Capture-based aquaculture of mud crabs (*Scylla* spp.)

Colin Shelley
YH & CC Shelley Pty. Ltd
Brisbane, Australia
E-mail: ccyhshelley@ozemail.com.au

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*. No. 508. Rome, FAO. pp. 255–269.

SUMMARY

There is limited understanding of wild mud crab resources and how best to manage them in many countries, particularly where fisheries management resources and enforcement capabilities are limited. The growth of mud crab aquaculture is likely to lead to changes to the ecological, socioeconomic and livelihoods currently associated with mud crab fisheries. This paper provides an overview of the issues, needs, opportunities and risks in trying to maintain sustainable mud crab fisheries, whilst supporting the ecologically sustainable development of mud crab aquaculture.

The uncontrolled fishing of juvenile crabs for farming in some countries has led to recruitment overfishing, even though mud crabs are very fecund and have extended spawning seasons over much of their range. Conserving of mud crabs primary habitat, mangrove forests, is critical to supporting their populations, as is the regular monitoring of stocks to guard against their over-fishing. Environmentally sustainable farming of mud crabs in mangrove pens is seen as an important tool in both conserving mangrove forests, and expanding farm production areas.

Significant growth of mud crab aquaculture is only going to occur from hatchery sourced seed-stock, as wild populations are at either at their limit or over-fished in many countries. Such growth will also be dependent on the development of formulated diets to reduce mud crab farming's current dependence on trash-fish, a resource which is already under pressure from other types of aquaculture.

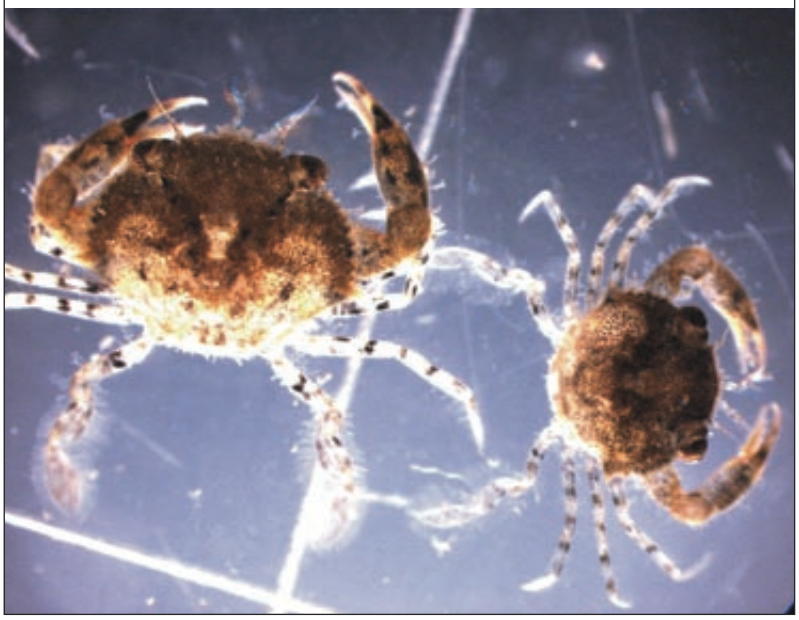
During the transition from an industry dependent on wild mud crab seed-stock and wild feed resources, to hatchery produced seed-stock and formulated fields there will be changes to the current supply chains, and employment opportunities. Consideration needs to be given to programmes to assist fishers of both wild mud crab seed-stock and trash-fish (and associated middlemen) as the farming of mud crabs moves to a more industrial scale as is currently taking place in China, as both groups are amongst the poorest in many coastal communities.

DESCRIPTION OF MUD CRABS AND THEIR USE IN AQUACULTURE

Species

There are four species of mud (or mangrove) crabs in the genus *Scylla*, *S. serrata*, *S. olivacea*, *S. tranquebarica* and *S. paramamosain* (Keenan, 1999b; Keenan, Davie

FIGURE 1
Juvenile mud crab



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and Mann, 1998), all of which support capture fisheries and aquaculture. In most countries where mud crabs are fished or farmed, they are an important source of income from both export and local sales, and are utilized by recreational fishers.

Life cycle

All mud crabs commonly display 6 larval stages; 5 zoeal stages, followed by a megalops larval stage which precedes the first crab stage (Figure 1). Mud crabs typically undergo 14–16 moults prior to reaching their maximum size. Reported daily weight gain for mud crabs varies from 1–4 g per day and varies with species, and sex, with males reportedly growing faster than females (Trino, Millamena and Keenan, 1999b; Christensen, Macintosh and Phuong, 2004). All mud crabs can mature within their first year of life, with *S. paramamosain* maturing at a size of 102 mm carapace width at around 160 days from settlement (Le Vay, Ut and Walton, 2006; Le Vay, Ut and Walton, 2007), whilst *S. serrata* have reportedly grown to 750 g within 145 days and shown signs of maturity at day 147 (Field, 2006). They are highly fecund with individual females carrying over 3 million eggs. Apart from spawning migrations where females may travel considerable distances offshore most crabs appear to move little within their local habitat, which is typically mangrove forest (Hill, 1975; Hill, 1976; Le Vay, Ut and Walton, 2006; Le Vay, Ut and Walton, 2007). Mud crabs of different sizes occupy different niches within mangrove forests and the adjacent sub-tidal zone (Walton *et al.*, 2006).

Habitat

Mud crabs are a common component of the fauna of mangrove forests, usually burrowing in mud or sandy-muds. They have a diverse diet and are omnivorous in nature, feeding on a wide range of animal and plant resources (Hill, 1976).

Geographical distribution

The distribution of mud crabs extends from South Africa, along the southern coasts of middle-eastern countries, across the Indian Ocean and northerly to the southern tip of Japan, east as far as Micronesia and south to the east coast of Australia. *Scylla serrata* is the most widely distributed species, whilst Indonesia appears to be the centre of diversity for the genus, where all four species of *Scylla* are found.

Capture fishery

The mud crab is a targeted species for harvest across its range. Techniques vary from catching by hand to the use of fishing gear including tangle nets, baited traps and lift nets. Fishery trends for the last decade are detailed in Table 1. However it should be noted that figures for Sri Lanka and Australia were missing from the FAO database and not included here, so that these figures represent an underestimate of the production of

TABLE 1
Capture of *Scylla serrata* in tonnes

Country	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Indonesia	7 980	7 342	8 298	8 161	8 707	8 774	11 753	11 240	14 802	20 129	18 750
Philippines	4 835	4 258	1 133	1 124	1 211	1 247	1 604	1 692	1 663	1 466	1 432
Taiwan PC	1 339	935	180	215	269	299	230	337	375	9	717
Thailand	5 776	4 243	4 031	3 732	5 736	6 921	5 417	3 823	1 259	2 859	1 865
Fiji Islands	234	208	290	270	281	250	268	180	82	324	280

Source: FAO–FIGIS

Scylla serrata. Whilst Indonesia has shown an increasing catch, all other major producers have shown either a decreasing or static catch.

FIGURE 2
Live crabs on sale in Viet Nam

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Harvest products

Juvenile crabs or crablets are actively harvested throughout Southeast Asia for use as seed-stock for crab farms. Sizes harvested vary from a few centimetres across the carapace to just under harvest size for sale direct to market.

Crabs of close to, or at a marketable size are caught for a range of activities. Crabs which have recently moulted and have not fully grown to fill their new shells are commonly referred to as "empty" crabs. Such crabs may be put into fattening pens, ponds or enclosures and fed until they are "full" and ready for market. Other crabs of varying sizes will be caught and put into soft shell shedding facilities. Such crabs are commonly placed in individual containers and monitored until they moult. On moulting the crabs will either be chilled and put on ice, or frozen for the soft shell crab market, where all parts of the crab can be consumed as the shell has not been allowed to harden after moulting. Finally, hard-shell crabs of a marketable size are collected, secured to ensure traders and customers are not injured by their powerful claws and sold; most commonly in the live form (Figure 2). The size of crabs marketed varies with species. In the Philippines *S. serrata* is most commonly harvested at weights over 500 g, whilst for *S. olivacea* and *S. tranquebarica* the weight is usually over 350 g.

Whilst mud crabs are usually a targeted species, they may be caught occasionally in various nets which are targeting other mangrove or reef species and are caught as they move across their habitat. Only a very small part of the mud crab harvested is bycatch of other fisheries. Mud crabs adapt very well to a farmed environment. With their omnivorous diet they will eat a wide range of feeds, from trash fish through to pelletised aquaculture feeds.

There are a number of problems encountered by collectors and farmers, involved with using wild harvested crabs in various farming systems. Stock will often consist of a wide variety of sizes, and as mud crabs have a tendency to cannibalism, larger specimens will often predate on smaller crabs, causing significant mortalities amongst farm stock.

Life cycle status

Mud crabs born in captivity have been successfully mated with both wild and other captive stock so that some organizations and companies now use domesticated stock. Almost all hard shell, mature females collected from the wild will have been impregnated and will spawn if held under appropriate conditions. Each mature female will usually be able to spawn 2 or 3 batches of larvae when held under satisfactory conditions following a single copulation.

The use of farm produced seed is now becoming common in Viet Nam and China in particular. In some countries, such as the Philippines, there has been caution in the use of hatchery produced stock to date (Shelley, 2004a). Farmers have reported a range of concerns with crablets produced in hatcheries; will they be as robust as wild stock, will they grow as fast, will they be more prone to disease, and which is the better value for money – wild or farm produced stock?

In some countries where mud crab fisheries are actively managed e.g. Australia, crablets or under-size crabs cannot be legally harvested.

Farming techniques

Considerable efforts have been made over the last few decades to develop effective technology for mud crab aquaculture (Brick, 1974; Angell, 1992; Heasman and Fielder, 1983; Keenan and Blackshaw, 1999a; Anon., 2001; Anon., 2005; Shelley *et al.*, In Press; Wang *et al.*, 2005). A significant body of work on mud crab aquaculture is contained in a number of workshops, conference proceedings and review papers (Angell, 1992; Anon., 2001, 2005; Keenan and Blackshaw, 1999a). The successful development of techniques to support the mass culture of mud crab larvae in hatcheries drove the rapid expansion of mud crab farming in China during the 1990s, and its subsequent expansion, often in polyculture with shrimp, fish and algae (Wang *et al.*, 2005). In China, in 2003, over 34 000 ha of culture area for mud crab produced just over 100 000 tonnes whilst over 79 000 tonnes were taken from the wild, making China the worlds largest producer of mud crabs (N. Zhou, Network of Aquaculture Centres in Asia-Pacific, personal communication).

Until recently, larval production of mud crabs had been difficult with low and inconsistent quantities of crablets produced. However in recent years average survival rates have increased (Wang *et al.*, 2005), and production of crablets for farms is now practised at a commercial scale in countries including Viet Nam, China, Philippines and Australia. Maintaining stable water quality conditions, minimising bacteria build-up and providing high quality feeds at appropriate densities have proven to be the key needs for successful larval production of mud crabs (Shelley *et al.*, In Press).

There are a range of nursery systems used to grow mud crabs from the late zoeal stages, through megalops to settlement and metamorphosis to crablet. A variety of tanks, ponds and *hapa* nets within ponds have been successfully used. A complex 3-dimensional habitat within such systems increases the densities which can be carried by any particular system. Suitable habitats include netting, plastic mesh and artificial sea grass. An appropriate temperature and salinity range is required in nursery systems to maximize survival (Ruscoe, Shelley and Williams, 2004).

The grow-out of crabs is undertaken in various systems. The two major system types are: a) open; which includes ponds and mangrove enclosures where crabs are maintained at varying densities, and b) closed; where crabs are held in individual containers e.g. soft shell crab (Figures 3 and 4), or restrained in some way e.g. fattening enclosures (Figure 5). In Viet Nam culture techniques have been defined as extensive, intensive and cage culture (Thach, 2003). Crabs were fed on diets including trash fish, molluscs and small crustaceans. In extensive system seed crabs were stocked at 1 crab/5–10 m^2 with wild seed, 1 crab/2–5 m^2 for smaller hatchery seed, whilst an intensive stocking rate was considered to be 1–1.5 crabs/m^2. Cage culture in Viet Nam is a fattening exercise where

large crabs (200–400 g) are held in high densities of 35 crabs/m^2 and fed until marketable. Lindner (2005) further described systems in Viet Nam, that included a range of low-input systems such as pens in mangrove forests and extensive shallow mangrove silviculture ponds that do not require supplemental feeding. In some areas in Viet Nam rice fields are flooded with brackish water that contains crab and/or shrimp seed, which become an important technique for farmers to supplement their income. More intensive Vietnamese systems that stock ponds at higher densities using purchased crablets commonly use trash fish or shellfish as feed and can produce 1–2.0 tonnes/ha^{-1}/crop (Lindner, 2005).

In open production systems the cannibalistic behaviour of mud crabs is a major impediment to their high density production. Cannibalism can be minimized by using relatively low stocking densities and by utilizing some form of enclosures or shelter to provide refuge. Antagonistic behaviour between crabs can also result in loss of limbs by mud crabs. As a result, a percentage of crabs at harvest will have limbs missing and will fetch a lower price, or need to be kept longer on the farm for limbs to regenerate. To minimize the impact of cannibalism on survival a useful management strategy is to routinely undertake partial harvests of crabs (Say and Ikhwanuddin, 1999) of a commercial size in grow-out systems, leaving sub-harvest size crabs to grow to harvest size with a reduced incidence of predation, in more space and with less competition for feed (Christensen, Macintosh and Phuong, 2004).

The statistics for aquaculture production of the mud crab (*S. serrata*) in Tables 2 and 3 indicate that in recent years Chinese production of mud crabs is approximately an order of magnitude greater than that of the next highest producing country

FIGURE 3
Mud crab fattening bamboo box in the Philippines

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FIGURE 4
Mud crab individual fattening bamboo boxes in the Philippines

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FIGURE 5
Mud crab fattening pen in Indonesia

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(Viet Nam). In the last few years the Vietnamese production of farmed mud crabs has increased significantly, however statistics were not available from FAO for the country. It should also be noted that FAO statistics are nominally for *S. serrata*, however as three other species of mud crab are farmed in different countries it is believed that these figures are likely to more accurately represent production of the genus *Scylla*, rather than the species (*S. serrata*). These figures also demonstrate that the aquaculture production of mud crabs now exceeds that of wild harvest, notably because of the massive growth in the farming of mud crabs in China in recent years.

TABLE 2
Aquaculture of *Scylla serrata* in tonnes

Country	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
China	0	0	0	0	0	0	0	0	100 870	108 503	111 423
Indonesia	1 906	1 339	5 176	866	5 143	5 126	3 879	9 039	7 152	2 243	4 379
Malaysia	623	381	277	231	188	225	219	311	204	174	162
Philippines	2 782	2 463	3 759	4 033	4 826	4 968	4 608	4 747	4 809	6 245	6 861
Taiwan PC	1 526	797	430	796	381	315	423	239	226	239	240
Thailand	45	132	115	19	9	9	5	10	10	23	20

Source: FAO–FIGIS

TABLE 3
Aquaculture value of *Scylla serrata* in US$

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
China	0	0	0	0	0	0	0	0	201 740	216 959	245 329
Indonesia	3 240	2 343	8 282	1 559	9 257	9 227	6 982	4 831	2 014	3 948	9 108
Malaysia	1 389	1 673	1 184	1 262	601	743	971	886	795	679	463
Philippines	18 031	14 375	22 430	16 968	23 782	21 270	16 713	19 642	19 374	28 375	30 775
Taiwan PC	15 530	8 538	4 464	8 274	4 157	3 235	4 090	1 880	2 109	2 159	1 907
Thailand	91	394	308	43	28	27	19	40	41	92	85

Source: FAO–FIGIS

DESCRIPTION OF MUD CRAB FISHING

Gear used to fish for juveniles

The techniques for collection of juvenile crabs were comprehensively reviewed in the seminar on mud crab trade and culture, conducted by the Bay of Bengal Programme (Angell, 1992). In particular details were provided for the Bay of Bengal (Sivasubramaniam and Angell, 1992), and countries attending the seminar (Cholik and Hanafi, 1992; Kathirvel and Srinivasagam, 1992; Khan and Alam, 1992; Ladra, 1992; Tookwinas, Srichantulk and Kanchannavasiste, 1992). For juvenile and larger crabs, the gear used can include baited traps, lift nets or lines, together with hand held hooks, scoop nets, gillnets and fish corrals. For crab larvae and very small juvenile crabs, which are yet to settle, fine meshed push nets or drag nets can be used.

In the Philippines a small meshed net is mounted on a V-shaped bamboo frame and pushed across muddy substrates to collect juveniles, whilst for larger crabs a variety of traps are used with fish baits to attract the crabs. In Viet Nam juvenile crabs are collected from canals and coastal waters using a bottom seine net (Johnston and Keenan, 1999).

Statistics on juvenile collection

Whilst production figures on farmed mud crabs are available for most countries, there appear to be no official statistics on the collection of juvenile crabs. It has been estimated that juvenile (20–60 mm carapace width) *S. paramamosain* can be found at densities of over 1 000 ha^{-1} (Le Vay, Ut and Walton, 2007) in some locations where their commercial harvest is undertaken.

Post-harvest techniques

Juvenile crabs caught specifically for farming will typically be packed, without water, in boxes or bags and kept in a moist environment during transport, either to a middleman or farmer. Juvenile crabs can be transported in this manner successfully for several days without significant mortalities if properly packed.

If crabs of commercial harvest size are collected there are 3 main ways in which they are handled. *Method one* for hard shelled, "full" crabs is for the crabs to be tied to secure their limbs and packed into boxes or bags, kept moist and then transported to market, typically via an agent, or middleman. The vast majority of mud crabs are sold live. *Method two* is the fattening of "empty" or "soft" recently moulted mud crabs (Ladra, 1992; Liong, 1992; Rattanachote and Dangwatanakul, 1992). This can be regarded both as a post-harvest technique and as a specific type of aquaculture. In India, Patterson and Samuel (2005), described the success of a crab fattening project operated by a self-help women's group. In the wild fishery approximately 7–10 percent of the catch on average was "empty" and would usually be discarded, but these crabs when fattened for 21–30 days to a "full" crab, increased in average value by over 200 percent (US$4.63 to US$9.53 per kg), making a good profit for the women's group. *Method three* is for smaller crabs in the range of 50–150 g. Such crabs can be held in individual containers and checked regularly to see if they have moulted. On moulting, whilst their shells are still soft, they are either chilled or frozen for the "soft shell" crab trade, a market segment rapidly gaining in popularity, particularly because soft shells fetch an even higher price per kilogram than do hard shell crabs.

AQUACULTURE DEPENDENCY ON THE WILD STOCK

Reliance on wild seed

As mud crab hatchery development on a commercial scale has only occurred in a few countries, farms in most countries are dependent on wild caught stocks. It is only in

countries such as China and Viet Nam, where there is significant expansion of the mud crab hatchery sector, that hatchery produced seed-stock will contribute a significant percentage of overall production in the near future. In the Philippines it is estimated that 95 percent of crab seedstock is collected from the wild. In contrast in countries where collection of wild seed stock is banned under management plans e.g. Australia, the farming of crabs is totally dependent on hatchery produced stock.

Limits of seed supply

The loss of mangrove forests, over-exploitation of wild crab stocks and inadequate wild production to support increasing demand are the key factors that have driven the development of hatchery technology for mud crabs (Lindner, 2005). The supply of seed-stock from the wild varies over time, as recruitment to the fishery is seasonal (Walton *et al.*, 2006b), as reflected in the variation of zoeal abundance in near shore waters (Sara *et al.*, 2006). As zoeal distribution and abundance is correlated with salinity, recruitment to different areas will also be affected by climatic variability (Sara *et al.*, 2006).

Heavy fishing pressure on mud crab fisheries in the Philippines has been reflected in decreasing relative abundance, mean size at capture, yield and catch per unit effort (CPUE) in two studies (Lebata *et al.*, in press).

In some municipalities in the Philippines, the number of crablets being transported out of the municipality is being restricted because of fears of over-fishing. A number of research organizations are helping municipalities by assessing their stocks of crabs and providing support to policy and management plans.

Threats to mud crabs generally, which would also impact on seed supply, can include algal blooms, industrial and urban run-off, and their over-exploitation such as occurred in India in 1990 which led to their export being banned (Aldon and Dagoon, 1997). The supply of crab seed-stock can also be limited by the number of fishers targeting the species (Say and Ikhwanuddin, 1999).

In some countries up to 4 species of mud crab can be found. As a result, stocking with wild crab seed-stock can result in multiple-species being grown in the same grow-out system. This creates problems as all species have different growth rates, and the faster growing species may well cannibalise the slower growing species, and generally complicate animal husbandry.

The need for a consistent, reliable year-round supply of mud crab seedstock to support farm expansion will underpin the future significance of mud crab hatcheries.

Economics of wild versus farmed seed

There are a number of reports on the economic performance of mud crab culture (Aldon, 1997; Baliao, De Los Santos and Franco, 1999a; Cann and Shelley, 1999; Say and Ikhwanuddin, 1999; Christensen, Macintosh and Phuong, 2004; Samonte and Agbayani, 1992a; 1992b; Trino, Millamena and Keenan, 1999a). Information regarding wild seed versus farmed seed appears anecdotal at best, with most trials using either wild or farmed seed, not both. As hatchery reared stock have only relatively recently become available in a few countries, most economic reports to date were based on grow-out of juvenile crabs collected from the wild (Figure 6).

It has been demonstrated that profitable crab farming operations can occur using wild seed-stock at various densities (Trino, Millamena and Keenan, 1999a), although the most profitable density is likely to be related to both the system and management of operations that can minimize cannibalism and improve the food conversion ratio (FCR). It has also been shown that farming mono-sex cultures of crabs may increase economic return, with one report reporting a return on investment of over 100 percent (Trino, Millamena and Keenan, 1999a).

The effects of harvesting regime on the profitability of mud crab farming in ponds was examined by Rodriguez, Trino and Minagawa (2003) who found that a bimonthly

FIGURE 6
Hatchery-produced mud crab juveniles

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selective harvesting regime could improve profits compared to one terminal harvest. They argued that a selective harvesting regime increased overall survival to harvest as more space was available to those crabs left in the ponds and a more homogenous size range of crabs was maintained, as typically large crabs enter harvesting traps first.

The profitability of growing mud crabs in mangrove pens has also been documented (Trino and Rodriguez, 2001). They found a stocking density of 1.5 crabs/m^{-2} fed on a mixed diet of mussel flesh and fish bycatch to be most profitable, obtaining returns of 49–68 percent return on capital investment.

Dependence on wild caught feed

In a workshop examining the status of mud crab aquaculture, Allan and Fielder (2003b) summarized that "... diet development to reduce dependence on trash fish in Indonesia, the Philippines and Viet Nam, and to allow for grow-out in Australia, was the highest overall priority for mud crab aquaculture." This reflects the current situation in most countries where mud crabs are farmed, where the principal source of feed is wild caught trash fish and molluscs.

A key challenge facing the rapidly growing mud crab farming sector in countries such as Viet Nam, Indonesia and the Philippines is the lack of a formulated aquaculture feed made especially for mud crabs (Allan and Fielder, 2003a). There are concerns that industry growth may ultimately be constrained by the dependence on low value trash fish and fishmeal popularly referred to as the "fishmeal trap" (Funge-Smith, Lindebo and Staples, 2005).

Whilst formulated mud crab feeds are now available in a number of countries where mud crabs are farmed e.g. China, Philippines and Viet Nam, there is scope to improve formulations and to reduce their cost.

Availability of wild feed

Wild caught feed resources

Crabs have a varied diet naturally and seem to grow well on a wide variety of feeds. In the Philippines typically chopped trash fish are used, but animal hide, entrails and snails (golden kuhol) have also been reported (Aldon, 1997), as has brown mussel flesh (Rodriguez, Trino and Minagawa, 2003). While research is underway to develop a specialized crab feed, trash fish resources in many regions are under severe pressure. This pressure is resulting in higher prices for trash fish and also conflict with human consumers of seafood, who themselves would like to consume so-called "trash fish".

ENVIRONMENTAL IMPACTS OF JUVENILE CRAB FISHING

Impact of the seed fishery on wild stocks

Removal of mud crab seed-stock from the wild can result in recruitment failure for the stock as a whole if fishing pressure is high enough. This appears to have happened in a range of localities in the Philippines. The impact of the seed fishery on the wild stocks will depend on the size of the population, the take of the fishery, food availability and maintenance of the habitat supporting the fishery. In Viet Nam, Lindner (2005) considered "there may be limited scope for further expansion of crab fattening due to its reliance on wild crab stocks that are claimed to be fully exploited".

It has been shown that mud crab recruitment can be continuous throughout the year in some fisheries which may explain why such fisheries can be quite resistant to heavy fishing pressure (Le Vay, Ngoc Ut and Jones, 2001). However, unlike the fishery examined by Le Vay, Ngoc Ut and Jones (2001), few mud crab fisheries have been well researched, so that changes in baseline variation in crab abundance can be monitored to assess the effectiveness of either management provisions, habitat change or fishing pressure.

Impact of seed collection on the ecosystem

Apart from over collection of mud crab seed-stock resulting in decreased crab populations in some areas, little appears to have been researched regarding the impact on ecosystems of this practise.

SOCIAL AND ECONOMIC IMPACTS OF THE FARMING

Social impacts

Description of the supply chain

Whilst there are variations from country to country, the supply chain from the collection of a juvenile crab may include one or more middlemen to a farmer, and then from a farm a further number of middlemen to an exporter, or if for local trade to a retailer (Cholik and Hanafi, 1992). In some countries the crabs marketed locally are often those that are not of sufficient quality to be exported (Khan and Alam, 1992).

The supply chain often has an additional link in it which includes mud crab fattening. Where fishermen or farmers harvest post-moult or "empty" crabs, these may be send to a farmer who specializes in fattening crabs (Rattanachote and Dangwatanakul, 1992).

How does aquaculture change supply chain arrangements

The major change in the supply chain occurs if hatchery operations are introduced into the industry. In time, growth of the hatchery sector for mud crabs may result in collectors of wild seed loosing a source of income if farmers favour hatchery stock over wild. There are a number of reasons why hatchery produced stock would in time be favoured by farmers. Stock would be of a more uniform size (minimizing cannibalism), of just the one species and also available in large numbers on a year-round basis.

However in the short- to medium-term, the demand for mud crab seed-stock in most countries would indicate that collection of wild stock will remain a viable fishery for some time, subject of course to sustainability issues.

How does aquaculture influence employment and skill development

In Bangladesh it was reported that most crab catchers are otherwise jobless and landless (Khan and Alam, 1992). As more hatchery operations for mud crab start up there will be an increased demand for skilled and semi-skilled technicians, and for training programmes to support such development. Viet Nam has developed a very successful train-the-trainer programme in mud crab aquaculture which has supported the rapid expansion of the mud crab hatchery sector in that country (Shelley, 2004b).

With hatchery production of crab seed-stock, the expansion of the industry will not be limited by the supply of wild seed-stock in the medium to long term. As a result the industry is expected to expand dramatically over the next few years. This will stimulate a demand for more workers to manage ponds, harvest and pack crabs and in support industries such as feed production, transportation and construction.

Economic issues

Winners and losers

In the Philippines, Aldon (1997) provided advice on how to establish and operate mud crab culture in mangrove areas. Information on the economics of such a venture indicated that a return on investment of 44 percent was possible, with a payback period on establishment costs of 2.27 years. This was based on a production yield of 600/kg/h^{-1} and survival rates of 65–70 percent. A similar model from the Philippines (Baliao, De los Santos and Franco, 1999a) had a payback period of 1.4 years.

Mud crab aquaculture is now commonly being undertaken in enclosures or pens in mangrove forests (Baliao, De los Santos and Franco 1999b; Chang Wei Say and Ikhwanuddin, 1999; Rodriguez, Trino and Minagawa, 2001; Trino and Rodriguez, 2002). This is putting a significant value on mangrove forests and encouraging their conservation and in some places re-planting. Whilst mangrove enclosures are productive systems for mud crab aquaculture, the mangroves themselves are also valuable and critical to sustain wild mud crab fisheries (Ronnback, 2001).

MANAGEMENT

Amongst all the countries where mud crabs are commercially fished, the fishery is most highly regulated is Australia. All states and territories where mud crabs are fished have detailed management plans, which are backed up by legislation and enforcement by specialised fisheries enforcement agencies. The number of commercial fishers and the number of crab pots used is strictly limited. All commercial mud crab fishers in Australia must complete logbooks recording the date, the number of crabs caught and the location of their catches. Information from these logs are collected on a monthly basis, entered into databases and analysed routinely. For recreational fishers, the number of crab pots that can be used, the number of mud crabs in possession and where and when they can fish is legislated. Considerable research and monitoring is also targeted on the mud crab fisheries in Australia to ensure management arrangements are working (Hay *et al.*, 2005). No crabs under a specified minimum size limit can be collected, so utilization of mud crab seed-stock in Australia is not an issue as none is allowed. In Queensland, all female crabs are protected, so only males can be legally harvested by commercial or recreational fishermen, making Queensland the most regulated mud crab fishery in Australia.

Many countries have regulations or plans, which seek to control mud crab fisheries. However economic necessity and the lack of resources to enforce such legislation appear to result in a low level of compliance in most countries. In many countries

strings of immature, under legal size crabs are routinely sold for human consumption, in addition to the collection of seed-stock for farming, putting enormous pressure on the reproductive population.

Whilst there have been some efforts to examine the potential for stock enhancement of mud crab fisheries from a research perspective, there appears to have been little long-term efforts to do this on a commercial scale, apart from Japan.

CONCLUSIONS

Mud crabs can be the focus of commercial fishing activities throughout their life cycle in many countries, which can put intense fishing pressure on stocks. Juveniles (crablets) of varying sizes can be collected to stock farms for grow-out for either hard or soft shell crab production, whilst larger crabs are harvested for direct sale, or for fattening if the crabs are "empty" when collected, as is the case in the first few weeks post-moult.

The development of hatchery technology for mud crabs to support industrial scale development of crab farming is beginning to impact on the ecological, socio-economic and livelihoods traditionally linked to mud crab fishing in some countries.

The growth of mud crab aquaculture will increase demands on the collection of wild stock for grow-out and for limited trash fish and molluscan resources to feed crabs. To cope with increasing pressure on mud crab fisheries innovative management regimes need to be developed where fisheries management and enforcement resources are limited. The need to develop economically viable feeds for mud crabs to minimize the use of trash fish, is one shared with many types of aquaculture, as is the replacement of fishmeal and fish oils generally in stock feed formulation.

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