a single mating. With their pleopods, the female carries their eggs beneath the abdomen during the embryo development which takes about 2 to 4 months (Bob, 2018). Secondary spawns are seldom used in hatcheries, since egg and larval quality and quantity are reduced (Ji et al., 2006). Both intensive indoor and extensive or semi-intensive outdoor larviculture approaches are used to rear mitten crab larvae (Zeng et al., 2012). Recent protocols are reliable and elaborate, with a series of water exchange protocols throughout the zoeal stages and feeding of zoea using stage-dependent diets with changing proportions of microalgae, rotifers, copepods, *Artemia sp*. nauplii and egg yolk, supplemented from the zoea 3 stage onward with soybean milk and *Spirulina sp*. powder (Zeng et al., 2012). The entire larviculture process takes about three weeks before megalopae can be transferred to nursery facilities.

Mastery of crab culture methodology requires a long attention-span. Hatchery methods for mitten crabs have consistently been refined in China since the late 1970s, and a persistent long-term commitment to technology development has produced exemplary results. Yangtze River Delta in southern China is the center of hatchery processes followed by the Liao River area in northern China. Most megalopae used in China are produced in these areas and distributed to other parts of China for the continuous grow-out phases. Among the principles that have guided this body of work, some recurring themes have contributed more than others to the emergence of practical methods for the mitten crab fishery in China. Both brood-stock and larval feeding and nutrition have remained the subject of sustained research efforts. Adult mitten crabs have been described as voracious detritovores that can eat and survive on almost anything, but attention has been focused on optimizing the nutritional quality of broodstock conditioning diets. Larval diets are also continually being tested and refined in a continuous push from acceptable toward optimal, since improving and synchronizing molts during the development of zoea contributes substantially to their health and to the collective survival of a cohort.

Strategic thinking about intensive megalope production has evolved, from earlier green-water culture methods to the replacement of chemical treatments with careful and deliberate microbial management (e.g. the establishment of mature microbial ecosystems to discourage opportunistic pathogens; Sui et al., 2011; Wang et al., 2016). Antibiotic use was formerly routine, but reliance on antibiotics has been sharply reduced and, in some cases, eliminated. Formal standards for antibiotic use in the GAA certification approved for Zhejiang Aoling, mentioned above, discourage the use of antibiotics except in strictly regulated, supervised, and reported applications (GAA, 2017).

1.1. *Erocheir Sinensis* Status and Prospects

Dining on mitten crabs has been fashionable in China for a thousand years (Sui, 2008; Naser et al., 2012). Their cultural significance and the rich aquatic farming tradition in China have combined to elevate the status and advance the technical caliber of mitten crab hatchery and farm production. Mitten crab culture is by far the largest of worldwide crab production component among aquaculture industries.

An urgent need for genetic management has been identified (FAO, 2006-2018). High market values have driven rapid growth, and earlier poorly planned transfers of formerly isolated genetic stocks have resulting in crossbreeding, enhanced rates of gene flow and reductions in genetic diversity (Sui et al., 2011). Overexploitation of wild stocks and an earlier lack of genetic conservation have undermined seed quality, which is recognized as a continuing and as yet unresolved problem in mitten crab culture (FAO, 2006-2018). Reduced performance in genetically compromised strains may include reduced growth rates and a high incidence of precocious sexual maturation of crabs during the nursery phase (Chang et al., 2017). The causes for this syndrome are poorly understood; early maturation followed by reduced growth is accompanied by and could be mediated by altered gene expression in the endocrine eyestalk, (Xu et al., 2015); it can result in the loss of up to 30% of a farmed crop of mitten crabs (Zeng et al., 2012; Chang et al., 2017).

E. sinensis has become a government-endorsed companion crop to rice in China, replacing traditional carp/rice culture to a large extent, adding a new and environmentally friendly market for mitten crab seed, and new incentives for conservation (Li et al., 2007). Selective breeding programs have produced five certified strains of genetically improved mitten crabs, with growth rates increased by up to 26.0% (Liu et al., 2018). With sufficient maintenance of genomic diversity, the continued development of genetically improved or domesticated mitten crabs could produce strains that are highly adapted to farm production, and to production in rice fields. Marked progress in the development of salt tolerant rice strains (Pang et al., 2017; Gregorio and Senadhira, 1993) may open new opportunities for co-culture with mitten crabs in brackish coastal environments.

Steady growth and intensification in mitten crab farming help to meet unwavering demand in the profitable Chinese market. Expansion and intensification of crustacean farms has been associated with increased rates in the emergence of new microbial pathogens (Stentiford et al., 2012), so the need to maintain a high standard of health and water quality management is urgent. Some models suggest that the intensity of crustacean culture, genetically-mediated immune system response, and susceptibility to pathogens may be functionally linked (Kao et al., 2012). Economically devastating lessons have been learned about the role of culture intensity in the emergence of new viruses and lethal *Vibrio spp*. bacterial outbreaks in intensive Penaeid shrimp monocultures (Kautsky et al., 2000). Penaeid shrimps are more vulnerable to viral and bacterial epidemics than crabs are, but relationships of intensification, immune capacity, and environmental degradation including chemical and microbial environments must remain prime concerns in the assessment of risks in mitten crab culture (Sui et al., 2011; FAO, 2006-2018).

The suitability of mitten crab hatchery technology for other crab species will be limited by differences in the biological characters of the species involved, especially the relatively mild degree of aggressiveness in small mitten crabs. *E. sinensis* is less cannibalistic than most crab species, and the captive cultivation of others such as mud crabs (*Scylla spp*.) and the blue crab (*Callinectes sapidus*) are often seriously disrupted by cannibalism in the hatchery. Refined diets in mitten crab zoeal stages are designed to contribute to synchronized molting, and reduced cannibalism; a similar approach and other steps will likely be necessary for other species.

2. Atlantic Blue Crab

The common name Blue Crab refers to at least four aquatic crab species: *Callinectes sapidus*, the Chesapeake or Atlantic blue crab endemic to coastal areas in the US and introduced elsewhere, *Portunus armatus* (formerly *P. pelagicus*), the blue swimmer crab of the western Pacific, *Portunus trituberculatus,* the heavily fished Japanese blue crab, native to the Northwestern Pacific, and *Paralithodes platypus,* the blue king crab of the North Pacific. The same common name is also used for two terrestrial crabs, *Cardisoma guanhumi*, and *Discoplax celeste*. Aquaculture of *C. sapidus* has been proposed for both stock enhancement and farming purposes and some preliminary research and encouraging demonstration work has been completed, but FAO data show that aquaculture production has remained at zero for the last 14 years,

Viewed locally in the middle Atlantic coast of the USA as a national treasure (CBF, 2008), estuarine Chesapeake blue crab populations have been on the brink of collapse in recent years. Blue crab capture fisheries are located primarily in three areas – the Chesapeake Bay, the Gulf of Mexico, and the southeastern US coast. Harvests have been declining since 1993, when 129,570 tonnes were captured (FAO, 2018). That harvest, valued at about US $100 million, was estimated to be the capture of about 30% of the population (Chesapeake Progress, 2018). A slight upturn in abundance has raised the possibility that a reversal of the downward trend may be occurring, although the 2017 crabbing season was shortened in Maryland because of unexpectedly poor estimates of *C. sapidus* population size (CBS Baltimore, 2017). Declines in the abundance of blue crabs are attributed to environmental degradation, poor water quality, the loss of suitable and sheltered nursery areas, and a pattern of overharvests. Long-term declining harvests have been accompanied by sharp reductions in spawning stocks and in poor rates of larval abundance and recruitment (Lipcius and Stockhausen, 2002). Although their analysis indicates that population abundance is down and the Chesapeake Bay area is considered to be overfished, Monterey Bay Aquarium's Seafood Watch advisory service with expertise in sustainability lists wild-caught Chesapeake Bay blue crab as a "best choice" (Monterey Bay Aquarium Seafood Watch, 2018).

An environmental restoration plan for the Chesapeake Bay is underway, with participation from six US states and numerous state and federal agencies (EPA, 2017). Extensive environmental actions and control measures have been implemented with the intention of improving the ecological status of the bay, with targets for reversing eutrophication by establishing limits of nutrient (N and P) concentrations and sediment loads in the watershed. The loss of seagrass, oyster reefs, and other shallow water habitat in middle Atlantic coastal areas in the US has eliminated important sources of refuge for wild juveniles, increasing their exposure and their vulnerability to predation and cannibalism (Hines and Ruiz, 1995). Ambitious conservation measures appear to have produced some progress toward restoration targets, although ecosystemic recovery is a slow process. It is also a process that appears to have been hampered by political and other issues (Baltimore Sun, 2017).

Efforts to culture and farm *C. sapidus* have been sporadic, and limited for the most part to demonstration-scale projects. Academic hatcheries in the US at the University of Maryland and the University of Southern Mississippi have reared blue crabs as demonstrations, toward eventual privatization. Out-of-season spawning, problem-free larval rearing, and successful metamorphosis to the postlarval stage on a diet of rotifers (*Branchionus plicatus*) and *Artemia sp*. nauplii were reported by Sulkin et al. (1976). The culture of large numbers of zoeae is not especially challenging, but survival among post-metamorphic megalopae is problematic. Cannibalism accounts for up to 97% of the juvenile diet in this species, and the degree of cannibalism in a wild cohort is considered to be the primary determinant of its recruitment success (Hines and Ruiz, 1995). The extremely high incidence of cannibalism has stifled hatchery production of juvenile blue crabs.

A multidisciplinary consortium was organized in 2001 to promote the development of technology to support the *C. sapidus* fishery, with a focus on aquaculture. Importantly, this consortium had government backing and industry (Phillips Foods) and commercial fisheries participation. The Blue Crab Advanced Research Consortium (BCARC) subscribes to principles outlined by Blankenship and Leber (1995) and others for responsible, scientifically informed and multifaceted environmental management.

The decline of breeding stocks and persistent overexploitation of Chesapeake and Carolina *C. sapidus* populations suggest a potentially favorable prospect for the replenishment of wild stocks from hatchery sources. Stock enhancement is considered promising for populations that are consistently smaller than environmental carrying capacity, as is the case with *C. sapidus* in Chesapeake Bay (Seitz et al., 2008). A BCARC-affiliated University of Maryland (UM) study of the feasibility of blue crab culture for stock enhancement purposes examined a variety of methods that appear to have some potential to reduce the rate of cannibalism by megalopae. The observation that juvenile crabs reared individually in isolation exhibited 100% survival was cited as evidence that losses to cannibalism can possibly be reduced. Manipulations of diet, stocking density, grading by size and the provision of shelter substrates were tested at the UM Center for Marine Biotechnology, or CMB (Zmora et al., 2004). Larval culture yielded large numbers of zoeae (>40%) that metamorphosed into megalopae, and extensive cannibalism reduced the proportion of surviving juveniles to about 10%. Tagging and release in 2002 of >290,000 hatchery-reared juveniles and their recapture as adults supported the conclusion that stock enhancement of this species is capable of helping to rebuild declining wild blue crab populations (Davis et al., 2005). Hatchery reared blue crabs totaling 515,000 were released between 2001 and 2007 in annually increasing quantities, with favorable rates of recovery and a demonstrable entry into the pool of actively reproducing adults (Zohar et al., 2008). Cultured crabs in those studies performed similarly to their wild counterparts. Additional investigations described as under development experimentally addressed the effectiveness of release strategies as functions of timing, location, juvenile age, conditioning, stocking variables, habitat, and hatchery operating costs (Heinz et al., 2008). Citing the success of these demonstrations and the effectiveness of a program of stock enhancement of the Japanese blue swimming crab, *Portunus trituberculatus* (Arayama et al., 2001), Zohar and colleagues forecast the release of up to 16 million cultured *C. sapidus* crabs per year into Chesapeake Bay waters (Zohar et al., 2008).

Callinectus sapidus impact on biodiversity is disturbing. It mutilates trapped fish, preys on bivalves such as clams, mussels, and oysters in wild and in aquaculture operations as well (CABI, 2019). It is the most notable predator of clams and oysters especially in the United States of America, contributing heavily to the large-scale mortality of American bivalves. It is recorded that it can prey on 575 clams per day with highly destructive impacts. So CABI (2019) suggests protection and control measures in any culture with abundant *C. sapidus*.

Juvenile crabs from the CMB study were also used to stock ponds for culture on at least one freshwater farm in North Carolina (NCSU, 2008), with a prediction that 20% survival of crabs in freshwater ponds could be anticipated, with expected revenues of $36,000 per acre. A flurry of YouTube, eHow, and Pintrest posts followed, recommending commercial *C. sapidus* farming. FAO aquaculture data between that time and the present tell a less optimistic story. *C. sapidus* harvests from aquaculture occurred over an eight-year period with a peak harvest in 2001 and zero after 2004 till the present date, as exemplified in figure 3, below.

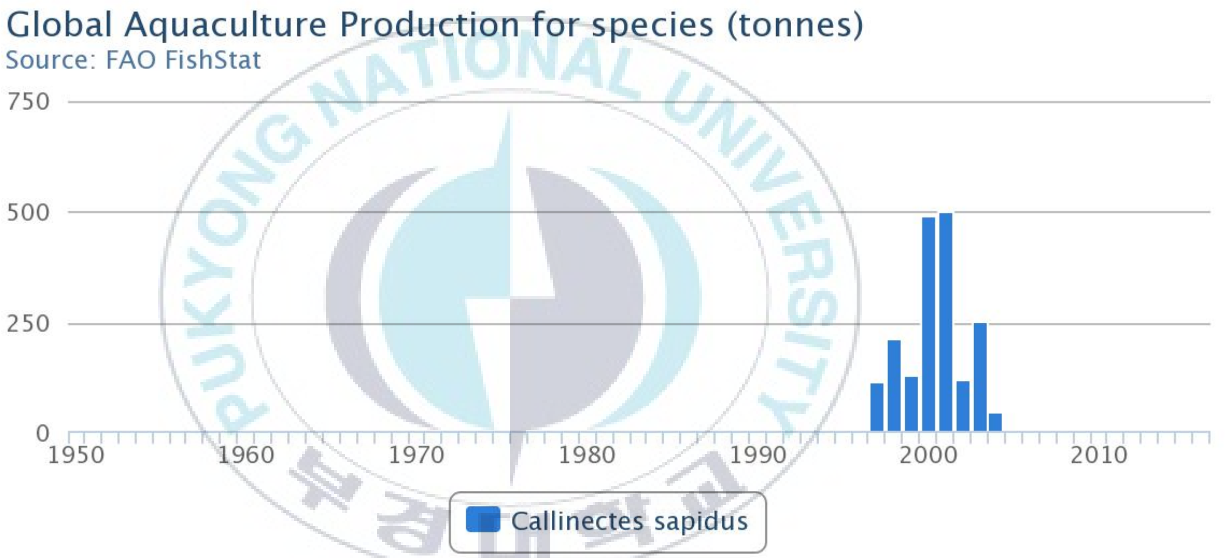

Figure 3: Aquaculture production of Callinectes sapidus between 1950 and 2016

2.1. *C. Sapidus* Status and Prospects

Harvests of *C. sapidus* have been on a declining trend (FAO, 2018), as indicated on the figure above and at least in part because of the reduction by more than 80% of the spawning stock (Lipcius and Stockhausen, 2002). Highly fecund, omnivorous R-selected species like the blue crab have the capacity for resilient recoveries, but reproductive stock abundance has remained generally depressed (see Hines et al., 2008) followed by some inconsistent signs of recovery (Maryland Department of Natural Resources, 2017).

The multidimensional recovery plan implemented for the Chesapeake Bay and in particular the plan to rebuild the *C. sapidus* population (EPA, 2017) has produced some encouraging results; the total number of crabs in the bay has increased from 2008 to the present, but it is still far below 1990 and 1991 levels (Maryland Department of Natural Resources, 2017). It is also subject to unexpected and short-term fluctuations. The abundance of crabs in Chesapeake Bay declined 18% from 2016 to 2107, and the recruitment of young crabs declined by 54% during the same period (Maryland Department of Natural Resources, 2017). Disappointment in those 2017 survey results and the apparent reversal of a short-term trend of improvement led to conflicts and the disruption of scientifically-based management processes (Baltimore Sun, 2017).

The Chesapeake Bay appears to be a suitable location for blue crab stock enhancement activities. The MCB studies cited above and more than a decade of hatchery research at the Gulf Coast Marine Laboratory, University of Southern Mississippi (Blue Crab Technical Task Force, 2015) identified the movement of laboratory demonstrations of hatchery and stock enhancement toward full implementation, but that has not happened. Plans call for habitat restoration in the form of improved Atlantic estuarine water quality, the recovery of oyster reefs and seagrass beds, and other factors contributing to ecosystemic health. Practical technology for hatchery production of ample numbers of megalopae has been demonstrated (Zmora et al., 2005; Zohar et al., 2008), as has their probable incorporation into reproductive *C. sapidus* stocks (Hines et al., 2008), but economic feasibility and the harmonious cooperation of user groups remain uncertain.

3. Mud Crab

There are four main species of mud crab, *Scylla serrata*, *S. tranquebarica*, *S. paramamosain* and *S. olivacea.* These four species can be produced from both commercial fisheries and aquaculture production throughout their distribution (Shelley & Lovatelli, 2011). They are among the most valuable crab species in the world and are mainly sold live. Among the four, *S. serrata* is preferred by farmers because it is larger and less aggressive than the other species (Quinitio et al., 2009). Interest in the aquaculture of this species has been high due to the high demand/price for them, high flesh content, and rapid growth rates in captivity. In addition, they have a high tolerance to both nitrate (Romano & Zeng, 2007B) and ammonia which is beneficial because Ammonia-N is often the bottleneck to production in closed aquaculture systems (Romano & Zeng, 2007A).

Mud crab aquaculture is dependent on the above-mentioned traits and crab seed collection from the wild, mostly from estuaries and coastal mangrove areas. The low success in hatchery and larval rearing is attributed to high mortalities at every level of larval development. Cannibalism, poor water quality, bad environmental conditions, problems of feeding and nutritional deficiencies, parasitic infections, fungal infections, viral diseases and bacterial diseases all contribute to early mortality. These high mortalities can be seen in the ending part of rearing period as well because during rearing, the water quality deteriorates from the accumulation of feces, dead larvae and uneaten food at the pond bottom, promoting the outbreak of pathogenic bacteria and other diseases organisms. Application of probiotics to the medium is seen by some as a suitable solution (Lavilla-Pitogo *et al*., 2002). The use of antibiotics has been recommended, e.g. 20 mg/L streptomycin (Takeuchi et al. 2000) or 2 mg/L Sodium Nifurstyrenate (Hamasaki et al. 2002b) or as a bath (100 mg/L Oxytetracycline) for Z1 larvae before being stocked into pilot scale systems (Baylon and Failaman 2001), formalin: e.g. 25 mg/L of formalin (Kaji et al. 1991) and a 24 hour LC50 for S. serrata Z1 has been estimated at 37 mg/L (Churchill 2003). Other prophylactics that kill bacteria can be used to mitigate the problem. Note that these references advocating antibiotic and disinfection approaches are all somewhat dated, and these methods are viewed less favorably now. Other control measures include proper hygiene, treatment of water before use and high rates of water exchange.

There has been an increasing trend in mud crab production during the last two decades (up to 2008). The total production of mud crabs from aquaculture in Asia and Africa was over 138,000 tonnes valued at nearly USD 377 million in 2008 according to FAO (2008) and China is the largest producer of farmed mud crabs. The Philippines and Indonesia are also major producers, followed by Myanmar. With the establishment of hatcheries in some countries, worldwide mud crab production is expected to continue to increase. FAO in 2016 reported that global total farmed mud crab (*S. serrata*) production was 89,390 tonnes which showed a remarkable increase in production from year 2010 total production of about 36,992 tonnes. The figure below, significantly shows the total production of mud crab since 2010 has been on the increase till 2017 when there is a slight decrease in productions. Cannibalism, disease outbreak, farmers abandoning crab farming are some of the reasons the total landings have been on the decline. The peak production was in 2016, where more than 90 thousand metric tonnes of mud crab were landed.

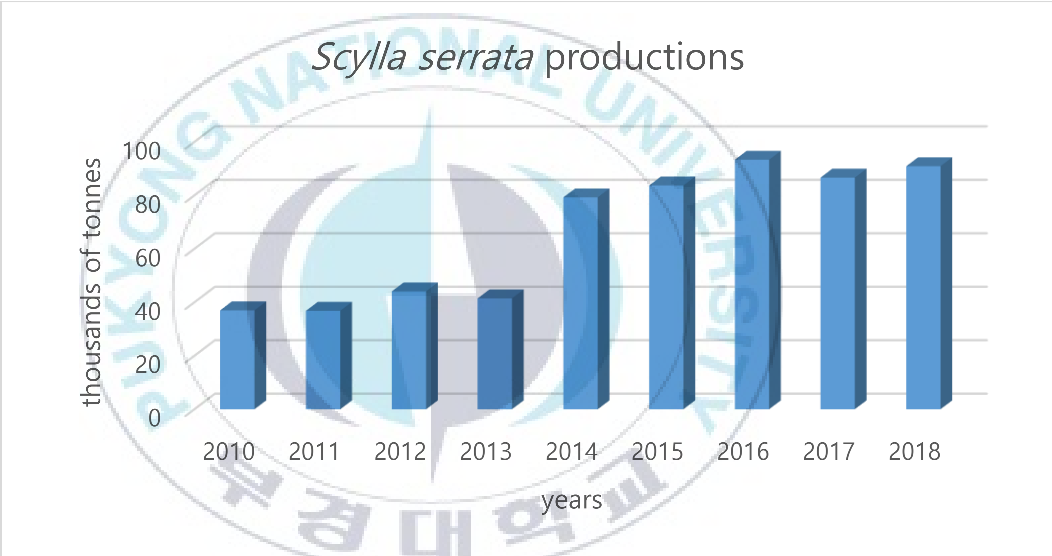

Figure 4: Aquaculture production of Scylla serrata between 2010 and 2018. redrawn from FAO data

This increase in mud crab aquaculture production also led to the increase in value in USD over the years and has contributed to the world economy, majority of these coming from China, South Asia and Africa. It was recorded by FAO in 2010 that the total value of mud crab aquaculture was about 2 hundred thousand

USD and in 2011 it was about 7 hundred thousand USD showing the corresponding increase in value with increase in total tonnes of yearly productions. The yearly production of 2015 was higher in tonnes than that of 2014 but the monetary value of that 2014 is higher than that of 2015, and the same issue was repeated between 2017 and 2018 (highest production in 2018 but the value is low compared to that 2017). There is little room for doubt that prominent success in the hatchery technology or procurement of larvae and juveniles will further increase the harvest and at the same time increase the value of total production. This increase in value over the years is shown in figure 5, below.

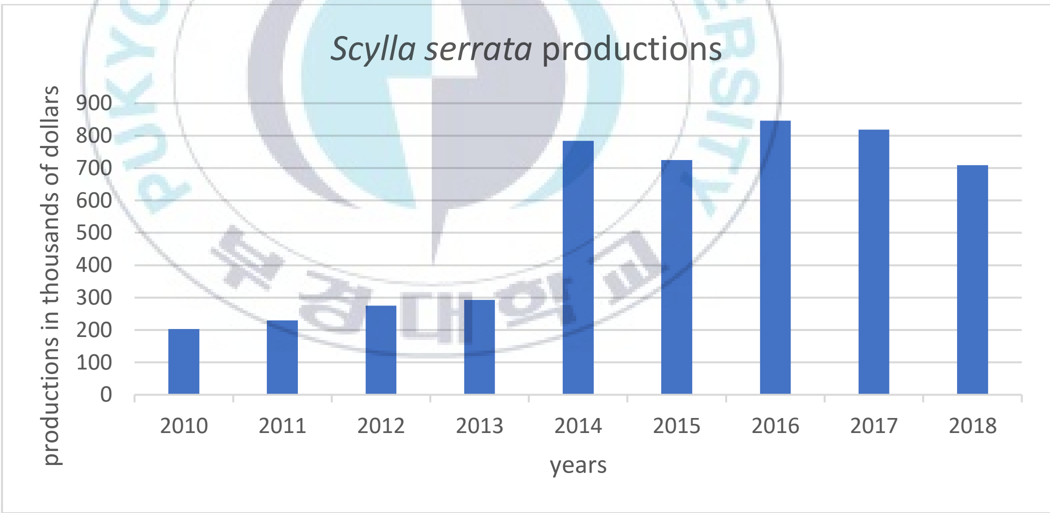

Figure 5: Increase in total harvests value in USD of the mud crab aquaculture industry, redrawn from FAO data.

Mud crab culture as stated by Primavera et al. (2010) has a relatively moderate effect on the environment, since low stocking densities are used to limit cannibalism by these species. The cannibalistic behaviour in mud crab can be reduced by sorting and grading by size, as well as by making shelter available for them (Mirera et al., 2013). The small crabs and crablets use the shelter as refuge and cannibalism in larger crabs tends to decrease. The culture can contribute to environmental conservation through integration with mangroves and the reseeding of natural populations. Construction of ponds and for farming is not encouraged, partly to avoid further deforestation and destruction of mangroves. The culture of mud crab in mangroves where they exist mutually is a symbiotic and environmentally friendly relationship, and a good approach to the sustainable culture of mud crabs. The mangroves serve as shelter and refuge to the mud crabs while the mud crabs burrow the soil for easy penetration of the roots of the mangroves.

The global problems of mud crab farming are associated with the unavailability of crablets for the expanding industry, disease prevention and control in hatchery and grow-out, cannibalism especially in nursery phase and increasing use of fish meal in the production and feeding of mud crabs. Cannibalism has been the most challenging problem of them all, which farmers have little or no knowledge on how to avoid entirely other than the reduction of stocking density.

4. Gazami Crab

Portunus trituberculatus, the Gazami crab known as Japanese blue crab or horse crab is the most widely sought-after crab of Portunus species or the most fished Portunus crab species in the world. It is mostly seen at the off the coast of east Asia as in Japan, Korea, China and southeast Asia countries (Hamasaki et al., 2006) and form important part of fisheries of these countries (Hamasaki et al., 2004, Yu et al., 2006). It is closely related to *Portunus pelagicus* and it is one of the dominant species of swimming crabs, of which the other two are *Portunus pelagicus* and *Callinectus sapidus*. The fisheries of the three dominant species appear to have grown over the past three decades, but harvests of the two Portunus species have increased at a more rapid pace than for *C. sapidus* (FAO 2000 and David et al., 2002). A decline in natural resources and everyday increase in market demands have led to interests in development of aquaculture techniques for *P. trituberculatus* (Xue et al., 1997). This led to rapid emergence of the hatchery seed production and pond-culture of *P. trituberculatus* which spread quickly along the coastal regions of east China since the 1990s (Xie et al, 2002). The interests in farming of *P. trituberculatus* have been affected by the outbreak of viral diseases in shrimp farms especially in China over the years, according to Xue et al.,1997 and Xie et al., 2002, since Portunid crabs can act as carriers for viruses. *P. trituberculatus*, in east China has been seen and encouraged as an alternative species to farmers for saltwater pond aquaculture (Shi et al., 2007) and this consequently increased aquaculture production of *P. trituberculatus* to 83,465 tons in 2006 (Liu et al., 2007). Interest in the aquaculture of this species just like other species of crabs has been high due to the high demand/price for them, high flesh content, and rapid growth rates in captivity especially in Japan and neighbouring countries. Other driving forces include; high export and import value, low labour cost, ability to withstand harsh weather conditions, good source of protein especially to the coastal communities and a viable source of employment for the teeming population.

Gazami been widely distributed has high genetic diversity, this challenges our knowledge and understanding of its biogeography (Bradley et al., 2020). The interest in stock enhancement (supplementing natural fish population using hatchery produced fingerlings/juveniles) and aquaculture of this crab led to the interest and research on its early life stages (Bradley et al., 2020). Just like other crab species, high mortalities in the early life stages of the larval development are the major cause of poor hatchery and production output. This early life stage mortality is a result of several factors like cannibalism, poor water quality, bad environmental conditions, problems of feeding and nutritional deficiencies, parasitic infections, fungal infections, viral diseases and bacterial diseases. Cannibalism and aggressiveness of this species contributes more to this problem, which is a major discouragement to hatchers and grow out farmers.

Currently, the brood stocks from the wild are used for seed production of *P.*

trituberculatus, which could hinder or stunt development of this crab aquaculture industry in China sustainably (Xie et al., 2002, Shi et al., 2007), Japan, Korea and other parts of east Asia. The quality and quantity of those wild caught brood stocks are inconsistent, and can introduce pathogens into farming system (Coman et al., 2006, Meng et al., 2009). Furthermore, the natural recruitment process and fisheries production of crab could be affected by the constant and increasing removal of mature crabs from the wild to serve as brood stocks for hatcheries (Fu et al., 2006). Coman et al., 2006, Peixoto et al., 2008 and Gao et al., 2008 opined that the only remedy to this problem is the utilization of domesticated stocks for hatchery production which should also facilitate genetic selection for desirable traits, such as rapid growth and pathogen resistance.

There have been trends of increasing and decreasing Gazami production over the past ten years. The capture fisheries of Gazami crabs are supplemented by the crablets from the hatchery and aquaculture. So, stock enhancement has been a very important part of Gazami capture production, as in Japan where a "put and take" enhancement method is practiced by releasing hatchery produced juveniles and fingerlings into water bodies. They are caught by the fishers after 6 to 8 months of their release prior to spawning and reproduction (Hamasaki et al., 2011). For this reason, it is impractical to view the production of Gazami crabs by capture fisheries and aquaculture productions because the two are thoroughly integrated. The production is mainly in Asia and was over 385,000 tonnes in 2010 (FAO, 2010) and south east Asia is the largest producer of Gazami crabs. It was reported by FAO in 2018 that global total production of Gazami crabs (*P. trituberculatus*) was 493,134 tonnes which showed remarkable increase in production from year 2010 total production of about 385,346 tonnes, but there was a decline in total production when compared that of 2018 to 2017 total production.

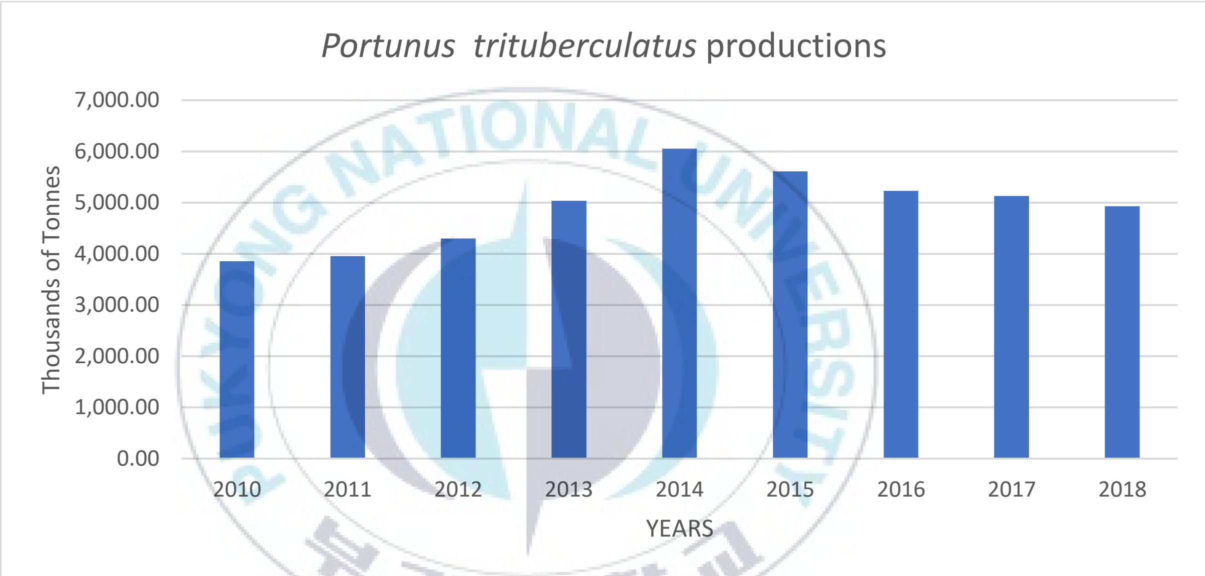

Figure 6: Growth in total harvests in the Gazami crab aquaculture industry, redrawn from FAO data.

Figure 6 shows the total production of Gazami crab from 2010 to 2018. This illustrates a consistant increase in total production from 2010 till 2014 and from 2015, the production started declining till date. The peak production was in 2014, where more than 600,000 metric tonnes were produced. A number of factors might be responsible for this decline in production. These factors include; lack of hatchery success, lack of reliable seedstock source, aggressiveness and cannibalistic nature of the species, broodstock availability, lack of capital to foster the production processes, lack of technical know-how, disease outbreak, pollution, poaching, etc.

5. Blue Swimming Crab (*Portunus Pelagicus*)

Portunus pelagicus, recently has its name changed to *Portunus armatus* (Craig, 2016) and can also be referred to as Flower Crab, Blue Crab, Blue Swimmer Crab, Blue Manna Crab and Sand Crab depending on the location found. It is famously called *rajungan* in Indonesia. The crab is commonly found in most of the Australia estuaries and east to New Caledonia (Lai et al., 2010). "Blue Swimming crab lives in a wide range of inshore and continental shelf areas, including sandy, muddy or algal and seagrass habitats, from the intertidal zone to at least 50m depth" (FAO, 2014). Studies recently revealed that the crab can adapt to a variety of habitats and populations may be comprised of different species. According to Lai et al., 2010 the known *Portunus pelagicus* actually has four different species which are *P. pelagicus, P. segins, P. reticulatus, and P. armatus* differentiated by their colors of the carapace and other morphological features. It can be seen in southeast Asia (Japan and Philippines), East Asia (Indonesia), Fiji Islands, westward to the Red Sea and east Africa.

Portunus pelagicus is heavily fished. In Indonesia and India where its an integral part of the aquaculture and valuable seafood industries, its supply and harvest are declining because of the yearly increase in demand for the crab from the growing population, which leads to overexploitation (Mehanna et al., 2013). This pattern can be seen in yearly catches, both in quantity and in quality. The livelihood of the people depending on *P. pelagicus* as source of protein is threatened together with concerns about sustainability, which can directly or indirectly affect the economy of these countries. To combat this rising problem, rearing and stock enhancement of blue swimming crabs is seen as most desirable solution (Gadhavi et al., 2013). The rate at which it is been fished is higher than the natural recruitment rate, which leaves stock enhancement process as the only way to curb this defect, avoiding the species from extinction (Nicholas et al., 2007). Soundarapandian et al., (2013) also opined that conservation and good management practices are the biggest challenges and the promotion of sea ranching is an effective solution. Muthiga (1986), suggested that releasing of juveniles, gravid crabs and newly moulted ones to the wild is a means of avoiding overexploitation and transitioning to sustainable harvesting.

The capture of young, undersized and gravid *P. pelagicus* should be discouraged through education, creation of awareness among fishermen and implementation enforcement of laws. Closure of fishing area, the release of non-target/undersized crabs immediately, minimizing of fishing effort, seasonal banning of crab shipment, mesh size regulation, regulation of fishing areas, restriction and ban of destructive gears and prohibition of unorthodox fishing methods are good ways to eliminate these problems. In Australia, some areas such as South Australia, New South Wales, Western Australia and Queensland states prohibit the catching of crabs with carapace sizes below 11cm, 6cm, 12.7cm and 11.5cm respectively (Wikipedia 2021).

Wild blue swimming crabs are caught, domesticated and used in hatcheries to propagate crablets and make them available for culture and the replenishment of the wild stock. It is a good aquaculture crop because of their fast growth rate, ease of larviculture, high fecundity, tolerance to ammonia (Nicholas et al., 2007a Nicholas et al., 2007b), acceptance of artificial feeds and adapt to changing/new environments. The desirable increase in *P. pelagicus* production can be achieved through intensive aquaculture system (Harris et al., 2014). Capture and aquaculture compliment the other because the hatchery depends on wild broodstock animals while the wild stock depends on hatchery produced crablets for recovery. The success of aquaculture of *Portunus pelagicus* as reported by some researchers is attributed to low growth performance and survival rate (Fujaya et al., 2016), disease incidence during culture, molting syndrome, cannibalism, and lack of feeds for optimal nutrition (Govindasamy and Srinivasan 2012). Nutrient completeness and adequacy are important to ensure the normal growth and development of the crabs and the nutritional requirements for proteins, fats, carbohydrates, vitamins, and minerals differ by crab type, age and size (Efrizal et al., 2019).

The grow out aquaculture production of blue swimming crabs both in the past and present show a pattern of diminishing landings. This is guessed to be as result of the use of the majority of crablets from hatcheries for enriching the wild stock. FAO data (2018) indicate that the production of blue swimming crabs is carried out primarily aquaculture in Asia, Africa and Oceania. FAO (2018) reported that global total cultured Blue swimming crab production was 24 tonnes, which showed considerable variability in production from year 2009, with the lowest annual production in recent years of 20 tons.

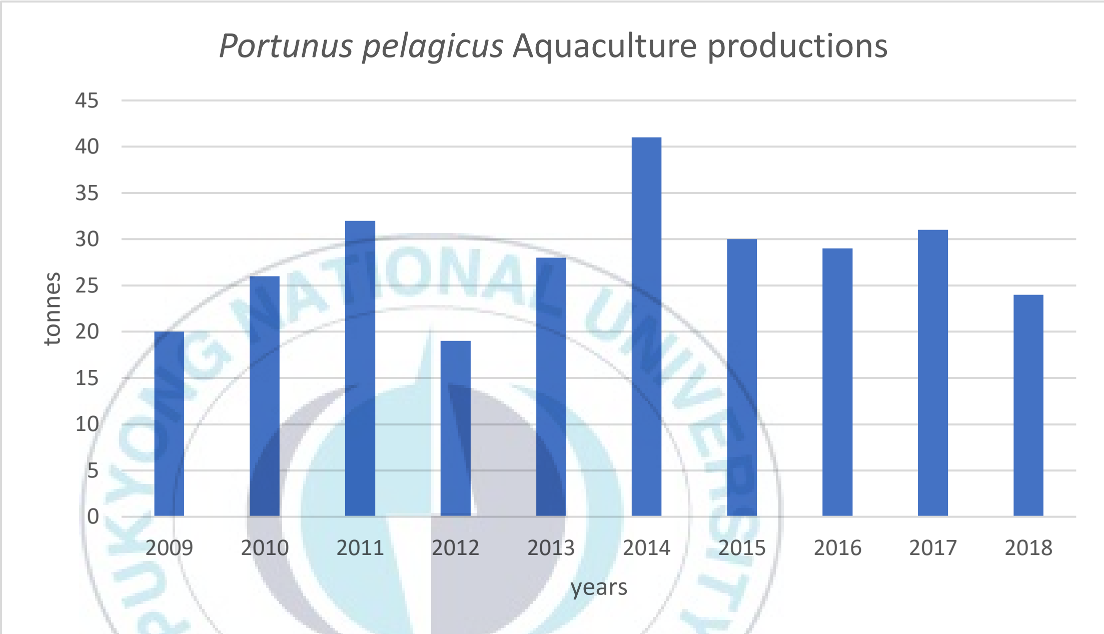

Figure 7: Aquaculture production of Portunus pelagicus between 2009 and 2018. Redrawn from FAO data.

This production compared to aquaculture production of other crab species is very small and serious attention is needed in this species to optimize produciton. From figure 8, the total production of *Portunus pelagicus* since 2009 has been fluctuating. There have been increases and decreases in yearly production since 2009 but the highest landing of 41 tonnes was recorded in 2014.

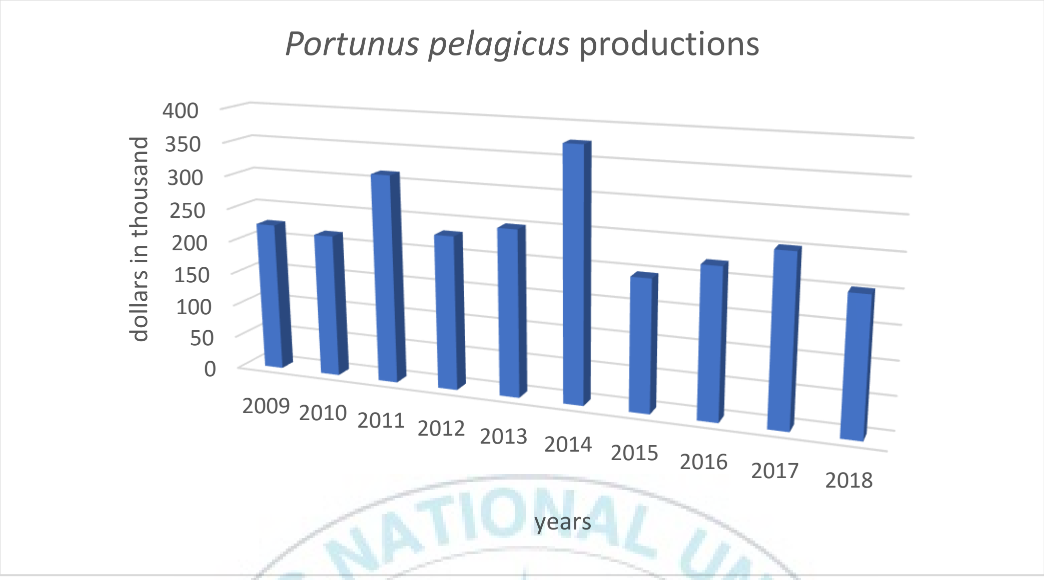

Figure 8: Total harvests value in USD of the Blue swimming crab aquaculture ind ustry, redrawn from FAO data

Figure 8 shows the yearly monetary values in USD between 2009 and 2018 as recorded by FAO in 2018. The total value of blue swimming crab aquaculture was about 225,000 USD in 2009, 376,000 USD in 2014 which shows there was increase in value as the production increases. 2014 happened to be the year of highest return in value as well and 2015 the year of lowest return in value but among the highest producing years in tonnes.

III. POTENTIAL OF CRAB FARMING IN AFRICA

Capture fisheries dominated in Africa before the turn of 20th century when aquaculture was introduced to enhance stocks for the recreational fishing needs of the then colonial masters (Hecht et al., 2006). FAO in 2005 reported that static water was used first to successfully culture Tilapia in Kenya in the 1920s. This is known to be the first aquaculture activity in Africa before it was more broadly adopted in order to attain sustainable food production. This act was driven by the bid to combat poor nutrition and lack of employment especially in rural areas, and to provide an additional source of income. Aquaculture in Africa concentrates on finfish, with smaller quantities of shellfish culture. The most common finfish species cultured are catfish and tilapia and culture is primarily found in Egypt, Nigeria and Uganda as key players of aquaculture industry in Africa (Babatunde et al., 2020). Tilapia in Egypt is the most cultured species, which account for 67% of the total cultured fish in 2014 (Shaalan et al., 2018). Other species cultured in Egypt include mullet, gilthead seabream, European seabass, Penaeus, catfish and meager (Shaalan et al., 2018). Catfish, tilapia and carps are commonly cultured species in Nigeria but the catfish culture dominates, accounting for more than 80% of aquaculture production followed by tilapia (Anetekhai Agenuma 2010).

Historically, ancient Egypt was among the very early aquaculture practitioners. Most African aquaculture farmers concentrate on finfish, leaving the aquaculture of shellfish relatively undeveloped. Africa's aquaculture contributes about 2.7% to the total global production, which is a relatively insignificant portion considering population size and nutritional requirements (Halwart 2020). Freshwater aquaculture dominates by contributing about 99% of Africa total production while marine aquaculture contributes 1% (FAO 2018). Factors like capacity building and human development, research and development, fund accessibility, promotion of private sector led aquaculture, etc. has led to remarkable increase in the aquaculture of these top countries over the years (Satia 2017). Industry growth in Egypt sees has been the subject of government interventions in past years, coupled with increasing investments in private sector, yielding positive aquaculture growth and development (Soliman and Yacout 2016). These increases are largely a consequence of investments in catfish and tilapia production, with relatively little attention to shellfishes (crustaceans and mollusks) such as shrimps, crabs, oysters, clams, etc. This component of aquaculture is much more substantial in Asia, Europe and the Americas. FAO in 2016 reported total production to be 2,115,000 tons, which shows a dramatic increase in total production to what was produced as far back as 1995 which is 150,000 tons and this might be as a result of those factors mentioned earlier. More than 6.2 million people are employed in African aquaculture, majority of them are women who engage in commercial aquaculture (Satia 2016). This author indicates that African women are mostly employed in postharvest and marketing components of African aquaculture business. It is believed that they engage more in fish handling, processing, packaging and storage because of the perception that outfield activities of aquaculture are not easy to run, leading to their concentration in post-harvest activities and the marketing sector.

The world human population continues to increase steadily and it is predicted by experts to reach 9.6 billion come 2050, with Africa as a continent expected to have faster growth rate than others (UNDESA, 2013). UNDESA in 2009 reported as well that about 1.4 billion people are living in poverty (< 1.25 US dollars/day) of which 28% of are from Africa. Poverty is not just all attributed to the lack of or low income, but the lack of access to good education, housing and health care contribute to hunger and malnutrition. The demand for fishery products by the teeming African population has resulted in capture fishery stocks currently being in a fully exploited state, often seen as on the verge of collapse (FAO, 2012). Problem of climate change and overfishing causes the declining trend of African and other tropical capture fisheries (Worm and Branch 2012). Because of these complications, aquaculture of finfish alone is not likely to be an adequate solution to the limited availability of fishery products, and the development of a crab culture industry in Africa can help substantially to solve these rising problems. Crabs are among the mostly consumed and farmed shellfish after shrimps and prawns. In Africa, the mud crab (*Scylla serrata*) is mostly seen as a candidate for large-scale production to help compensate for the declining capture fisheries in order to meet the ever-increasing market demand. Mud crab aquaculture in 2011 contributed about 0.2 million tons to the world total aquaculture production and over 89% of this production is from China and south east Asia (Shelley, 2008; FAO, 2012). As is the case everywhere, Africa faces the challenge of sourcing of seed animals, coupled with high dependency on and limited availability of wild juveniles. This has hindered the continuous expansion of crab aquaculture. Moreover, in southeast Asia and China, mud crab hatcheries are being set up to address this issue within the most recent decade (Quinitio et al., 2011) but that is not the case of Africa. FAO, in recent years set up a hatchery in Cameroon but it failed to live up to the expectation, possibly as a result of lack of trained personnel to manage the activities in the hatchery. “Availability of juveniles from hatcheries reduces competition with wild fishery, increase mud crab production per area, facilitates planning for production by farmers and reduces the size difference of the seed stock as opposed to when seeds are collected from the wild” (Shelley, 2008). However, the procurement of seeds from the hatcheries is more expensive compared the collection of wild seed because of technological requirements and initial investment costs. Consequently, the dependence of crab farms on wild seeds in Africa is almost certain to persist unless there is technological advancement, investment by the governments and cooperative efforts toward hatchery development.

Efforts to develop crab farming in Africa have been slowed by a number of factors including the lack of knowledge of rearing techniques, poor extension services, high rate of mortalities, lack of crablets and good quality seeds, lack of good quality feed, etc. (David et al., 2014). There are no known hatchery facilities and that are currently fully operational in Africa, but in south east Asia and China there are a number of improved crab hatcheries meeting the need for seed supply for crab farming in those areas (Mirera, 2011). The spread of this technology in south east Asia and China is worthy of emulation, if the crab farming development in Africa is to be reality. The initiatives developed in the past to help boost the aquaculture of crab in Africa have failed to achieve sustainability, and the lack of history of aquaculture, political instability, socioeconomic constraints and inadequate technology have all contributed to the failure (Troell et al., 2011). This is in contrast with east and southeast Asia where all these factors are well managed and are in place, leading to dramatic increase in growth of crab farming in the last decades (Jiang, 2010). There can be collaboration between developing countries and countries that have been successful with crab farming to foster the development in Africa. Countries such as China, Philippines, Vietnam, etc., are industry leaders and their expertise could facilitate the development of crab farming in Africa. Success in this discipline could help foster the development of aquaculture in Africa generally. Inclusive research, training and workshops that involves experts collaborating with the farmers is a good medium to improve their skills and further develop the industry (Lionberger and Gwin, 1991), and China in particular has a history of this sort of technical relationship with developing countries.

The development and success of crab farming as part of aquaculture in Africa is possible just like that of catfish and tilapia. This could boom when the problems and factors earlier mentioned are addressed because it is a known profitable venture. Addressing these problems means that there should be proper and good extension services, development of active hatcheries for the provision of crablets all year round, inculcating knowledge of rearing techniques (crab behaviour in captivities at all stage) in potential farmers, support and development of private sectors by the government and the use of rearing techniques that will reduce mortalities (David Oersted and Mirera 2014). Studies on crab mortality revealed that mortality is lower in cultures relying on seeds from hatcheries than the seed from the wild dependent farms (David Oersted and Mirera 2014). So, crab farming, if developed and managed well could be a good source of livelihood, welfare and a source of food (protein) to the rising population of Africa and other developing countries, especially their poor communities and settlements (Brummett and Williams, 2000). The ever-increasing pressure on fish and beef as sources of protein will reduce as a result of availability of crab meat readily in the market and to some length help solve the problems of malnutrition that has devastated so many communities in African countries. Because Aquaculture promotes economic development through provision of employment and much needed job opportunities (Bene 2005), developed crab farming as part of aquaculture will contribute the job and wealth creations in Africa, thereby reducing the problem of unemployment, poverty and wastage of manpower in the teeming population. Aquaculture, has excellent foreign exchange potential and this potential is attained through the export of processed and nutritionally rich crab meat and its byproducts to international markets. Asia, Europe and the Americas are lovers of crab meat and the production in large quantity here in Africa and exportation to these places will promote international trade relationships of countries involved and as well improve their foreign exchange earnings, thereby improving countries economy directly (Megan et al., 2018) and indirectly through the purchase of products such as feeds, tanks, chemicals, etc., used in the production processes. The success of these allied industries is driven by the success and failure of the aquaculture industry.

1. Economic, Nutritional, and Medicinal Benefits of Crabs.

Many scientists and commercial fishers hold crab as an important creature. They are considered as plastic animal because of its ability to withstand wide range of environmental variation (Saroj, 2018). The availability of crabs couple with its plastic nature, made researchers and biologists to always use it as biological model (Reinecke, et al., 2003). Their ecological role in food web which is provision of prey for both vertebrates and invertebrates, they feed on so many plant materials which brew competition between them and herbivorous fishes together with other small animals that feeds on vegetations. The capture of both small and large crabs, keeping of the colorful ones in the aquarium shows its recreational and aesthetic values. Crab been the most diverse crustacean that exists, with few of them known to be poisonous, many of them are eaten by human in almost every parts of the world (Saroj, 2018) and they serve as food to many organisms too. They add more natural oils such as omega 3 fatty acids into diets and helps regulate cholesterol levels because of the provision of white meats as opposed to red meats from beef and other meat sources. Crabs are an important protein source which are sought after and consumed in every parts of the world. The availability, reduces the deficiency diseases of protein such as kwashiorkor. Saroj (2018), reported that true brachyuran crabs which is the most important, valuable and edible of the British and European coasts are being consumed and has being making waves commercially since world war II. Moreover, in north America, the most consumed and commercially important crabs are the blue crab (*Callinectes sapidus*) and the Dungeness crab (*Cancer magister*) (Zannatul et al., 2010). *Scylla serrata, S. tranquebarica, Portunus sanguinolentus, P. pelagicus, Podophthalamus vigil, Charbdis feriata, C. lucifera, C. natator, C. granulata and C. truncata* made up of crab fishery in India and this sector is developing very fast because of the meat delicacy and nutritional richness (Samuel et al., 2004). This as well contributes to the development of the India aquaculture industry in general (Reddy and Reddy, 2006), provision of employment, food, income and improves the country's economy through the earning of foreign exchange. Aquaculture of crabs also reduces the time spent on the sea by the fishermen looking for wild crabs. It gives them ample free time to go after other economic activities that will give them extra income. *Scylla serrata* (mud crab) is an important delicacy in Africa, especially in east Africa (Kenya) but harvested mainly from the wild, aquaculture of this crab is still underdeveloped. The aquaculture of crabs will help reduce seafood trade deficit at a very low production cost because the importation of crab meats especially from China and other south east Asia will be reduced and the local production will offer fresher and cheaper seafood due reduced transport cost and time.

Kashyap, (2017), opined that crab meat is energy giving source and as well a good remedy for blood diseases. *Cancer pagurus* can be used to cure cough and cold and its dried skin boiled with water is a remedy for joint and muscle pains (Bagde and

Jain, 2016). Typhoid and cold can be cured using crab curry (Padghane et al., 2016). Pahari ethnic group in Nepal uses crabs (*Himalapotamon atkinsonianum*) that are roasted to stop children from bed wetting and another group called danuar eats cooked crab to aid in healing of wound and cure of asthma as well (Lohani, 2016). *Scylla serrata*, can be used to cure whooping cough, pneumonia, asthma, wounds, boils, womb disorders, tuberculosis, earache, epilepsy and many more (Roy, 2014), diabetes at old age (Chinlampianga, et al., 2013). So, aside the economic and nutritional benefit of crabs, they have medicinal values and can be used to cure several diseases such as the ones earlier mentioned.

IV. DISCUSSION AND CONCLUSION

The motive behind this research was to review the culture and status of crab globally and trying to figure out what the development of crab aquaculture will contribute to aquaculture in Africa. From the research, it was understood that culture and status of crab farming is affected by so many factors such as lack of hatchery success, lack of reliable seedstock source, aggressive nature of the animal, cannibalism, lack of broodstock nutrition, inadequate capitals, high cost of labour, lack of technical know-how, diseases, pollution and poaching. These factors are prominent both in fattening and grow-out systems and of which when addressed can lead to further development of crab aquaculture and aquaculture in general. Further development of the culture globally, especially in Africa can go a long way in improving the total production of aquaculture products, provide employment opportunities, improve food security and serve as an alternative to other protein sources and finally improving the economy and economic development.

V. REFERENCES.

Anetekhai Agenuma. M. 2010. Catfish aquaculture industry assessment in Nigeria. AfrJ Biotechnol. 9(1):73–76.

Ariyama, H, Katayama, T, Matsuda, Y, Hamano, Y., Takagaki, Y., Uratani, F., and H. Ohyama. H. (2001). Marking and tagging methods of swimming crab Portunus (*Portunus*). *trituberculatus*. II. Method for small sized crabs. *Bulletin of the Osaka Prefectural Fisheries Experimental Station*, 13: 29–43.

Babatunde Adeleke, Deborah Robertson-Andersson, Gan Moodley & Simon Taylor (2020) Aquaculture in Africa: A Comparative Review of Egypt, Nigeria, and Uganda Vis-À-Vis South Africa, Reviews in Fisheries Science & Aquaculture, DOI: 10.1080/23308249.2020.1795615.

Bagde Neelima and Jain Shampa (2016). Ethnozoological Practices of Arthropod Animals by Tribes and Rurals of Chhindwara District of Madhya Pradesh, India (2016) World J Pharma Pharmaceuti Sci. 5: 1155-1167 10.20959/wjpps201612-8248.

Baltimore Sun, (2017). March 4, 2017. Fired crab manager was not at war with watermen. Retrieved online April 22, 2018. http://www.baltimoresun.com/news/maryland/danrodricks-blog/bs-md-srodricks-0305-20170304-story.html.

Bene, C. 2005. Small-scale fisheries: Assessing their contribution to rural livelihoods in developing countries, FAO fisheries circular No. 1008. FAO Rome.

Blankenship, H.L., and Leber, K.M. (1995). A responsible approach to marine stock enhancement. Am. Fish. Soc. Symp., 15: 167–175.

Blue Crab Technical Task Force (2015). The blue crab fishery of the Gulf of Mexico, United States: a regional management plan. 2015 Revision. Publication 243. Gulf States Marine Fisheries Commission. 2404 Government St., Ocean Springs, MS 39564.

Blumenshine, S.C., Tsukimura, B., Rice, A., and Rudnick, D.A. (2012). Environmental factors influencing the dynamics of Chinese mitten crab zoeae in the San Francisco Bay-Delta. Aquatic Invasions (2012) Volume 7, Issue 1: 111–124.

Bradley G. stevens and Thomas j. miller (2020). Crab fisheries. Fisheries and aquaculture. Volume 9. 198 Madison avenue, New York, Ny 10016, united states of America. Oxford University Press 2020.

Bromilow A.M., Lipcius R.N. (2017). Mechanisms governing ontogenetic habitat shifts: role of trade-offs, predation, and cannibalism for the blue crab. Mar Ecol Prog Ser 584:145-159. https://doi.org/10.3354/meps12405

Brummett, R. E. and Williams, M. J. 2000. The evolution of aquaculture in African rural and economic development. Ecological Economics, 33, 193-. 203.

CABI; Centre for Agriculture and Biosciences International (2018). Invasive species Compendium. *Eriochir sinensis*; Chinese Mitten Crab. https://www.cabi.org/isc/datasheet/84120 . Accessed 04/23/2018.

CABI; Centre for Agriculture and Biosciences International (2019). Invasive species Compendium. *Callinectus sapidus*; Atlantic blue Crab. https://www.cabi.org/isc/datasheet/90126 . Accessed 01/05/2021

CBF Chesapeake Bay Foundation (2008). Bad Water and the Decline of Blue Crabs in the Chesapeake Bay. Chesapeake Bay Foundation report, retrieved online April 21, 2018. www.cbf.org/document-library/cbf-reports/CBF_BadWatersReport6d49.pdf

CBS Columbia Broadcasting System, Baltimore (2017). CBS news online, retrieved April 22, 201http://baltimore.cbslocal.com/2017/06/27/crabbing-season-cut-short-report-finds-decline-in-crab-population/

Chang, G., Wu, X., Cheng, Y., Zeng, C., and Yu, Z. (2017). Reproductive performance, offspring quality, proximate and fatty acid composition of normal and precocious Chinese mitten crab *Eriocheir sinensis*. *Aquaculture 469*: 137–143.

Cheng, Y., Wu, X., Yang, X. and Hines, A.H. (2008). Current trends in hatchery techniques and stock enhancement for Chinese mitten crab, *Eriocheir sinensis*. *Reviews in Fisheries Science* 16(1-3):377-384.

Chinlampianga V, Ranjay M, Singh K and Shukla AK (2013). Ethnozoological Diversity of Northeast India: Empirical Learning with Traditional Knowledge Holders of Mizoram and Arunachal Pradesh. Ind j traditional knowledge 12: 18-35.

Churchill, G. J. 2003. An investigation into the captive spawning, egg characteristics and egg quality of the mud crab (Scylla serrata) in South Africa. MSc thesis, Department of Ichthyology and Fisheries Science. Rhodes University, Grahamstown, South Africa.

Coman G.J, Arnold S.J, Peixoto S, Crocos P.J, Coman F.E and Preston. N.P (2006). Reproductive performance of reciprocally crossed wild-caught and tank-reared Penaeus monodon broodstock Aquaculture, 252 (2006), pp. 372-384.

Craig, John F. (2016-01-12). Freshwater Fisheries Ecology. Wiley. pp. 57–. ISBN 9781118394403. Retrieved 2 November 2017.

Oersted, D. and Mirera, D (2014). Capture-based mud crab (*Scylla serrata*) aquaculture and artisanal fishery in East Africa – Practical and ecological perspective. Linnaeus University Dissertations No 159/2013, ISBN: 978-91-87427-70.

Davis, J.L. Young-Williams, D.A. Hines, A.H. and Zohar, Y. (2005). Assessing the potential for stock enhancement in the case of the Chesapeake Bay blue crab, *Callinectes sapidus*. Can. J. Fish. Aquat. Sci., 62: 109–122.

Efrizal E., Zakaria I.J., Rusnam R (2019). Studies on Biological Test of Formulated Diets Supplementation of Vitamin E for the Broodstock of Females Blue Swimming Crab, Portunus pelagicus (Linnaeus, 1758).

EPA; US Environmental Protection Agency (2017). Restoration of the Chesapeake Bay. Available online, retrieved May 4, 2018. https://www.epa.gov/restoration-chesapeake-bay

FAO (2005). National Aquaculture Sector Overview. Kenya. National Aquaculture

Sector Overview Fact Sheets. Text by Nyandat B. In: FAO Fisheries and Aquaculture Department [online).

FAO (2008). Species Fact Sheets. *Scylla serrata*. Retrieved from http://www.fao.org/fishery/species/2637/en

FAO (2011). Cultured Aquatic Species Information Programme. Scylla serrata (Forsskål, 1755). Retrieved from .http://www.fao.org/fishery/culturedspecies/Scylla_serrata/en.

FAO (2016). The State of World Fisheries and Aquaculture 2016. Contributing to food security and nutrition for all. Rome: FAO. p. 200.

FAO (2018). The State of World Fisheries and Aquaculture 2018-Meeting the sustainable development goals. License: CC BY-NC-SA 3.0 IGO. http://www.fao.org/3/i9540en/i9540en.pdf.

FAO, 2012. The state of world fisheries and aquaculture 2012. FAO Fisheries and Aquaculture Department, Rome, Italy. 230 pp.

FAO. 2014. Species fact sheets *Portunus pelagicus* (Linnaeus, 1758). Fisheries and Aquaculture department.

FAO; Food and Agriculture Organization (2006-2018a). Cultured Aquatic Species Information Programme. *Eriocheir sinensis*. Cultured Aquatic Species Information Programme. Text by Weimin, M. In: FAO Fisheries and Aquaculture Department [online]. Rome. Updated 7 April 2006. [retrieved 19 April 2018]. http://www.fao.org/fishery/species/3466/en

FAO; Food and Agriculture Organization (2018). Cultured Aquatic Species Information Programme. *Callinectes sapidus*. Cultured Aquatic Species Information Programme. Text by Weimin, M. In: FAO Fisheries and Aquaculture Department [online]. Rome. Updated 7 April 2006. [retrieved 22 April 2018]. http://www.fao.org/fishery/species/2632/en

FAO; Food and Agriculture Organization (2018). Cultured Aquatic Species Information Programme. *Portunus pelagicus*. Cultured Aquatic Species Information Programme. Text by Weimin, M. In: FAO Fisheries and Aquaculture Department [online]. Rome. Updated 7 April 2006. [retrieved 22 April 2018]. http://www.fao.org/fishery/species/2629/en

FAO; Food and Agriculture Organization (2018). Cultured Aquatic Species Information Programme. *Portunus trituberculatus*. Cultured Aquatic Species Information Programme. Text by Weimin, M. In: FAO Fisheries and Aquaculture Department [online]. Rome. Updated 7 April 2006. [retrieved 22 April 2018]. http://www.fao.org/fishery/species/2630/en

FAO; Food and Agriculture Organization (2018). Cultured Aquatic Species Information Programme. *Scylla serrata*. Cultured Aquatic Species Information Programme. Text by Weimin, M. In: FAO Fisheries and Aquaculture Department [online]. Rome. Updated 7 April 2006. [retrieved 22 April 2018]. http://www.fao.org/fishery/species/2637/en

FAO; Food and Agriculture Organization (2018). Cultured Aquatic Species Information Programme. *Cancer magister*. Cultured Aquatic Species Information Programme. Text by Weimin, M. In: FAO Fisheries and Aquaculture Department [online]. Rome. Updated 7 April 2006. [retrieved 22 April 2018]. http://www.fao.org/fishery/species/3461/en

FAO; Food and Agriculture Organization (2018). Cultured Aquatic Species Information Programme. *Cancer pagurus*. Cultured Aquatic Species Information Programme. Text by Weimin, M. In: FAO Fisheries and Aquaculture Department [online]. Rome. Updated 7 April 2006. [retrieved 4 May 2018]. http://www.fao.org/fishery/species/2627/en

FAO; Food and Agriculture Organization (2018). Cultured Aquatic Species Information Programme. *Chionoecetes opilio*. Cultured Aquatic Species Information Programme. Text by Weimin, M. In: FAO Fisheries and Aquaculture Department [online]. Rome. Updated 7 April 2006. [retrieved 4 May 2018]. http://www.fao.org/fishery/species/2644/en

Fujaya Y, Trijuno DD, Aslamyah S, et al.: Domestication and selective breeding for producing fast growing and high meat quality of blue swimming crab (Portunus pelagicus). AACL Bioflux. 2016; 9(3): 670–679.

GAA; Global Aquaculture Alliance (2018). BAP-Certified Aquaculture Facilities. https://bapcertification.org/CertifiedFacilities [Cited 19 April 2018].

Gadhavi, M.K., H.K. Kardani, P. Rajal, P.C. Prajapati, and K.D. Vachhrajani. 2013. Impact of trawl fish ban on artisanal brachyuran crab fishery in and around Sikka, Gulf of Kutch, Gujarat, India. Res. J. Animal, Veterinary & Fishery Sci., 1(1): 22-27.

Gao, G. (2015). In China, 1980 marked a generational turning point. Retrieved 21 April, 2018 from http://www.pewresearch.org/fact-tank/2015/11/12/ in-china-1980-marked-a-generational-turning-point/

Gao. B.Q, Liu. P, Li. J, Dai. F.Y, Luo. Y and Dai Y.J (2008). Heterosis of F1 *Portunus trituberculatus* from mating and crosses among the different geographical populations. Oceanol Limnol. Sin., 39 (2008), pp. 291-296.Global Invasive Species Database (2018).

Govindasamy C. and Srinivasan R. (2012) Association of bioluminescent bacteria from blue swimmer crab *Portunus pelagicus* (Linneaus, 1758). Asian Pacific Journal of Tropical Disease. 2012; 2(Supplement 2): S699–. S702.

Gregorio G.B. and Senadhira D. (1993). Genetic analysis of salinity tolerance in rice (*Oryza sativa* L.). Theor Appl Genet. 86(2-3):333-8. doi: 10.1007/BF00222098.

Halwart, M. (2020). Fish farming high on the global food system agenda in 2020. FAO Aquaculture Newsletter. 61: II–III.

Hamasaki, K., Obata, Y., Dan, S., and Kitada, S., (2011). A review of seed production and stock enhancement for commercially important portunid crabs in Japan. Aquacult Int (2011) 19:217–235.

Hamasaki, K., Suprayudi, M.A. and Takeuchi, T. (2002). Mass mortality during metamorphosis to megalops in the seed production of mud crab *Scylla serrata* (Crustacea, Decapoda, Portunidae). Fisheries Science. 68(6): 1226-1231.

Hamasaki, K., Y. Obata, S. Dan, S. Kitada (2011). A review of see production and stock enhancement for commercially important portunid crabs in Japan. Aquacult Int.19:217- 235.

Hamasaki, K. Fukunaga, K., Kitada, S. (2006). Batch fecundity of the swimming crab *Portunus trituberculatus* (Decapoda: Brachyura) Aquaculture, 253; 359-365.

Hamasaki. K, Imai. H, Akiyama. N and Fukunaga. K (2004). Ovarian development and induced oviposition of the overwintering swimming crab *Portunus trituberculatus* (Brachyura: Portunidae) reared in the laboratory Fish. Sci., 70, pp. 988-995.

Harris D, Johnston D, Sporer E, et al.: Status of the blue swimmer crab fishery in Page 11 of 16 F1000Research 2019, 8:1466 Last updated: 27 JAN 2021 Shark Bay, Western Australia. Fisheries Research Report No. 233, Department of Fisheries, Western Australia, 2014; 79

Hecht. T, Moehl. J F, Halwart. M and Subasinghe. R P (2006). Regional review on aquaculture development. 4. Sub-Saharan Africa. Fisheries Circular. No. 1017/5. Rome: FAO. p. 97.

Herborg, L.M., Rudnick, D.A., Silang, Y., Lodge, D.M. and Macisaac, H.J. (2007). Predicting the range of Chinese mitten crabs in Europe. Conserv Biol. 21(5):1316-23.

Hines, A. H. and G. M. Ruiz. (1995). Temporal variation in juvenile blue crab mortality: nearshore shallows and cannibalism in Chesapeake Bay. Bull. of Marine Sci. 57(3):884-901.

Hines, A.H., Johnson, E.G., Young, A.C, Aguilar, R., Kramer, M.A., Goodison, M., Zmora, O. and Zohar, Y. (2008). Release strategies for estuarine species with complex migratory life cycles: stock enhancement of Chesapeake blue crabs (*Callinectes sapidus*). Reviews in Fisheries Science, 16(1–3):175–185

Ji, Y., Sui, L.Y., Wu, X.G., Cheng, Y.X., Willie, M., and Sorgeloos, P. (2006). Effects of different diets on reproductive performance and HUFA composition of Chinese mitten crab (*Eriocheir sinensis)* broodstock during second spawning. J. Fish. Sci. China 13:93-99.

Jiang. S (2010). Aquaculture, capture fisheries, and wild fish stocks. Resource and Energy Economics, 32, 65-77.

Samuel. J.N., Thirunavukkarasu N., Soundarapandian P., Shanmugam A., and Kannupandi T (2004). Fishery potential of commercially important portunid crabs along Parangipettai coast Proceedings of International conference and exposition on marine living resources of India for food and medicine Aquaculture Foundation of India, Chennai 165-173.

Kaji, S., Kanematsu, M., Tezuka, N., Fushimi, H. and Hatai, K. 1991. Effects of formalin bath for Haliphthoros infection on ova and larvae of the mangrove crab *Scylla serrata.* Nippon Suisun Gakkaishi. 57(1): 55-51.

Kao D., Lai, A.G., Stamataki, E., Rosic, S.3, Konstantinides, N., Jarvis, E., Di Donfrancesco, A., Pouchkina-Stancheva, N., Semon, M., Grillo, M., Bruce, H., Kumar, S., Siwanowicz, I., Le, A, Lemire, A., Eisen, M.B., Extavour, C., Browne, W.E., Wolff, C., Averof, M., Patel N.H., Sarkies, P., Pavlopoulos, A., Aboobaker, A. (2016). The genome of the crustacean *Parhyale hawaiensis*, a model for animal development, regeneration, immunity and lignocellulose digestion. eLife;5:e20062 DOI: 10.7554/eLife.20062

Kashyap RV (2017). Ethno-Zoological study in Gondwana Vindhyan Region (Madhya Pradesh), India. Int J Zoo Studies 2: 66-67.

Lai., Joelle C Y., Peter K L., Davie, Peter J.F (2010). "A revision of the *Portunus pelagicus* (Linnaeus, 1758) species complex (Crustacea: Brachyura: Portunidae), with the recognition of four species". The Raffles Bulletin of Zoology. 58 (2): 199–237. ISSN 0217- 2445.

Lavilla-Pitogo, C.R., Catedral, D.D., Pedrajas, S.A.G. and de la Peña, L.D. 2002. Selection of probiotics for shrimp and crab hatcheries. Pages 136-150 in Inui, Y. and CruzLacierda, E.R. (Eds.), Disease Control in Fish and Shrimp Aquaculture in Southeast Asia – Diagnosis and Husbandry Techniques, Proceedings of the SEAFDEC-OIE Seminar-Workshop, Iloilo City, The Philippines). SEAFDEC Aquaculture Department, Tigbauan, Iloilo, The Philippines.

Leger, P., Bengtson, D.A., Simpson, K.L., Sorgeloos, P. (1986). The use and nutritional value of *Artemia* as a food source. Oceanography. Mar. Biol. 24, 521–623.

Li, X., Dong, S., Lei, Y., and Li, Y. (2007). The effect of stocking density of

Chinese mitten crab *Eriocheir sinensis* on rice and crab seed yields in rice–crab culture systems. Aquaculture 273: 487–493.

Lionberger. H.F. and Gwin.P.H (1991). From Researchers Technology to Users Transfer. University of Missouri, USA.

Lipcius, R.N. and W.T. Stockhausen. (2002). Concurrent decline of the spawning stock recruitment, larval abundance, and size of the blue crab *Callinectes sapidus* in Chesapeake Bay. Marine Ecology Progress Series 226: 45-61.

Lipcius, R.N., Seitz, R.D., Seebo, M.S., Colon-Carrion, D. (2005). Density, abundance and survival of the blue crab in seagrass and unstructured salt marsh nurseries of Chesapeake Bay Journal of Experimental Marine Biology and Ecology 319:69–80.

Liu, X., Zhao, J., Zheng, Y., Sun, N., Li, X., and Yang, R. (2018). Genetic analysis for absolute and relative growth of body weight and main morphological traits in Chinese mitten crab, *Eriocheir sinensis*. Journal of the World Aquaculture SocietyVolume 49, Issue 2.

Liu. Q, Chen. E.Y, Guo. R and Guo. Z.F (2007). China fisheries statistical yearbook of 2006, Bureau of Fisheries, Ministry of Agriculture of China, Beijing (2007), p. p28.

Lohani U (2016). Healing with animals in Nepal. J Nepal Sci Olympiad 1: 41-47.

Maryland Department of Natural Resources (2017). 2017 Blue Crab Winter Dredge Survey. Retrieved May 6, 2018 http://dnr.maryland.gov/fisheries/Pages/blue-crab/dredge.aspx

Meng. X.H., Jang. I.K., Seo. H.C and Cho. Y.R (2009). White spot syndrome virus quantification in blue crab *Portunus trituberculatus* hatchery-produced larvae and wild populations by TaqMan real- time PCR, with an emphasis on the relationship between viral infection and crab health. Aquaculture, 291 (2009), pp. 18-22.

Mirera. O. D (2011). Trends in exploitation, development and management of artisanal mud crab (*Scylla serrata*-Forsskal-1775) fishery and small-. scale culture in Kenya: An overview. Ocean & Coastal Management, 54, 844-855.

Molla. M.A.G., Islam. M.R., Islam. S and Salam M.A. (2009). Socio-economic status of crab collectors and fatteners in the southwest region of Bangladesh. *Journal of the Bangladesh Agricultural University* 7(2):411-419.

Monterey Bay Aquarium Seafood Watch (1999-2017). Crab Recommendations. Retrieved online April 26, 2018. http://www.seafoodwatch.org/seafood-recommendations/groups/crab?type=blue&q=Crab,%20Blue&t=blue%20crab

Muthiga NA (1986). Edible crabs of Kenya. Kenya Aquatic 3: 61-65.

Naser, M.D, Page, T.J., Ng, N.K., Apel, M., Yasser, A.G., Bishop, J.M., Ng, P.K.L. and Clark, P.F. (2012). Invasive records of *Eriocheir hepuensis* Dai, 1991 (Crustacea: Brachyura: Grapsoidea: Varunidae): Implications and taxonomic considerations. BioInvasions Records (2012) Volume 1, Issue 1: 71–86 doi: http://dx.doi.org/10.3391/bir.2012.1.1.15

NCSU; North Carolina State University. (2008). "Turning Freshwater Farm Ponds into Crab Farms." ScienceDaily. ScienceDaily, 15 October 2008. Retrieved April 24, 2018 www.sciencedaily.com/releases/2008/10/081003191417.htm

Romano, N and Zeng, C (2007a). "Acute toxicity of sodium nitrate, potassium nitrate and potassium chloride and their effects on the hemolymph composition and gill structure of early juvenile blue swimmer crabs (*Portunus pelagicus* Linnaeus, 1758) (Decapoda, Brachyura, Portunidae)". Environmental Toxicology and Chemistry. 26 (9): 1955–1962. doi:10.1897/07-144R.1

Romano, N and Zeng, C (2007b). "Effects of potassium on nitrate mediated changes to osmoregulation in marine crabs". Aquatic Toxicology. 85 (3): 202–208. doi:10.1016/j.aquatox.2007.09.004. PMID 17942166.

Mirera. O.D and Moksnes. P.O (2013) Cannibalistic interactions of juvenile mud crabs *Scylla serrata*: the effect of shelter and crab size, African Journal of Marine Science, 35:4, 545-553, DOI: 10.2989/1814232X.2013.865677.

Pang, Y., Chen, K., Wang, X., Wand, W., Xu, J., Ali, J., and Li, Z. (2017). Simultaneous improvement and genetic dissection of salt tolerance of rice (*Oryza sativa* L.) by Designed QTL Pyramiding. Front Plant Sci. 8: article 1275. doi: 10.3389/fpls.2017.01275

Peixoto, S., Wasielesky, J., Martino, R., Milach, A, Soares, R, Cavalli. R.O. (2008). . Comparison of reproductive output, offspring quality, ovarian . histology and fatty acid composition between similarly-sized wild and domesticated *Farfantepenaeus paulensis*. Aquaculture, 285 (2008), pp. 201-206.

Primavera, J.H., Biňas, J.B., Samonte-Tan, G.P.B., Lebata, M.J.J., Alava, V.R., Walton, M. & Le Vay, L. (2010). Mud crab pen culture: replacement of fish feed requirement and impacts on mangrove community structure. *Aquaculture Research*, 41:1211-1220.

Qi, J., Gu, X., Ma, L. Qiao, Z., and Chen, K. (2013). The research progress on food organism culture and technology utilization in crab seed production in ponds in China. Agricultural Sciences 4(10):563-569.

Quinitio, E.T., Rodríguez, E.M. & Parado-Estepa, F.D. (2009). Nursery and grow-. out of mud crab. *In: Training Handbook on Rural Aquaculture*, pp. 87-95. SEAFDEC/AQD, Iloilo, Philippines.

Quinitio, E. T. and Estepa, F. D. P (2011). Survival and growth of mud crab, *Scylla serrata*, juveniles subjected to removal or trimming of chelipeds. Aquaculture, 318, 229-234.

Quinitio, E.T. (2003). Mud crab hatchery and nursery operations. SEAFDEC Asian Aquaculture, 25(3), 20.

Reddy, P.R and Reddy. P.S. Isolation of peptide hormones with pleiotropic activities in the freshwater crab, *Oziotelphusa senex senex* (2006) Aquaculture259: 424-431. https://doi.org/10.1016/j.aquaculture.2006.05.019.

Romano., N and Zeng., C (2007c). "Effects of potassium on nitrate mediated alterations to osmoregulation in marine crabs". *Aquatic Toxicology*. 85 (3): 202–208. doi:10.1016/j.aquatox.2007.09.004. PMID 17942166.

Roy, M.D (2014). Crustacean bio-resources of ethno-medicinal value, traditional knowledge Proceedings of the National Seminar on traditional knowledge and social practices Promoting Biodiversity Conservation, Annandale Hall, ZSI, Kolkata 127-136.

Santos, M.D., Lopez G.V and Barut. N.C (2010). A pilot study on the genetic variation of eastern little tuna (*Euthynnus affinis*) in Southeast Asia. Philippine Journal of Science, 139(1): 43–50

Saroj, R (2018). Multiformity and Economic Importance of True Brachyuran Crabs. Edelweiss Applied Science and Technology (ISSN: 2576-8484).

Satia, B.P (2016). An overview of the large marine ecosystem programs at work in Africa today. Environ Dev. 17:11–19. doi: 10.1016/j.envdev.2015.06.007.

Satia, B.P (2017). Regional review on status and trends in aquaculture development. in sub-Saharan Africa - 2010/Revue régionale sur la situation et les . tendances dans l'aquaculture en afrique subsaharienne -2010. FAO Fisheries and Aquaculture Circular, I,III,IV,V,1-7,9-23,25-33,35-41,43-45,47-51,53-59,61-67,69-117,119-137,139-161,163 . 191.

Seitz, R.D., Lipcius, R.N., Knick, K.E., Seebo, M.S., Long, W.C., Brylawski, B.J. and Smith, A. (2008). Stock enhancement and carrying capacity of blue crab nursery habitats in Chesapeake Bay. Reviews in Fisheries Science, 16(1–3):329–337.

Shelley. C and Lovatelli. A (2011). Mud crab aquaculture – a practical manual. FAO Fisheries and Aquaculture Technical Paper No. 567. FAO, Rome. 78 pp.

Shelley, C (2008). Capture-Based aquaculture of Mud crabs (*Scylla spp*.). In: A. Lovatelli and P.F. Holthus (eds). Capture-based Aquaculture. Global Overview. FAO Fisheries Technical Paper, 255–269.

Shi. H.X, Jiang. H.L, Jin. W.Z and Wang. J.B (2007). The study of healthy seed production for swimming crab, *Portunus trituberculatus*. Modern Agric. Sci.

Technol., 4 (2007) 106, 109.

Shrimp News (2018). February 16, 2018 issue, available online. Retrieved May 5, 2018: http://www.shrimpnews.com/FreeReportsFolder/NewsReportsFolder/VietnamCaMauProvinceCrabFarming.html

Soundarapandian P, Varadharajan D, Anand T (2013) Sea Ranching of Laboratory Produced Seeds of Blue Swimmer Crab, *Portunus pelagicus* (Linnaeus) from South East Coast of India. JEarth Sci Climate Change 4:138. doi:10.4172/2157-7617.1000138.

Speir and Harley (2002). A Review of Predation on Blue Crabs in the Chesapeake Bay. Maryland Recreational Fisheries. 18 July 2002. Department of Natural Resources. Retrieved online on 15 April, 2018. www.dnr.state.md.us/fisheries/recreational/articles/crabpred.html

Stentiford, G.D.; Neil, D.M.; Peeler, E.J.; Shields, J.D.; Small, H.J.; Flegel, T.W.; Vlak, J.M.; Jones, B.; Morado, F.; Moss, S.; Lotz, J.; Bartholomay, L.; Behringer, D.C.; Hauton, C.; and Lightner, D.V. (2012). Disease will limit future food supply from the global crustacean fishery and aquaculture sectors. Publications, Agencies and Staff of the U.S. Department of Commerce. 350. http://digitalcommons.unl.edu/usdeptcommercepub/350 Stock assessment of the blue swimmer crab *Portunus pelagicus* (Linnaeus, 1766) from the Oman Coastal Waters. International Journal of Fisheries and Aquatic Sciences, 2(1): 1-8.

Sui, L., Wille, M., Cheng, Y., Wu, X., and Sorgeloos, P. (2011). Larviculture techniques of Chinese mitten crab *Eriocheir sinensis*. Aquaculture 315:16-19.

Sui, L.Y. (2008). Hatchery techniques for Chinese mitten crab *Eriocher sinensis*. PhD thesis, Gent University, Belgium.

Sulkin, S.D., Branscomb, E.S., and Miller, R.E. (1976). Induced winter spawning and culture of larvae of the blue crab, *Callinectes Sapidus* Rathbun. Aquaculture, 8:103—113.

Tacon, A.G.J. (1987). The nutrition and feeding of farmed fish and shrimp - A training manual. 1. The essential nutrients. FAO Field Document, Project GCP/RLA/075/ITA, Field Document No. 2, Brasilia, Brazil, 117 p. http://www.fao.org/docrep/field/003/ab470e/AB470E00.htm

Takeuchi, T., Yoshihiko, N., Hamasaki, K., Sekiya, S. and Watanabe. T (1999). Requirement of (n-3) highly unsaturated fatty acids for larval swimming crabs *Portunus trituberculatus.* Bulletin of the Japanese Society of Scientific Fisheries. 65(5): 797- 803.

Troell, M. Hecht, T., Beveridge, M. Stead, S. Bryceson, I. Kautsky, N. Ollevier, F. and Mmochi, A (2011). Mariculture in the WIO Region - Challenges and Prospects. WIOMSA Book Series No. 11. viii + 59pp.

Tsukimura, B. (2008). Environmental conditions affecting mitten crab abundances in the San Francisco Bay-Delta. Sea Grant California.

UNDESA (2009). Rethinking poverty. Report on the world social situation 2010. Department of Economic and Social Affairs. ST/ESA/324. ISBN 978-92-1-130278-3. 203 pp.

UNDESA (United Nations Department of Economic and Social Affairs) (2013). Millennium development goal 8. The global partnership for development. The challenge we face. MDG Gap Task Force Report 2013. 100 pp.

Veilleux, É., and de Lafontaine, Y. (2007). Biological synopsis of the Chinese mitten crab (*Eriocheir sinensis*). Can. Manusc. Rep. Fish. Aquat. Sci.

Wang, Q., Liu, J., Zhang, S., Lian, Y., Ding, H., Du, X., Li, Z., and De Silva, S.S. (2016). Sustainable farming practices of the Chinese mitten crab (*Eriocheir sinensis*) around Hongze Lake, lower Yangtze River Basin, China. Ambio 45:361–373

Wikipedia (2021). *Portunus armatus*. 28 February 2021 00:02 UTC. Retrieved fromhttps://en.wikipedia.org/w/index.php?title=Portunus_armatus&oldid.. =1009322498.

Williams, M.J. and Primavera, J.H. (2001). Choosing tropical portunid species for culture, domestication and stock enhancement in the Indo-Pacific. American Fisheries Science 14: 121-142.

Worm B. and Branch. T. A (2012). The Future of Fish. Trends in Ecology and Evolution, 27, 594-599.

Xie. Z.M (2002). The breeding and culture of economic marine crabs, Chinese agricultural press, Beijing, china (2002), pp. 1-98.

Yu. G.C., Song. H.T., Yao. G.Z and Lv. H.Q (2006). Composition and distribution of economic crab species in the East China Sea Oceanol. Limnol. Sin., 37, pp. 53-60.

Zeng, C., Cheng, Y., Lucas, J.S. and Southgate P.C. (2012). Other Decapod Crustaceans, Chapter 22. In: Aquaculture (Farming Aquatic Animals and Plants, Second Edition). Lucas, J.S. and Southgate P.C., eds. Page 514. Wiley-Blackwell. 2812: vi + 45p.

Zannatul, F, Zhang, X and Hasan, M.R (2010). Mud crab (*Scylla sp*.) marketing system in Bangladesh. Asian J Food Agro-Industry 3: 248-265.

Zhao, N. G. (1980). Experiment on the artificial propagation of the woolly-handed crab (*Eriocheir sinensis*) in artificial sea water. J. Fisheries o/China, 4: 95-104 (In Chinese, English abstract).

Zmora, O., Findiesen, A., Stubblefield, J., Frenkel, V. and Zohar, Y. (2005). Large-scale juvenile production of the blue crab *Callinectes sapidus*. Aquaculture 244: 129–139.

Zohar, Y., Hines, A.H., Zmora, O., Johnson, E.G., Lipcius, R.N., Seitz, R.D., Eggleston, D.B., Place, A.R., Schott, E.J., Stubblefield, J.D. and Chung, J. S. (2008). The Chesapeake Bay Blue Crab (*Callinectes sapidus*): A Multidisciplinary Approach to Responsible Stock Replenishment, Reviews in Fisheries Science, 16:1, 24 – 34.