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Current Trends in Hatchery Techniques and Stock Enhancement for Chinese Mitten Crab, *Eriocheir japonica sinensis*

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Aquaculture of the Native Chinese mitten crab (Eriocheir japonica sinensis) *has developed quickly in China to reach 570,000 mt in 2005, which exceeds all other worldwide production of crab from aquaculture and capture fisheries combined. We review the development of aquaculture techniques and stock enhancement that account for this successful production of Chinese mitten crabs. There are two models for mitten crab larviculture. In the first model, intensive larviculture occurs in indoor concrete ponds, with conditions of temperature control, aeration, and a plentiful supply of food (algae, egg yolk, rotifers, Artemia nauplii). In the second model, outdoor extensive larviculture occurs in earth ponds with no temperature control. Grow-out of the mitten crab focuses on release of cultured seed crabs into net enclosures in lakes. As a rule, the production of adult crabs is 150–450 kg/ha and as high as 975 kg/ha. Recently, Chinese researchers noticed deterioration of water quality and the exhaustion of natural food resources in many lakes due to over-stocking crabs, and many studies are now beginning to investigate a model for the sustainable aquaculture of Chinese mitten crab in these systems.*

Keywords mitten crab, *Eriocheir japonica sinensis*, hatchery technique, pond culture, stock enhancement

INTRODUCTION

Chinese mitten crab (*Eriocheir japonica sinensis*; Tang et al., 2003) is a native crustacean of high economic value in China. In recent years, Chinese mitten crab culture has developed very quickly, such that its aquaculture now occurs all over China except in Tibet Province. The total production was about 368,000 mt in 2003, more than 40 times the production level in 1991 (China Fisheries Yearbook, 2004), and is continuing to increase (Figure 1). According to the life cycle of the Chinese mitten crab in Yangtze River delta described in Figure 2, the culture stages of the mitten crab can be divided into three stages: hatchery stages, coin-sized seed crab culture stage, and market crab culture (Table 1).

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The increase of recent Chinese mitten crab culture mainly resulted from breakthroughs and improvements of hatchery techniques after approximately 20 years of development. Artificial seed (i.e., megalopa stage) is produced in very large quantities by larval rearing (5 zoea [Z1–Z5] and a post-larval megalopal stage [M]) in coastal brackish water for subsequent transfer to freshwater systems inland for juvenile growth to market size. Based on recent China Fisheries Bureau statistics, the quantity of mitten crab megalopae artificially produced in China has exceeded 200,000–600,000 kg per year, with increasing production each year (277,000 kg in 2001, 346,000 kg in 2002, 521,893 kg in 2003). Nearly all of the megalopal production occurs in the Yangtze River delta; production is also high in Liao River region of northern China. For example, in 2003 total megalopa production in Jiangsu Province was 360,586 kg, while in Zhejiang Province it was 37,445 kg. Using a range of hatchery techniques, juvenile mitten

Table 1 Chinese mitten crab culture stages in the Yangtze River delta of China. The life span is from 18–24 months

Time	Duration (months)	Stage	Molt Times	Initial and Last Weight	Culture Stages	Natural Habitat
(The first year) 4.15–5.15 (for hatchery productions) 5.25–6.10 (for wild production)	1	Z1-M (larvae)	5	0.13 mg and 5 mg	Hatchery	Z1-Z5 (salinity 10–30 ppt, optimum 20–25 ppt); Temperature13–25°C, optimum 18–24°C
5.15–11.20	6	Crab 1—crab 8 (juvenile stages)	7–8	10.0 mg—5–10 g	Coin-sized crab culture	Temperature: 0–30°C, optimum 20–28°C Eat: natural food in lakes, such as water plants and mud snails.
11.20–9.20 (the second year)	10	Crab 8—crab 12 (yellow crab)	4–5	5–10 g—125–200 g	Market crab culture (stock enhancement in lakes)	As above, prefer to live in the lake area where there are abundant water plant and rich in zoobenthos.
9.20–11.20	2	Last molt and reproductive migration	1	150–250 g	Harvest season and broodstock crab enrichment	
11.20–4.15 (the third year)	5	Embryonic development			Ovigerous	

crabs are stocked into a variety of highly managed and natural habitats for growth to adult size for harvest.

The Chinese mitten crab is often described as an invasive species and has been found in many places around the world, including a recent new record in Chesapeake Bay (Ruiz et al., 2006). It is considered to pose a significant risk of ecological and economic impacts. Knowledge about the mitten crab biology, culture and fishery in China, especially the knowledge of larviculture, grow-out, and stock enhancement of the crab, is not well known outside of China. Because few publications in English describe this program, we review the current trends in aquaculture and stock enhancement for Chinese mitten crab in China. This information may be useful not only for future culture of other crab species, but also for understanding how to avoid establishment of invasive populations of the Chinese mitten crab in other areas.

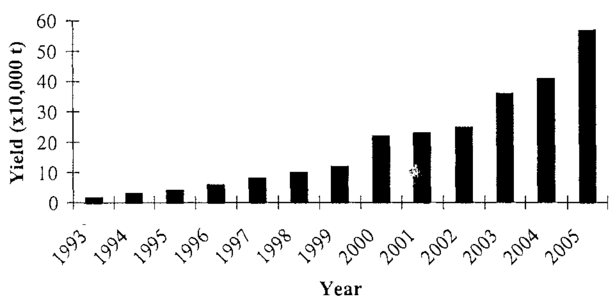

Figure 1 Total aquaculture production of the mitten crab in China.

HATCHERY TECHNIQUES FOR THE CHINESE MITTEN CRAB IN CHINA

Development of Chinese Mitten Crab Hatchery Techniques

Mitten crab culture began in the 1970s, and in 1980 Zhao first reported his successful breakthrough in hatchery techniques using artificial seawater (Zhao, 1980). At almost the same time, good results were also obtained by using natural seawater. From the 1980s to the early 1990s, no further progress was made, probably because mitten crab culture did not spread to other locations along the coast of China.

Hatchery techniques for mitten crabs spread to most coastal areas along the Yangtze River and Liao River after 1990, following marked declines in the abundance of megalopae in the region (Figure 3). The loss of this wild natural resource stimulated development of mitten crab culture in hatcheries to produce seed crab for stock enhancement and aquaculture (Tables 2 and 3). During the 1990s, the hatchery techniques for mitten crabs

Table 2 Comparison of meglopae released in open lake in Jingsu Province (Zhao et al., 1991)

Lake	Area (ha)	Recapture Rate %	Density of Megalopae Release (ind/ha)	Adult Crab Yield Per ha (kg)	The Period of Release (Year)
Tai Lake	213,333	0.7	1065	0.9	1968–1987
Hongze Lake	196,000	2.2	1440	3.9	1971–1987
Gaobao Lake	99,333	2.7	1605	5.4	1970–1987
Baima Lake	11,000	4.4	5730	27.9	1976–1987

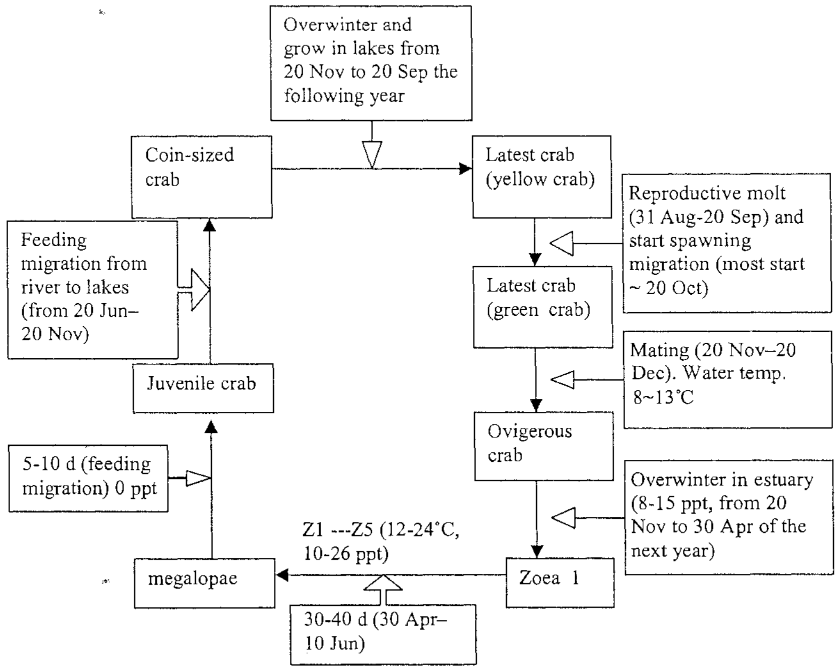

Figure 2 The life history of Chinese mitten crab *Eriocheir sinensis* in theYangtze River delta.

were gradually developed and improved for practical, large-scale production of megalopae, juveniles, and adults.

Broodstock and Preparation before the Larvae Rearing

Broodstock Dietary Enrichment. The key to successful hatchery techniques is to obtain good breeding stocks of male and female crabs. Broodstock nutrition is crucial during gonadal development in the fall (from late September to mid November). Good diets consist of formulated diets that are artificially supplemented with fats or natural diets such as constricted tagelus (*Sinonovacula constricta*). Cheng (2003) compared the reproductive performance and larval quality of two groups of broodstock. Group I received an artificial diet enriched with HUFA (highly unsaturated fatty acids), phospholipid, cholesterol, vitamin C, and vitamin E during ovary development of gonadal somatic index (GSI) increasing from 2.4% to 12.3%. Group II received a diet of bivalves that was not enriched and GSI increasing from 2.4% to 10.2%. The results showed that female crabs fed enriched diets had a higher brood survival rate (broods developing from newly spawned eggs to egg hatching, 96.2%), GSI (12.3 $\pm$ 0.9%), HSI (hepato-somatic index, 4.1 $\pm$ 0.6%), egg production per female ((40.2 $\pm$ 3.2) $\times$ 10^4 eggs per female) than Group II brood survival rate (86.2%), GSI (10.2 $\pm$ 0.8%), HSI (3.4 $\pm$ 0.6%), and egg production per female ((27.8 $\pm$ 4.8) $\times$ 10^4 eggs per female). In addition, larval quality (Z1) was also better in Group I than Group II, with longer head length (606 $\pm$ 4 μm vs 588 $\pm$ 11 μm), better resistance performance under osmotic shock (cumulative mortality index, 336.3 $\pm$ 128.1% vs 543.3 $\pm$ 35.7%), and a starvation tolerance test, higher survival rate, and shorter larval duration time from Z1 to M (7 days less than Group II). Therefore, broodstock dietary enrichment is currently emphasized as necessary maternal conditioning before larval rearing in hatchery farms.

Mating. After dietary enrichment of female broodstock, good gonad development is obtained in the late fall (mid-November), and male and female crab are typically put to the seawater ponds to mate and spawn the eggs. The optimal temperature range for copulation is 8–12°C, with a salinity of 14–20 ppt. An appropriate sex ratio of females to males is 2–2.5:1. In the Yangtze River area, copulation may also be delayed until the following March. This delay has the advantage of avoiding potentially early brood production and maintaining ovigerous crabs over winter, but it has the risk of producing lower quality Z1 larvae.

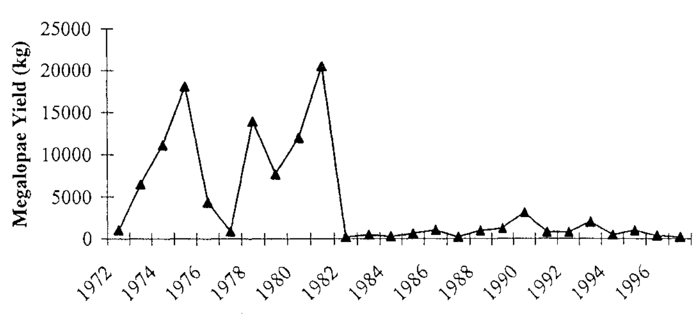

Figure 3 The annual yield of mitten crab megelopae (kg) caught in the Yangtze River estuary from 1972–1997 (from Zhan et al., 1999). Note steep drop in yield in 1982 to persistent low levels.

Table 3 Comparison of net enclosures used for grow-out of Chinese mitten crab in lakes

Lake (Province)	Enclosure Area (ha)	Seed Crab Stock Date	Stock Density (ind / ha)	Stock Size (g)	Feeding	Adult Crab Yield (kg/ha)	Adult Crab Size (g)	Recapture Rate (%)	Harvest Period (dates)	Reference
Hongze Lake (Jiangsu)	24.4	1990–5–2 to 1990–6–16	8352	25	yes	628.8	133	56.6	1990: Oct 20 to Nov 27	Liu et al., 1992
	48.4	1990–4–30 to 1990–6–6	7699	24.9	yes	581.2	136	54.8	1990: Sept 20 to Nov 27	
East Tai Lake (Jangsu)	1.6	1996–2	3750	8.3	No	242.2	105	61.5	1996: Oct	Wu et al., 2001
	0.67	1996–2	6090	14.7	Yes	532.5	145	60.0	1996: Oct	
Huyuan Lake (Anhui)	133	1997–3	1425	7	Little	135.3	165	28.7	1997: Oct	Cui and Xiao, 2000
	133	31998–3	1365	7	Little	142.9	155	34.1	1998: Oct	
	133	1999–2	1500	7	Little	206.7	165	41.8	1999: Oct	
	133	1999–3	2550	7	Little	260.1	150	34.0	1999: Oct	
Nusan Lake (Anhui)	40	2004–2–20	1500	5	Yes	93.08	143.2	43.3	2004: Sept 20 to Oct 20	Liu, 2006

Hatchery Technique Models. There are two models of hatchery techniques for Chinese mitten crab in China: indoor intensive larviculture and outdoor extensive larviculture.

Indoor intensive larviculture. As described by Sui et al. (2005), indoor intensive larviculture (IIL) occurs in indoor concrete ponds/tanks (typically 5 m × 5 m× 2 m), with conditions of temperature control (starting at 18°C for Z1 and increasing 1°C before each larval stage molt to 24°C by the molt to meglopa), aeration and supply of live food (algae, rotifers, *Artemia* nauplii), as well as other foods such as frozen rotifers, copepods, and egg yolk. The Z1 density is typically 0.2–0.5 million larvae m^{-3}, and the megalopal production is usually 150–500 g m^{-3}, or 20,000–70,000 individuals m^{-3}. Survival is about 10%–15% from Z1 to M. From Z1 to Z3, a little pond water (about 1/4–1/2) is changed; after Z3, a larger percentage of the pond water is changed, and by the megalopal stage water is changed twice per day. The best salinity for larval rearing is 20–25 ppt, although megalopa can be reared successfully in 10–30 ppt. To acclimate megalopae for transition to freshwater conditions of juvenile culturing, salinity reduction ("desalting") typically begins 3 days after the molt to megalopae, and by 6- to 7-day-old megalopae, the salinity is reduced to <5 ppt, and the duration from the first hatching Z1 to the late-stage, acclimated megalopae is 22–24 days, and the size of 6- to 7-day-old megalopae is 140,000 ind kg^{-1}. At this stage the megalopae can be sold to farmers for freshwater coin-sized seed crab pond culture in inland habitats. In this model, antibiotics such as tetramycin or tetracycline are usually added to the ponds to prevent disease.

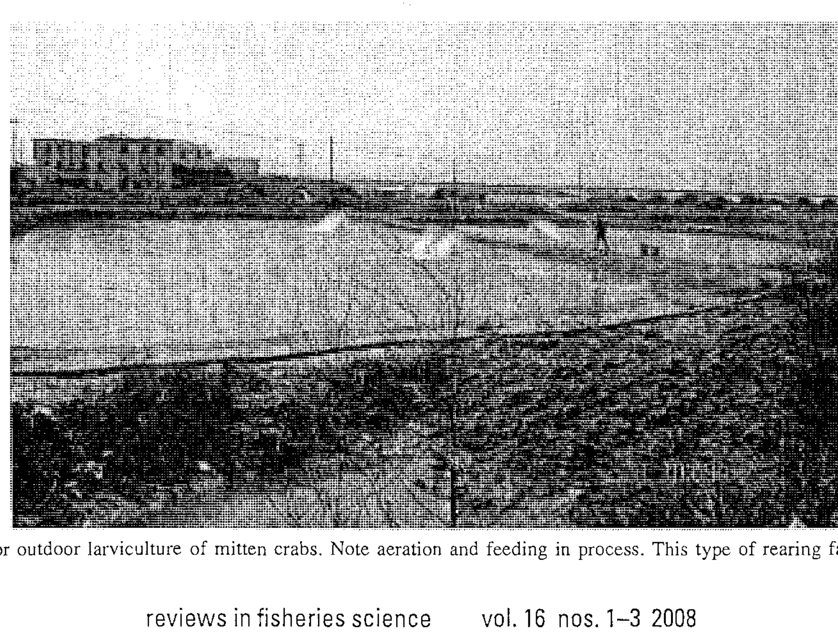

Figure 4 Earth ponds for outdoor larviculture of mitten crabs. Note aeration and feeding in process. This type of rearing facility is the model for outdoor half-intensive larviculture.

Table 4 Comparison of three larviculture techniques of *Eriocheir sinensis*

	Indoor Intensive Larviculture (IIL)	Outdoor Half-intensive Larviculture (OHL)	Imitated Ecological Larviculture (IEL)
Culture structure	Concrete ponds	Earth ponds	Earth ponds
Area of ponds (m^2)	12–30	400–700	10,000–15,000
Stocking density of Z1	200,000–500,000 ind/m^3	20,000–30,000 ind/m^3	≤ 10,000 ind/m^2
Diet of Z1–Z5	Algae, egg yolk. *Artemia nauplii*, frozen rotifer and copepod	Algae, soybean milk, *Artemia nauplii*	Algae and live rotifers (main diet)
Diet of Z5–M	*Artemia nauplii*, frozen adult Aetemia, and copepod	*Artemia nauplii*, frozen adult Artemia, and copepod	Live rotifers (main diet), frozen adult Artemia, and copepod
Antibiotic used?	Yes	No	No
Probiotics use?	Only in early Z1–Z2	Yes	Sometimes
Megalops yield	150–500 g/m^3	15–30 g/m^3	1–7.5 g/m^2
Survival to megalops (%)	10–15%	5–10%	2–4%
Cost to produce 1 kg megalops (RMB)	600–1200	500–1000	300–500
Megalopa quality	Variable	Good	Good
Duration of larviculture	22–24 days	28–30 days	28–30 days
Temperature (°C)	18–24	10–23	10–23

The water used for rearing larvae can come from natural seawater or brackish water from an estuary or from artificial seawater in inland areas. However, in the latter case, the cost for rearing larvae is high and consequently is rarely used. The process of indoor larviculture can be completed 2–3 times a year.

Outdoor extensive larviculture. The second hatchery technique is outdoor extensive larviculture (OEL) in earth ponds with no temperature control. This approach has been a new trend since 2000, and its use is spreading in China. For example, in 2003 there were 2,000 ha outdoor earth ponds being developed for outdoor larviculture in Qidong County of Jiangsu Province (Zhang, 2003); but by 2006, megalopa production in earth ponds had spread to two other counties, with Rudong County producing 50,000 kg of megalopae (Tang, 2006), and Sheyang County producing about 200,000–300,000 kg of megalopae (Xu and He, 2006). Development of this model has been rapid because the technique is simple and fewer facilities are needed than in the intensive hatchery models that require a building with heat and aeration systems. In addition, antibiotics are typically not used in this model, and quality of the megalopae is better and more favored by the farmers who use them for aquaculture of "coin-sized seed crab" (described below).

This technique of outdoor extensive larviculture has two variations. One, called outdoor half-intensive larviculture (OHL), in Zhejiang Province uses small ponds (400–700 m^2) equipped with water mill aeration machines (Figure 4). Another variation of this model is called imitated ecological larviculture (IEL) in Jiangsu Province and Liaoning Province, in which larviculture is practiced in big earth ponds (about 1–1.5 ha) without aeration machines. Yield of megalopae of the OHL is higher than IEL, but the cost is higher (Table 4).

Pond Conditions. Larval culturing ponds are chosen near estuarine areas and must be capable of taking in both high salinity water (20–25 ppt) and freshwater. The best constructed ponds have smooth, hard-clay bottoms. The OHL ponds are typically 1–3 ha in size and are often square or round, with 1.5 m water depth. For the IEL model, ponds are bigger, often more than 7 ha, are rectangular, and are established in areas of the high tide zone where it is difficult to obtain water depths of 1.5 m. Accordingly, a 1.5 m deep channel is dug around the perimeter of each pond. This channel buffers the water from large temperature fluctuations in weather that can result in lethal low temperatures during the rearing season (from April to late May in the Yangtze River area). To prepare the ponds for larval rearing, they are typically disinfected by applying 1,500–2,000 kg calcium oxide/ha or 750–1,000 kg bleaching powder (Cl > 30%)/ha 15–20 days before the start of larvae hatching. About 7 days before releasing the larvae, the ponds are supplied with 40–50 cm deep filtrated sea water and may be fertilized to stimulate algal growth for the live food of the larvae.

Larval Rearing. For OHL model, the density of Z1 in ponds is 20,000 to 30,000 larvae m^3, and the megalopa production is 15–30 g • m^{-3}, (150 kg • ha^{-1} to 300 kg • ha^{-1}) (Liu, 2004). Z1 and Z2 are fed mainly with soybean milk and powder of the algae *Spirulina*. If the ponds are fertilized and rich in algae (often *Isochrysis* sp. and *Platymonas* sp., 2×10^5 to 4×10^5 cells/ml), the Z1 may not need this supplemental food and can molt to Z2 in 5 days. The Z3-M stages are fed mainly with *Artemia* nauplii, frozen adult *Artemia,* and copepods. Larviculture lasts from about April 20 to May 20, with water temperature ranging from 10–23°C.

The IEL model is preferred by mitten crab culture operators in Jiangsu Province and some parts of northern areas of the Liao River. The Z1 density is typically less than 10,000 larvae per m^2 (3–5 million larvae per 667 m^2 tank), but the megalopa yield is not stable and varies from 1–7.5 g m^{-2}, or 10–75 kg/ha (Zhou et al., 2004; Tan and Qiao, 2004). The larvae in all stages are mainly fed with live rotifers (*Brachiorus plicatilis),* except the Z1 stage which is not fed. Z2 and Z3 stages are fed 35–40 kg wet weight rotifers per ha per day to maintain a density of 2,000–3,000 ind l^{-1} in the earthen rearing ponds; Z4 stage larvae are fed 70–80 kg wet weight rotifers per ha per day; and Z5 stage larvae are fed 120–130 kg wet weight rotifers per ha per day. In later stages, especially Z5 to megalopa, rotifers may be supplemented with frozen copepod or adult *Artemia*. The rotifers fed to larvae are also reared in earth ponds located near the larviculture earth ponds, with a 1:1 ratio of pond areas for rotifer culture to crab larval rearing.

There are farmers who specialize in rearing rotifers in earth ponds to supply the needs of mitten crab larviculture. Rotifers have been reared largely on fermented organic fertilizer. The nutritional value of rotifers fed with organic fertilizer were almost indentical with those fed with algae, based on HUFA levels (Chen et al., 2006). Rotifer culturing ponds are inoculated with densities of 0.5–1.5 individuals per ml. After growing for 7–10 days, the rotifers are harvested at an average peak density of 82.3 mg/l; the harvest of rotifers is often after 7–10 days from inoculation rotifer to ponds (Liu and Li, 2000; Xu and He, 2006). Over a period of 20–25 days, average production is 900–1000 kg of rotifers per ha. The price of live rotifers is about US $700–800 t^{-1} wet weight. The features, cost, and profit of three different models of larviculture of mitten crabs in China are summarized in Table 4.

Megalopae Transport. As described above, whatever hatchery technique methods are used , the hatched megalopae are sold to coin-sized crab culture farms. Wood boxes are usually used to transport megalopae. The box size is usually 63 cm × 46 cm × 10 cm, with 4 net windows around 4 walls of the box. In the bottom of the box, a layer of clean water grass or wet towel is used. Each box can carry 500 g of megalopae. Transportation should occur between 14–18°C. These methods will provide 100% survival during 12 hr transport time and 90% for a 24 hr transport.

Coin-sized crab transport is usually accomplished by putting 500–800 crab into a net sack and transporting when temperatures are less than 16°C during late fall or before March 15.

STOCK ENHANCEMENT OF THE CHINESE MITTEN CRAB

Development of Stock Enhancement of the Chinese Mitten Crab in Lakes in China

In the late 1960s, people learned how to catch megalopae in rivers during upstream migration, a process called the "megalopae outbreak" that usually takes place during a 2-week period from June 5–22 in the Yangze River estuary. This availability of wild-caught megalopae during the early 1970s to the middle 1980s allowed stock enhancement of the mitten crab to be conducted mainly by releasing wild-caught megalopae into open lakes. Typically, releasing 1 kg of megalops into a lake yielded 400–800 kg adult crabs averaging over 140 g per crab one year after stocking. Although the recapture rate of adult, marketable crabs was very low at 2–4% of megalopae released, the farmers obtained good profit from this stocking strategy (Table 2). This profitability resulted in two main changes for subsequent stocking strategies. First, because of the low recovery rate, farmers changed from releasing megalopae directly into open lakes to releasing crabs into net enclosures within lakes. Second, because the megalopa is small and not suitable for enclosure within nets in lakes, the life stage at release shifted to bigger juvenile seed crabs. The seed crab stage currently used is about 2–3 cm carapace width, which is attained by growth in earth ponds during May to November after molting to the 7th to 8th juvenile instar. Called "coin sized crabs" at this stage, there are 140–280 individuals per kg.

The profitability of collecting wild megalopae for stock enhancement of the mitten crab also caused a sharp decline in the abundance of natural megalopae, especially at the beginning of the 1980s (Figure 3). With the marked decline in availability of wild-caught megalopae, the price of megalopae quickly increased from 400 RMB (Chinese dollars)/kg in 1987 to 12,000 RMB/kg in 1990. Both the high value of megalopae and the low recapature rate of releasing meglops into open lakes worked to accelerate development of artifical breeding techniques, pond culture of juveniles, and the release the coin-sized crab to the lakes. Now, with good juvenile crab pond aquaculture resulting in 667 m^2 earth ponds, 10,000–20,000 coin-sized crabs can be produced from 500 g megalopae stocking. One remaining problem for juvenile rearing is how to control precocious maturation of the juvenile crabs (Cheng and Wang 2000; Chen et al., 2003), which tends to occur in these conditions and prevents the crabs from growing to large market size before they die in April of the next year.

Grow-Out of the Chinese Mitten Crabs Based on Releasing Juvenile Crabs into Enclosure Nets

After the breakthrough in developing hatchery techniques and the improvement of large scale pond culture of coin-sized juvenile crabs, the grow-out of mitten crab in net enclosures became a stable approach and increasingly successful in crab production. After the 1990s, grow-out based on stocking juvenile crab in net enclosures spread quickly throughout the country, and it is now practiced in almost all inland lakes.

Construction of Net Enclosures. The net material used for enclosures usually consists of polythene with a mesh size of 1–2 cm. The nets are fixed in place with bamboo stakes that are 4–5 m long and 8–10 cm diameter and inserted 60–100 cm into the bottom at 5-m intervals. Along the bottom, the nets are rolled up and filled with stone, causing them to sink into the mud. The nets typically extend above the water level about 50–60 cm. To prevent the crabs from climbing up and over the nets, a 30 cm high strip of plastic forming a flap is fitted all along the inside top edge of the net (Liang, 2004; Liu et al., 1992).

Site Selection for Enclosure Nets. Habitat characteristics are important for net enclosure culture, including abundant (80% of water area) submerged water plants (especially Vallisneria spiralis, *Hydrilla verticillata ,Ceratophyllum demersum, Potamogeton maackianus and Myriophyllum spicatum)*, high biomass of zoobenthos (especially the mud snail Bellamya purificata), good water quality, slow water flow, stable water level, and suitable depth (1–2 m).

Stocking density, feeding, and harvest. Stocking densities range from 1500–9000 crabs per ha, depending on habitat conditions of the net enclosure site and feeding conditions. Size of seed crabs is 5–10 g with 2–3 cm carapace width per individual.

In most net enclosures, crabs just rely on the natural food in lakes, such as water plants and mud snails, without supplemental feeding. Sometimes, to compensate for insufficient natural food, the live mud snail (*Bellamya purificata*) may be put into the enclosures at a weight of about 6,000–7,500 kg/ha, often in April before stocking with crabs, and sometimes again during the crab culture season. Other main diet supplements include small freshwater fishes such as *Pseudorasbora parva*, *Carassius carassius*, and cooked corn and wheat. Before feeding, small fish are usually broken into small pieces for a feeding ration of about 7–8% crab weight per day, supplied 2 times a day at 0600–0700 hr and 1900–2000 hr.

The recapture (harvest) rate can be about 40–50% of stocked crabs (Table 3). The best time for harvest is after the crabs finish their last molt and just before they begin migrating downstream to the riverine and estuarine areas. In lakes of the Yangtze River watershed, this time is usually the latter half of October, when the air temperature is 12–20°C and water temperature is 14–16°C. In Liao River watershed lakes to the north, this is after September, one month earlier than in the Yangtze River. The traditional crab recapture method is a net trap with a series of rectangular boxes, stretched 10–20 m long and fitted with one-way entrances for crabs. These effective capture nets are called "Dilong" in Chinese and are described by Wang et al. (2006). The production of adult crabs is usually 150–450 kg per ha and can be as high as 975 kg per ha (Table 3).

Sustainable Aquaculture for Net Enclosures. The economic benefits of mitten crab net enclosure culture are higher and the costs are lower than other methods, because this type of crab culture has many combined advantages of both pond and lake culture. In net enclosures compared to ponds, water quality is better, the crabs can move in a larger space, the diets are abundant, and culture density is comparatively low. The sizes of adult crabs produced are larger, and their quality is better, yielding a good price in the market. Compared to open lake culture, the enclosures allow good control and recovery of the crabs produced. These advantages have led to overdevelopment of net enclosure culture, creating problems in some areas. To compete effectively for profit, farmers may overstock the crabs at high densities and then overfeed in the enclosures, causing nutrient pollution. Declines in water quality and overstocking may also result in small crab size and lower crab quality, starting a cycle of environmental deterioration. Further, successive overstocking of crab may exhaust a lake's natural food resources (plant and zoobenthos; Xu et al., 2003), which normally provide beneficial effects on lake water quality. (Wu et al., 2001).

Increasing attention is being paid to protecting the environment in net enclosure culture (Wang et al., 2006; Liu, 2006; Xu et al., 2003; Jin et al., 2003). Some studies indicate that in macrophytic lakes, the optimal stock density is 700 ± 60 crabs ha^{-1} (Wang et al., 2006), and the carrying capacity (yield) of crab is 29.35 kg ha^{-1} under conditions of no feeding (Jin et al., 2003). Good results of both crab culture and environmental conditions have been demonstrated in macrophytic lakes by combining or alternating mitten crab culture with culture of shrimp and some fish, so that water plants can be protected. In addition, habitat quality can be protected by planting water grass (e.g., *Vallisneria spiralis*, *Elodea sp.*, *Hydrilla verticillata*) before stocking mitten crabs in these sites. Good results are obtained when these species are planted along half of enclosure nets, with one side open to the lake bank, and by changing water levels with different seasons. However, the issue of how to develop mitten crab stock enhancement in a sustainable lake environment is still an important new area of research that needs more study.

Other Methods of Stock Enhancement of the Chinese Mitten Crab

Several other ecosystems may be adapted for stocking and culture of Chinese mitten crabs. Freshwater marshes, especially reed marshes, are suitable for crab growth. Usually the cost of production in these marshes is very low, and the sizes of adult crabs are large and their quality is good. However, the harvesting rate in marshes is very low, and the production is only 50–200 kg/ha, making these systems marginally important for large-scale stocking and production.

Release of the Chinese mitten crab into rice fields is a polyculture system that has been developing in the Liao River area. In this multifaceted approach, only small amounts of fertilizer are required, insect pests can be killed, and weeds may be removed, such that rice production increases, resulting in good profits both from the rice and the mitten crabs. In Panjin City in the Liao area, 47,000 ha of rice field were developed to culture the mitten crab in 2003 (Shun, 2004). Crab culture in rice fields may be adapted not only for adult crabs, but it is also suitable for seed crab (coin-sized seed crab) culture (Shun, 2004; Fu, 2004).

Rice fields need to be modified for mitten crab culture. First, a system for preventing the crabs from escaping must be built by using plastic fence with a flap fixed on the bank around the edges of the rice fields. Second, a loop channel must be dug within the plastic fence around the perimeter of the rice field. The "loop channel" is typically 1 m wide and 60–90 cm deep for seed crab culture and 150 cm deep for adult crab culture. This deeper channel serves as a cool-water refuge for the crabs during hot daytime temperatures. Macrophytes, such as *Vallisneria spiralis*, *Hydrilla verticillata*, and *Elodea sp.*, are usually planted before stocking the crabs.

For seed crab culture in rice fields, stock density is 70,000 megalopae per 667 m^2 or 7.5 kg megalopae per ha (1 kg megalopae =140,000 ind). For adult crab culture, stock density is 700–1,000 coin-sized crab per 667 m^2 (80–240 individuals per kg) or 10–15 kg seed crabs per ha. To obtain good production, the crabs are often fed with corn, wheat, and trash fish. As a rule, these rice fields can achieve high production, with about 75 kg of seed crabs per 667 m^2, approximately 300–450 kg of adult crabs per ha, and occasionally as high as 750 kg adults per ha.

CONCLUSION

These variations in successful approaches to culture and stocking of mitten crabs have spread extensively across China. The large market for this valuable product has sustained an increasingly intensive stock enhancement approach. As a consequence of the technical achievements, the extensive area used for culture, and this profitability, mitten crab production has increased to record high levels that now exceed the combined yield of all other crab fisheries and culture systems. Researchers and production managers are now focusing on reducing adverse environmental impacts of mitten crab culture and stock enhancement.

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