Advances in the culture of crabs

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Abstract:

Farmed crab production in 2005 reached 660,000 tonnes globally of which virtually all was produced in Asia. The freshwater Chinese mitten crab *Eriocheir japonica sinensis* accounts for two thirds of global crab production with the remainder, estuarine portunid crabs such as *Scylla* species. Initially reliant upon harvest of wild juveniles, the adoption of hatchery methods to supply “seed” makes a significant increase in aquaculture production possible. Many fundamental husbandry issues such as feeding and reproduction are only now receiving research attention.

Keywords:
Stock enhancement, broodstock maturation, manufactured diets, cannibalism, hatchery and nursery systems

Table of contents

1. Introduction

Reported farmed production of brachyuran crabs in 2005 reached 660,000 tonnes globally of which virtually all was produced in Asia. Total value was USD$ 2.8 Billion (FAO, 2008). The freshwater mitten crab *Eriocheir spp*. accounts for two thirds of global crab production. The remaining third is mostly portunid crabs, mostly the mangrove/mud crabs *Scylla* spp. with various other swimming crabs (*Portunus* spp.) accounting for the rest.

Crab aquaculture has appeared in the last two decades primarily as a live holding or marketing strategy, to bring certainty to supply of high value marine and freshwater crabs. The farmers ensure they will have “wild” product for sale by buying wild-caught “seed” crabs and growing them to market size in ponds, lakes or reservoirs (FAO, 2008).

This approach to aquaculture development has obvious drawbacks and risks. One “drawback” turns out to be a strength. While rapid expansion means there is little opportunity for farmers to really come to grips with the best techniques for farming the crabs, a huge industry emerges so quickly that it can command significant R&D assistance, the kind denied to a lone aquaculture pioneer. The obvious threat was that the rapidly escalating demand for seed endangered the sustainability of local stocks. Hatchery methods had to be developed and introduced to make up the short-fall as a fishery stock-enhancement strategy that turns into aquaculture. For *Eriocheir*, the line between aquaculture and stock enhancement becomes quite blurred (Wang et al., 2006). Hatchery techniques have been used in Japan and elsewhere purely for stock enhancement of crab fisheries (Obata et al., 2006)- the latest example of this being with the blue crab in the USA (Zmora et al., 2005).

The use of the plural “spp.” for farmed crab genera is deliberate, and highlights the fact that the taxonomy of these commercially important groups is or has been controversial. The original “*Scylla serrata*” monolith was broken up a decade ago (Keenan et al., 1998), who showed that there were four distinct species, requiring particular attention to discriminate them as juveniles (Macintosh et al., 2002). In contrast, the taxonomy of the mitten crab *Eriocheir* remains unstable, with recent findings indicating that all commercial varieties may in fact be sub-species of *E. japonica* (Tang et al., 2003). In this chapter, unless stated otherwise, “mitten crab” means the Chinese variety of mitten crab, which has otherwise been referred to as *E. j. sinensis*.

1.1 Chinese mitten crab

Known variously as “the most important crab in the world” or as a “space invader” the Chinese mitten crab has grown to dominate global farmed crab production in the last 20 years (FAO, 2008). It is not immediately obvious why freshwater mitten crabs should have flourished so much when farming of Asian marine crabs like *Scylla* spp has languished. Mitten crabs appear to be extremely robust and mitten crab hatcheries can routinely produce huge quantities of post-larvae (FAO, 2008). The mitten crab is also an easily managed omnivore suited to growth in the ponds and paddy fields of coastal China, making it attractive to low-income farmers, (FAO, 2008).

In some respects the phenomenal growth of the industry is its greatest threat. Along with growth has come a steep learning curve- evidenced by questions about environmental deterioration, precocious maturation and variable quality of seeds, (FAO, 2008). The recently recognised “Shaking leg” or tremor disease – caused by a spiroplasma bacteria- is a first for a crustacean, (Wang et al., 2004). The dominance of hatchery-reared stocks and closure of the lifecycle has led to unregulated movement and escapes of genetic stocks and this has probably already blurred the original genetic variation in different catchments across China, threatening the integrity of already pressured wild stocks, (Chang et al., 2006). Perhaps one day farmers will be regularly “calling in” some of the overseas gene pool, albeit restricted as it is by its recent origins (Herborg et al., 2007), in order to keep local selection programs running.

Eriocheir systematics is in a state of flux (Lee et al., 2004; Tang et al., 2003). In the past, a few widely recognised species *E. japonica* and *E. sinensis* and some more controversial minor ones were reported in China and neighbouring countries, (Chan et al., 2005; Tang et al., 2003). Given the similarity of the species and the fact that the taxa known as *E. japonica* and *E. sinensis* readily interbreed it is not surprising that cytological and morphological schemes proposed to discriminate the different taxa have been difficult to apply (Chu et al., 2003; Tang et al., 2003). Recent molecular evidence confirms that the commercial species of *Eriocheir* are very closely related- to the point where some authors recommend that they are essentially conspecifics (Tang et al., 2003) an outcome where taxonomy conflicts with product branding! At this point, much of the regional variation observed within the genus may be attributed to sub-species, for example *E. j. japonica* and *E. j. sinensis* according to broad geographic zones. Molecular research has revealed additional microsatellites that can be used to interpret the impacts of aquaculture “escapes” on local populations (Chang et al., 2006) as well as insights into the non-marine radiation of the Grapsidae (Sun et al., 2005). The existence of isolated population structures is not surprising given that the crab’s riverine-estuary life history must restrict gene flow between distant estuaries (Yamasaki et al., 2006). As experience in Europe and North America shows, in order to cross oceans, *Eriocheir* needs people. Artificial translocation, interbreeding and escape of the diverse stocks in China may ultimately reverse the process of regional speciation.

1.2 Mangrove crabs *Scylla* spp and other portunids.

Shrimp has usually been the most attractive prospect for coastal farmers in SE Asia, but recurring disease problems in that sector have stimulated interest in production of mangrove crabs in unused shrimp ponds (Christensen et al., 2004; Tri and Van Mensvoort, 2004). Mud crabs are asymptomatic carriers of white-spot syndrome virus (Hossain et al., 2001; Lavilla-Pitogo et al., 2007). The mono-specific *Scylla* species complex was broken up, less controversially perhaps, several years ago, (Keenan et al., 1998), with most Asian culture now involving *Scylla paramamosain*. Aside from studies to validate the new species mix, molecular fisheries studies have also selected microsatellites for identifying different stocks within a species (Gopurenko et al., 2002), an important precursor for broodstock management and selective breeding. Molecular studies are also examining genetic drift in *Portunus pelagicus,* another ubiquitous Indo-Pacific candidate for aquaculture (Bryars and Adams, 1999; Klinbunga et al., 2007; Yap et al., 2002), though the recent recognition of a formal lectotype (Holthuis, 2004), if nothing else, this has cleared up confusion caused by the inclusion of 3 different swimming crab species in the original description!

The relative ease with which mud crab juveniles could be harvested and sold led to a rapid expansion in the practice, threatening the sustainability of many local fisheries populations which were also directly threatened by human pressure on mangrove ecosystems. Since the Darwin conference in 1997 (Keenan and Blackshaw, 1999), a number of fruitful partnerships have been reported at international meetings at the University of the Philippines at Visayes in 1999 (see Asian Fisheries Science volume 14, issue 2) and at the SEAFDEC Aquaculture centre at Iloilo in 2004 (Aquaculture Research volume 38, issue 14) in order to improve the sustainability of the mud crab seed supply by developing hatchery methods for *Scylla* species. In the last decade, the published proceedings of regular meetings of these research teams provide a useful chart of the progress made.

Now that practical hatchery methods are available (Marte, 2003) and commercial hatcheries are already appearing in places like Vietnam (Ut et al., 2007b), research is turning toward addressing the next likely constraints upon industry growth: including development and adoption of manufactured feeds (Pavasovic et al., 2004; Tuan et al., 2006) and improving production efficiency.

2. Current situation

Crab farming has largely developed in advance of formal research programs. The current situation for product, growout, feeds and, finally, breeding of crabs is summarised in Table 1. There is probably still scope for significant improvements in production practices- particularly in the area of feed and genetics. The further progress made with mitten crab farming is evidenced by the emergence of genetics and broodstock quality as significant issues, while farming of portunid crabs has only achieved reliable hatchery production relatively recently. Subsequent sections examine product (section 3) and these various production issues (Section 4) in further detail.

3. Product issues

The market for farmed crabs is found largely in Asia, with the bulk of the mitten crab production consumed within China itself. There, the mitten crab is a culinary delicacy though the rapid expansion in farm production has put downward pressure on prices, taking some of the gloss off the sector (FAO, 2008).

Farmed crabs are marketed and transported alive. Meat recovery from crabs is understandably low (~ 15% of harvest weight for *Scylla serrata*, Chiou and Huang 2003) however, the edible yield is often higher, for example 33% for the mitten crab, (Chen et al., 2007). Edible recovery is increased by the marketing of mature adults, particularly females with ripe ovaries, which of course means that potential “broodstock” are marketed. While the consumer sees developed ovaries as a hallmark of “quality” – there is no guarantee that there is a simple correlation between maturation and flavour constituents so perhaps further work in this area is warranted (Chiou and Huang, 2003). Despite the ability of many farmed crabs to survive out of water for long periods- survival is not necessarily a guarantee of high quality or safety if the product is mistreated,(Chiou and Huang, 2004). Bacterial cross-contamination is certainly possible within live seafood markets (Yano et al., 2006) and the mitten crab can be a classic host of a lung fluke - a potentially serious human pathogen if crabs are eaten uncooked (Liu et al., 2008).

3.1 Mitten crabs

Intensively reared pond crabs are viewed as inferior to lake-stocked product (Wu et al., 2007a) –while consumers may prefer the idea that the latter are “wild” there may also be ways to change the characteristics of the pond crabs through improvements in selection, feeds and husbandry practices.

The most prestigious mitten crabs reputedly come from the waters of Yang Cheng Lake in Jiangsu Province. It is widely reported in Chinese media and elsewhere, that total sales of “Yang Cheng” crabs regularly exceed the lake’s actual production figures. To counter a burgeoning trade in these fake or “counterfeit” crabs, increasingly sophisticated labelling/tagging methods are being adopted by Yang Cheng growers to defend their premium sales. This labelling issue also has taxonomic overtones because the “purity” of the Yang Cheng population is very likely vulnerable to interbreeding from related strains. Attempts to use microsatellites and other molecular tools to brand crabs from particular localities will also run foul of the controversial species structure within *Eriocheir*, a problem being exacerbated by uncontrolled translocation of stocks.

3.2 Portunid crabs

Beyond the ready transportability of live *Scylla*, further processing of crabs, (eg. meat picking) is still largely the domain of the world’s high volume crab fisheries.

Processing or packaging of fresh or frozen farmed crabs is probably largely related to production of soft-shell crabs, which obtain a price premium.

Limb-regeneration, nutrition and stress will influence moulting in crustaceans (Hartnoll, 1982, 2001). Multiple limb autotomy is sometimes used by farmers in SE Asia to induce moulting but better knowledge of moulting mechanism may well improve efficiency (both in terms of shortening the period between moults and slowing the rate of hardening) and research is under way into the molecular basis of moulting (Kuballa et al., 2007a; Kuballa et al., 2007b). Moulting crabs are housed in compartmentalised systems, such as baskets in ponds or arrays of containers (Paterson et al., 2007). Because of the intensive nature of these shedding systems, care has to be taken to maintain acceptable water quality parameters. In the US, soft-shelled *Callinectes sapidus* sourced from wild pre-moults are normally marketed alive. The emerging trade in soft-shelled mud crabs in SE Asia currently requires freezing of packaged post-moults and our knowledge of quality constraints with this product are largely anecdotal.

4. Production systems

4.1 Grow-out

Extensive culture is still generally the rule with all forms of crab farming, where stocking densities are low (<1 crab m^{-2}) and if supplemental feed is supplied it is usually of an opportunistic or ad hoc nature (eg. low value fish or agricultural wastes) (Christensen et al., 2004; FAO, 2008). Farmed crabs are so valuable that it is tempting to try to raise stocking densities but cannibalism and reduced growth rates are significant challenges. Low intensity practices can also be less risky and more sustainable in the long term if the alternative is unregulated accumulation of nutrients and wastes in water bodies and local ecosystems (FAO, 2008).

Growth is central to issues of fisheries management, and there is a wealth of data on crab growth in wild fisheries. However, surprisingly, there is little research into changes in weight as brachyuran crabs grow. Most published research is fisheries modelling using carapace width as the indicator of size. The difficulty with this is that no one buys crabs by the millimetre and recent experimental studies of crab growth have questioned the importance of carapace width as a measure of moult increment, and certainly as a meaningful measure of yield in aquaculture (Paterson et al., 2007). Changes in carapace width growth from moult to moult as crabs regenerate claws or as they mature simply tell us that the carapace width growth (a measure adopted for convenience by humans) is sacrificed in favour of weight increase in important parts of the body (Paterson et al., 2007).

Moult by moult changes in weight by crabs and other crustaceans are most often measured when individuals are reared individually – such as in feeding trials (Cadman and Weinstein, 1988; Josileen and Menon, 2005; Paterson et al., 2007; Zhou et al., 1998).

4.1.1 Mitten crabs

The omnivorous habit of the mitten crab seemingly lends itself rice-crab farming systems where the animals are largely able to fend for themselves as long as care in management is undertaken- particularly avoiding use of insecticides! (FAO, 2008). In comparison with the breakneck individual growth rate in aquaculture by tropical and sub-tropical portunids like *Scylla* spp. and *Portunus* spp., the temperate mitten crab's growth rate is quite modest, requiring two growing seasons to obtain a final crop, the last stage in net enclosures in lakes. Growth was not in question when the industry first exploded so not surprisingly relatively little is known about the growth dynamics of *Eriocheir* in comparison to extensive growth modelling in other crab fisheries (Zhang et al., 2001). However, slowed growth is now a major concern for this species– part of this is attributed to poor genetic control of broodstock and possibly inadequate nutrition (FAO, 2008; Wen et al., 2006) but seasonality is also an issue because some “seed” crabs mature precociously if they are too large in their first autumn and all but cease growth as a consequence (Jin et al., 2001). Greater levels of precocity amongst seed crabs are observed at low stocking densities, when average final weights are the highest (Li et al., 2007).

4.1.2 Portunid crabs

Mud crabs, grown at densities of under 1 crab m^{-2} in earthen pond systems reach commercial size (200-500g, depending upon the species) in around 4-9 months. The smaller commercial size of soft-shell crabs (40-80grams pre-moult) means that crops can be rotated in 3 to 4 months. Because of the premium associated with ripe mud crab females, the economics of mono-sex culture has been considered (Trino et al., 1999), but further work could probably be done to establish this as a more common practice. Mud crabs are also grown in some areas in mangrove-based pens or ponds (Christensen et al., 2004; Trino and Rodriguez, 2002).

Before maturation begins, farm-reared portunids at least double their weight every time they moult. A portunid crab that is largest of its batch leaving the nursery will, all things being equal, have a good chance of being the largest crab on harvest day. In reality there will be a bit of slippage in rankings of crabs growing in ponds – and limb loss arising from agonistic encounters in ponds permanently sets back the growth of *Portunus pelagicus* and presumably other species as well, (Paterson et al., 2007). The cost of limb regeneration and not genetics may be a major cause of size variation amongst crabs grown in ponds (Paterson et al., 2007).

Where risks are high and seed relatively expensive, farmers inevitably stock ponds conservatively and there is little enthusiasm for pushing limits because of aggression and cannibalism amongst crabs. It’s only really since the inception of routine crab nursery production that there has been an imperative to try to intensify stocking densities of early juvenile crabs- perhaps developments in this area will follow through into improved efficiency in grow-out itself. Laboratory experiments with *P. pelagicus* confirm that small individuals and crabs that are moulting are particularly vulnerable (Marshall et al., 2005).

Container-based systems are an option, albeit a capital intensive one, for rearing crabs. This is based upon the relative ease with which crabs can be reared individually, with zero cannibalism, in feed trials, (Josileen and Menon, 2005; Nicholson et al., 2008; Paterson et al., 2007). For reasons of economy, crabs would have to be reared in the smallest container practical, both in terms of the well-being of the crab and the efficient operation of the system. One option for soft-shell crab production is to grow juvenile crabs in ponds until they are ready to move to the shedding facility. However, indoor containerised nurseries would probably also be feasible, (Nicholson et al., 2008). These authors showed that juvenile three-spot crab, *P. sanguinolentus* could be reared in containers so small that when ready for harvest the crabs can't sit flat on the floor. As long as the crab had room to moult, growth rate was unaffected. While there is still anecdotal evidence that crabs grow faster when free in extensive ponds, intensive indoor systems probably have an advantage in terms of biomass surviving per square metre.

4.2 Food and feeding

Crab farming began and thrived before a specific "crab feed" became necessary. Much of what can be recognised as formal feed research for farmed crabs is only now being conducted. Thanks to hatcheries, the sector is less limited by seed supply which has signalled a switch away from supplemental feeding practices associated with low intensity farming. At higher density rearing, the crabs will rely upon the diet they are given and this requires a greater understanding of nutritional requirements of the species.

While diets for growth and diets for maturation are to some extent separate issues, the distinction is clouded - crabs (*Scylla* spp. in particular) grow so fast that the “broodstock” are actually on the menu. So while research may consider the important effects of diet on ovarian maturation and how this impacts on larvae quality of following generations, as the ovaries are a major selling point for both mitten crabs and mud crabs – so the simultaneous impact of diet on flavour and marketability of the crabs also needs to be considered (Chiou and Huang, 2003). The natural diets of the freshwater and an estuarine species will received a different level of input from terrestrial oils, so attention is being placed on the PUFA and HUFA levels as well as relative omega 3 and omega 6 ratios of broodstock and for larval rearing (Alava et al., 2007a; Alava et al., 2007b; Ying et al., 2006).

4.2.1 Mitten crabs

The freshwater mitten crabs are omnivorous, and readily ingest plant material. Mu et al (1998) recommended a dietary protein of around 40% for *E. j. sinensis* (in experimental diets containing 7-11% crude lipid) and recent protein digestibility experiments used amino acid availability measurements to recommend soy bean meal and *Spirulina* meal as substitutes for fish meals (Mu et al 2000). Fine-tuning of manufactured diets for intensively-reared *Eriocheir* no doubt continues, seeking to bring the farmed crabs closer to the perceived qualities of lake-reared product and to fortify the reproductive capabilities of captive-reared populations. Recently, one manufactured diet received by pond-reared mitten crabs (38% protein, 4.5% lipid) produced relatively poor HUFA levels- even though lipid level was higher in the hepatopancreas/midgut gland (and GSI was lower) than in lake-stocked crabs (Wu et al., 2007a). The total HUFA and PUFA was low across the board in hepatopancreas of pond reared specimens- which could have consequences for their role as broodstock.

4.2.2 Portunid crabs

The mud crabs as adults are generally viewed as predators of gastropods and small crabs (Hill, 1979), and to date they are typically fed low value fish (="trash-fish") in farms. However, juvenile *Scylla* spp. are more opportunitistic and able to forage independently amongst the detritus and biota of the pond environment to the point that at typical low commercial densities supplemental feeding is unnecessary (Christensen et al., 2004). Specific research has even shown that *S. serrata* possess cellulases (Pavasovic et al., 2004) and can readily digest ingredients such as wheat flour etc (Catacutan et al., 2003; Tuan et al., 2006) so there is considerable interest in seeing the extent to which plant meals can be included in manufactured diets for this species. Perhaps *Scylla spp.* will also be able to utilise dietary carbohydrate? (Tuan et al., 2006). Similarly, *Portunus pelagicus* is also beginning to look less an obligate predator in recent years. Originally held to be a benthic predator which ingested plant material by accident (Williams, 1982) the persistent reports of ingested seagrass (de Lestang et al., 2000; Edgar, 1990) in this species certainly warrant further investigation.

Diet development is further advanced for *Scylla serrata* than other mud crabs but advances for that species will likely speed developments with *S. paramamosain* and other species. Existing recommendations for *S. serrata* are that they receive 32-40% dietary protein and 6-12% lipid (Catacutan, 2002). Commercial shrimp feeds are routinely used as substitutes for specifically formulated crab diets (Mann et al., 2007; Paterson et al., 2007), although pellet size is an issue as the crabs grow. A previous study, had shown that at constant dietary protein (~47%) growth is acceptable at dietary lipid levels as high as 13.8%(Sheen and Wu, 1999). Holme et al., (2007), using soy lecithin, also noted that *Scylla serrata* megalops had an optimum dietary lipid content that is on the high side of crustacean range (~10%). Lipid accumulation is one of the recognised "problems" with elevated dietary fat in crustaceans (D'Abramo, 1997) and not surprisingly, pond-reared *Scylla* broodstock have significantly more storage lipid than their wild counterparts (Alava et al., 2007b) which appears to reflect findings for lipid content in viscera of “farmed” *Eriocheir* reported above. Whether this is a problem for consumption of the viscera remains to be seen. The current recommendation for the diet to contain less than 40% protein was based upon changes in carapace width rather than body weight (Catacutan, 2002). This appears to point to morphometric shifts in crabs fed high protein diets, and this may have implications in the market. Strictly speaking, where farmers sell product by weight, the caparace width is less meaningful as a measure of growth as changes in carapace size may not always reflect differences in weight (eg. in the case of sexual maturation or limb regeneration, Paterson et al., 2007). Perhaps in future, particularly in respect to genetic selection programs, attention needs to be placed on carapace “depth” and other measures.

Studies on cholesterol requirement of *S. serrata* megalopa, (Sheen, 2000), indicated that while the nutrient is probably essential for growth- optimum dietary levels may be lower for *S. serrata* than for previously studied crustaceans, particularly if elevated levels of dietary lecithin are provided (Holme et al., 2006a; Holme et al., 2007).

4.3 Breeding and hatchery technology

Hatchery output is the major constraint to expansion of mitten crab and mud crab farming but the issues and strategies to address this differ between sectors. For the better established mitten crabs, the main issue is broodstock quality and nutrition are in question, while for *Scylla*, successful commercial hatchery rearing methods have only been available for a few years and the technology is still needed in many areas. Much of the literature on *Eriocheir* is not available in English but readers will find a recent review of hatchery practices for *Eriocheir* very helpful (Cheng et al., 2008).

4.3.1 Broodstock quality and nutrition

Crabs can be reared from wild or pond-reared broodstock, though as questions remain about the quality and diet received by crabs maturing in captivity, this is an area of continuing research.

Mitten crabs

Stopping mitten crabs from breeding is high on the agenda where this species is an invasive pest, but no breakthroughs appear to have been made there. Interestingly, mitten crabs mate in intermoult and do not apparently rely as much upon pheromone attraction- at least at a distance (Herborg et al., 2006)- as *Scylla* and other crabs that “mate guard” (where the successful male finds, protects and does not eat the moulting female) (Hayden et al., 2007). As is common with many decapods, mated female crabs extrude and retain the egg “sponge” within the abdominal flap where the hatchery operator can monitor progress of embryo development.

Perhaps related to the more extensive level of domestication already practiced with mitten crabs, the quality of farmed broodstock is emerging as a significant issue limiting hatchery output. Maturation diets and their fatty acid profiles have been given significant attention (Wen et al., 2002; Wu et al., 2007b; Ying et al., 2006). Early stocked individuals of *Eriocheir* are capable of precocious sexual maturation, maturing in their first rather than their second autumn – which is a problem for growout rather than reproduction per se because the maturing crab’s growth suffers, (Jin et al., 2001).

Portunid crabs

Broodstock quality is not so much of an issue for *Scylla* aquaculture while wild broodstock continue to be available. The crabs spawn readily in captivity and out-of-season spawning is a relatively straightforward practice (Zeng, 2007). The inception of hatchery-rearing means that use of farm-reared broodstock will become more common. To this end, broodstock maturation diets are increasingly under the spotlight, with some element of “natural” food still required to supplement artificial diets (Alava et al., 2007a; Alava et al., 2007b; Millamena and Quinitio, 2000).

4.3.2 Hatchery practices

Optimum control of hygiene is the first objective of the hatchery operator. Until recently, hatchery production of both mitten crab and mud crab larvae has relied on use of antibiotics at some point during development to sustain larval survival (Nghia et al., 2007; Cheng et al., 2008). Preventative use of antibiotics in this manner is unacceptable because of the danger posed by build up of antibiotic resistance in the environment- and in any case antibiotic-based methods do not necessarily produce healthy vigiorous larvae, (Cheng et al., 2008). Hatcheries keep the temperature as high as practical for the temperate mitten crab (22-25ºC) and tropical mud crab (28-30ºC) in the interests of efficient throughput of larvae. Possibly the relative ease of rearing *Eriocheir* larvae compared in particular to *Scylla serrata* relate to adaptation of larvae for entrainment within estuaries and migration into freshwater. However, recent observations indicate that except for the very early zoea, *S. serrata* larvae are not obliged to stay at marine levels of salinity (Nurdiani and Zeng, 2007).

Mitten crabs

Hatcheries for mitten crabs use either of two broad approaches: indoor intensive and controlled larviculture or outdoor extensive less controlled larviculture (Cheng et al., 2008). The indoor approach is similar to that seen in other crustacean hatcheries with a combination of live feeds provided (Sui et al., 2008). Z1's are stocked at high densities (200-500 per litre) so that even if the percentage survival through to megalops is relatively low, at 5-10%, the production output is still high (Cheng et al., 2008). Studies of larval nutrition in the area of fatty acid requirements and dietary protein have been undertaken, (Pan et al., 2005; Sui et al., 2007). The method for outdoor culture in earthen ponds is simpler and less reliant on keeping the system on a technological knife-edge. This extensive approach, while demanding more land and not necessarily boosting survival of megalops does apparently improve their quality and reduces the need to resort to antibiotics to contain bacterial pathogens (Cheng et al., 2008). During larval development, the outdoor ponds are still provided with typical live feeds such as *Artemia* and rotifers. One water quality problem recently identified in these systems involves larval mortality during outbreaks of calcium carbonate precipitation (Li et al., 2007b).

Portunid crabs

While water quality will deteriorate within culture media (Seneriches-Abiera et al., 2007), bacterial influences appear to be the main problem restricting hatchery output of *Scylla* species. However, rather than addressing this through use of antibiotics as has been done in the past, future improvements may be possible in system design and operation, for example, use of ozone, (Nghia et al., 2007a).

The technical bottleneck limiting hatchery production of *Scylla spp* has only been lifted in the last couple of years so it is worth considering this in more detail. Successful commercial hatchery methods are now either demonstrated or in use for both *S. serrata* and *S. paramamosain* (Rodriguez et al., 2007; Ut et al., 2007b) and similar methods have recently been applied to other portunids (Parado-Estepa et al., 2007; Paterson et al., 2007; Zmora et al., 2005).

These methods are adaptations of common hatchery practices for carnivorous larvae and currently rely on “work horse” live foods such as *Artemia* (all stages depending upon the larvae/ post larvae being fed) and in some cases rotifers for early stage larvae (Davis et al., 2005; Ruscoe et al., 2004). Supplements are already in use because of the uncertain nutritional value of these live feeds and promising research suggests that the costs and general complications associated with use of live feeds may be overcome in future using inert/microbound diets (Davis et al., 2005; Holme et al., 2006b). Clearly, successful microbound diets for *Scylla* larvae will have to be well bound so they will not fall apart when manipulated by larvae (Genodepa et al., 2007; Lumasag et al., 2007).

The importance of omega-3 HUFA fatty acid supplementation of *S. serrata* larval diets has been demonstrated experimentally (Suprayudia et al., 2004) though demonstrating a benefit in hatchery practice amidst all the other factors at play is not straightforward (Mann et al., 2001) so a better understanding of HUFAs levels during diet development may be required (Holme et al., 2007). High levels of HUFA in itself may not be desirable. A recent study examined HUFA and DHA/EPA ratios for larvae of *S. paramamosain*, finding effects on larval development rates rather than survival - particularly for low DHA/EPA ratios (Nghia et al., 2007b).

4.4 Nurseries

Nurseries are required to fully integrate artificial propagation into the crab farming sector. Until hatcheries appeared, crab farmers used rivers and estuaries as wild “nurseries.” Ready transportability of early crab stages rather than megalops is also another important reason for establishing nurseries (Quinitio, 2000). The post-larvae and fry of many fish and shellfish aquaculture species must be transported in heavy bags of water. Mitten crab and mud crab juveniles can be transported in damp packaging (there is a reason why crab farmers put fences around their ponds!).

4.4.1 Mitten crabs

The slower, seasonally oriented growth of the temperate mitten crab has inevitably led to nursery practices that spread the risk during the first year of production; ongrowing megalopa to produce “seed” or “coin-sized” crabs of a more convenient size for final on-growing (Cheng et al., 2008; FAO, 2008). The seed crabs (5-10g) are produced in a variety of tank and pond systems, with rice-crab systems being recommended (Li et al., 2007). Premature maturation of seed crabs is a danger if the juveniles become too advanced in their first year (Jin et al., 2001; Zhang et al., 2001). High density stocking, which puts most strain on submerged vegetation nevertheless reduces the incidence of precocity because of the increased competition and reduced growth rate, (Li et al., 2007).

4.4.2 Portunid crabs

With mud crabs, unfamiliarity with artificial seed has been a significant constraint, since farmers have required demonstration that the hatchery seed stock will perform as well as that from the wild (Ut et al., 2007b). Farmers comfortable with on-growing relatively large “seed” crabs from the wild are understandably reluctant to venture into hatchery ownership or buy tiny post-settlement juveniles. A nursery that brings the hatchery seed to a more equal footing with wild juveniles is an important intermediate step in this confidence-building process (Ut et al., 2007a).

The constraints applying to nursery or seed production are broadly the same as those for on-growing of large juveniles and sub-adult crabs (eg. cannibalism and aggression). The subtle difference is that farmers require large numbers of seed crabs from nurseries to stock their ponds and in turn want those crabs to grow in weight. This inevitably makes high intensity nurseries a sound proposition. These tank or pond based systems rear dozens of juveniles per square metre, feed them intensively and then harvest and sell them before the growing juveniles literally run out of space (Mann et al., 2007; Rodriguez et al., 2007; Ut et al., 2007a). When juvenile *P. pelagicus* are grown in ponds the largest individuals soon acquire the stable isotopic signature of cannibals (Møller et al., 2008). Survival can be improved by adding shelters or “habitat” to the nursery environment (eg. bricks or rolled fragments of net), apparently through a reduction in aggressive encounters and injury (Marshall et al., 2005, Mann et al., 2007, Ut et al., 2007a).

5. Future directions

Now that life cycles of farmed crabs have been closed and the process of refinement of existing ad-hoc farming practices is underway it is perhaps more instructive to use a more traditional order for topics to mapping out the work remaining in this sector.

5.1 Product

Crab farming is succeeding to varying extents in filling the void between the increasing demand in SE Asia for crabs and the, at best, static production from the wild fisheries. When constraints to industry growth are lifted by routine hatchery production a fall in price as supply increases is likely. This has already happened with mitten crabs (FAO 2008).

The mitten crab sector appears likely to remain segmented. Improvements in selection and husbandry of intensively-reared mitten crabs are needed to bring them on par with consumer preferences for "lake-stocked" crabs. The traditional market celebrates the changes of the seasons, so there is an implied contradiction in the very concept of an intensively-farmed mitten crab. However, it wouldn't be the first time that aquaculture broadened the market footprint of a sought-after product.

The portunid crab sector, dominated by *Scylla* spp., has a broader market demand. Within that, the emerging "soft-shell" crab sector will likely expand further but in doing so, better techniques for efficient management and control of moulting should evolve. While simple, easily implemented methods will have most application throughout Asia, countries more inclined toward intensification and automation of the process may find that a more comprehensive understanding of molecular mechanisms of moulting may be one useful avenue to follow.

5.2 Breeding

Better management of selected broodstock lines and separation from wild stocks is required for mitten crab culture, and will increasingly come to the fore with portunid culture now that routine lifecycle closure is possible. Selected to suit the most cost-effective production models for each species, including their consumer characteristics and reproductive quality, these broodstock will also need suitable maturation diets that carry on from the regular growout diets. The edible yield for live-marketed farmed crabs (with the exception of soft-shelled juveniles) includes ripe gonads, blurring the distinction between quality of broodstock and product and between diets for growout and for maturation. This will also make protection of selected lines problematic.

5.3 Hatchery methods

While not the bottleneck that it has been, some further refinement of hatchery techniques can probably be expected in both sectors in coming years as methods developed locally become more widely adopted. Eventually, there may be a shift from use of rotifers and other live feeds to formulated larval diets as larval requirements become better understood, (Holme et al., 2006b). While adoption of extensive practices has incidentally reduced the need for antibiotic intervention with mitten crabs (Cheng et al., 2008), it is possible that alternative water treatment methods may be found (Nghia et al., 2007a).

5.4 Nursery and grow-out

The low stocking rates of individuals remain a brake upon productivity. Aggression and cannibalism amongst over-stocked crabs remain significant issues, as is food supply when the crop exceeds the carrying capacity of the environment (Cheng et al., 2008; Wang et al., 2006) and beyond that point manufactured feeds formulated to the crab's dietary requirements must be available for semi-intensive production. Because of the various opportunities of using plant crops in ponds (eg. *Spirulina* or rice) knowledge of shelter use and behaviour emerging in work with nursery-sized individuals need to be extended further into growout. Useful parallels apparently exist between this problem and ecological studies of shelter use and foraging by crabs in the wild, (Hayden et al., 2007; Hovel and Fonseca, 2005).

Crabs can probably be selected to grow fast, and monosex culture deserves more attention with *Scylla spp*. Given that size is likely to be a major factor in aggression, practical methods of grading crabs should be examined both in nurseries and growout (Marshall et al., 2005).

6. Further information

http://www.fao.org/fishery/culturedspecies/Eriocheir_sinensis

FAO website (Cultured Species Information Program), (accessed 1/10/2008)

http://inco-cams.seafdec.org.ph/

Culture and Management of Scylla Species (CAMS) (accessed 1/10/2008)

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Table 1. Summary of current situation regarding aquaculture of crabs. For details and further reading refer to sections 3 and 4.

	Mitten crabs (*Eriocheir*)	Portunid crabs (eg. *Scylla*)
Ecology	Temperate freshwater omnivore with estuarine larval phase. Farmed in East Asia (especially China). Invasive species in US and Europe.	Tropical/Subtropical estuarine/marine predators with estuarine/marine larval phase. Farmed in South Asia and S.E. Asia.
Product	150-250 g wet weight. Transported live, meat recovery low but mature females with ripe ovaries prized. Lake-stocked product most valuable- leading to outbreaks of counterfeiting. Some caution required in cooking- host of a parasitic fluke.	300-500 g wet weight. Transported live, meat recovery low but mature females with ripe ovaries prized. Some species also marketed live or frozen as “soft-shell” crabs though common methods of moult-induction (multiple limb autotomy) are inefficient.
Grow-out	Extensive, Requires 2 years to grow. Wild juveniles or “seed” crabs “ purchased and stocked for “nursery” phase in first year (eg in rice paddies), in second year sold to operators of lake enclosures or earthen ponds. Instances emerging of poor growth rate (eg. due to precocious maturation) and some diseases concerns (“shaking leg disease”).	Extensive or semi-intensive. Harvested in less than one year Wild juveniles or “seed” crabs “ purchased and stocked directly to earthen ponds or mangrove enclosures. No significant disease outbreaks so far but can be asymptomatic carriers of white-spot syndrome virus (WSSV).
Feeding	Agricultural/plant wastes. Manufactured feeds are becoming more common but probably need improvement- especially for broodstock.	Low-value fish, manufactured feeds are becoming more common but probably need improvement- especially for broodstock. *Scylla* species readily digest plant meals.
Breeding	Hatcheries introduced to “restock” the industry with a reliable seed source. Quality of broodstock and the seed produced is increasingly under question, both in terms of broodstock diets and genetic management.	Was a significant bottleneck to industry growth. But now being introduced to reduce demand for wild juveniles and increase supply of “seed” crabs. Requires a “nursery” phase to ongrow metamorphosed crablets.