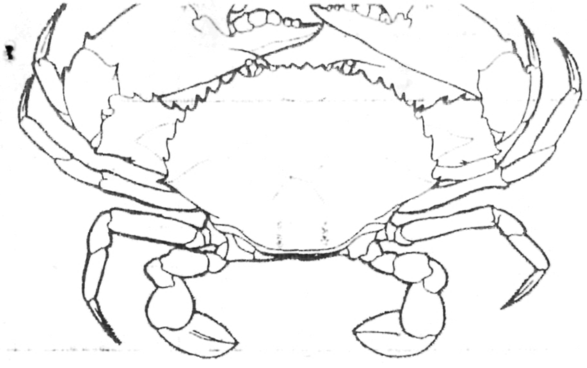

CRAB FARMING IN JAPAN, TAIWAN AND THE PHILIPPINES

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CHAPTER 1

INTRODUCTION

There has always been considerable interest in farming crabs in Australia, especially the mud crab Scylla serrata, a large-clawed, rapidly-growing crab with a high market value. However, until now, general ignorance of crab biology and appropriate cultivation technology has prevented the initiation of any serious ventures.

This report covers three countries in which crab farming has a long history, although it has developed at different rates and in different directions in each country. In Japan, modern technology is utilised to mass produce millions of juvenile crabs for fisheries restocking (Chapters 2 and 3). In Taiwan (Chapter 3), the crab farming industry is differentiated into nursery, grow-out and fattening operations, and commercial hatcheries are being developed. In the Philippines (Chapter 5), wild caught crabs are reared at low densities in intertidal ponds as a minor crop with prawns or milkfish.

The report is not a manual for crab farming in Australia. With differing ecological, socio-economic and legal environments in each country, potential crab farmers in Australia must be prepared to adapt overseas methods to local conditions (Chapter 6) and allow considerable time for their pioneering ventures to become serious investment propositions.

Information for this report was gathered between 1978 and 1981 while the author was resident in Japan. Observations of hatchery technology were made over periods of several months, spent mainly at the JASFA Tamano hatchery, Okayama Prefecture, and the Prefectural Fisheries Farming Centre, Katsuumi, Fukui Prefecture. In other centres, facilities were inspected and interviews were conducted with technicians during brief (1 to 2 day) visits. Trips were made to crab farming areas in the Philippines in 1980 (3 weeks) and Taiwan in 1980 and 1981 (3 weeks). Interviews were conducted with nine crab farmers or fry collectors in the Philippines and 25 in Taiwan, as well as with several research workers in both countries.

All prices are quoted in local currencies; that is, Japanese yen, New Taiwan dollars (NT) and filipino peso (₱). The June 1980 exchange rates for Australian dollars were about A$1 = 250 yen = NT$40 = ₱8.

The development of crab cultivation

For centuries, Portunid (swimming) crabs have constituted an important secondary crop in the traditional intertidal fishponds of Asia. The most commonly cultivated crab is Scylla serrata, which is distributed throughout the Indo-West Pacific from eastern South Africa to Hawaii and from northern Australia to southern Japan. It is known as the mud or mangrove crab (Australia), Samoan crab (Hawaii), alimango (Philippines), tsai jim (Taiwan) and nokogiri gazami (Japan). Occasional attempts have been made at pond rearing Portunus pelagicus (Sand crab or blue swimmer) and P. trituberculatus (the Japanese blue swimmer or gazami). Modern hatchery techniques for Portunus are well advanced.

P. pelagicus is found over much the same geographic range as Scylla, extending further into colder waters. P. trituberculatus is found in Japan, China, Taiwan and Korea. Important fisheries for all three species exist throughout their areas of distribution.

Originally, stocking of crabs and other species in fishponds was entirely passive: sluice gates were opened at high tide to allow the fry to enter. Greater control of the kinds and numbers of fry stocked was made possible by fishermen who specialised in fry collection, sorting and distribution.

Despite their constantly high market value, mud crabs were, and still are, often considered to be undesirable components of the typical multispecies culture system (polyculture). This is because of the 'troublesome' habits of destroying pond dikes, escaping, cannibalism and damage to other species during harvest. These behavioural characteristics require special preventive measures. Considering that there is also widespread ignorance of mud crab biology, it is perhaps not surprising that crabs have never attained the same importance in aquaculture as other species such as prawns and milkfish.

In Japan, pond rearing of crabs is negligible, but several hatcheries produce juvenile P. trituberculatus on a large scale. The sole purpose of this output is fisheries restocking: the crabs are released into the open sea in the hope of rebuilding depleted fisheries. This 'saibai gyogyo' programme began in the Seto Island Sea in the mid-1960s with restocking of juvenile prawns. A national network of hatcheries now exists comprising 12 national centres operated by the Japan Sea-Farming Association (JASFA), 37 prefectural (state) centres and 11 semi-governmental or private hatcheries, which together produce 15 species of fish, 5 species of crustaceans and 10 species of molluscs. Research and some mass production of juveniles is also carried out by the prefectural Fisheries Experimental Stations.

In Taiwan, research on crab cultivation is being conducted by the Taiwan Fisheries Research Institute and National Taiwan University; in the Philippines by the South-East Asian Fisheries Development Centre (SEAFDEC) Department of Aquaculture; and in Australia by the Fisheries Research Branch of the Queensland Department of Primary Industries (formerly Queensland Fisheries Service) and the University of Queensland.

Taxonomy

Disagreement still exists over whether there are one or more species of Scylla. Differences in colour, morphology and habitat were used by Estampador (1949, cited by Motoh, 1976) to divide the genus into three species (serrata, oceanica and tranquebarica) and one new variety (serrata var. paramosain). But this was rejected by Stephenson and Campbell (1960) for lack of quantitative evidence. For most purposes, the mud crab is described in the literature as belonging to one species S. serrata. Nevertheless, Japanese researchers claim that S. oceanica is indeed distinguishable from S. serrata mainly by its:-

(a) soft, rounded frontal teeth (spines), which lack enamel vs. the sharp enamelled spines of Scylla serrata, plus other differences in spines on the legs;

(b) distinctive red-pink patches on the chelae, even when small;

(c) geometric patterns on all legs and on the carapace vs. patterns on the rear legs only;

(d) larger maximum size of more than 18 cm carapace width vs. a maximum of 18 cm for S. serrata.

(e) habitat differences, S. oceanica preferring higher salinities;

(f) lower value (700 yen/kg vs. 3000 yen/kg) because of its watery flesh and unappealing flavour of the hepatopancreas (H. Yamakawa, Tokyo Univ. Fish., pers. comm., 1981; H. Fushimi, Shizuoka Fish. Exp. Stn., pers. comm., 1981).

Crab farmers in Taiwan also recognise three varieties of Scylla: the 'sand crab', which is large, aggressive and oceanic; the 'red-legged crab', which is small, hard-shelled and aggressive; and the 'white crab', which is of medium size, less aggressive and estuarine (Chen 1976). Chen assumes they are all of the same species.

Further study is required on the taxonomy of Scylla throughout its range.

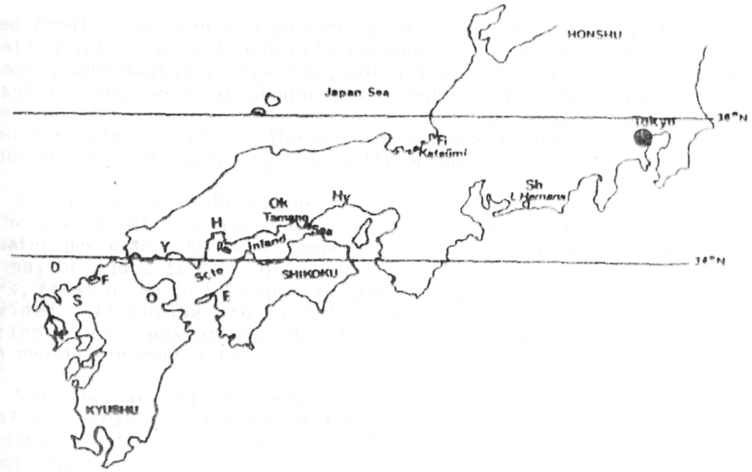

Figure 1. Southern Japan, showing prefectures of Fukui (Fi), Shizuoka (Sh), Hyogo (Hy), Okayama (Ok), Hiroshima (H), Yamaguchi (Y), Ehime (E), Fukuoka (F), Saga (S), Oita (O) and Nagasaki (N).

CHAPTER 2

CRAB SEED PRODUCTION (*Portunus trituberculatus*) IN JAPAN

Broodstock management

Capture of spawners

Mated female crabs can be captured by small bottom-trawlers, fixed or floating gill-nets and crab pots throughout spring (March-May) and summer (June-August). However, not all of the available breeding season is used for crab production. Beginning in spring or early summer, most hatcheries produce crabs for periods ranging from 3 weeks to no more than 3 months. The remaining methods are devoted to the production of other species, especially prawns and fish.

For journeys of 30 min or less, crabs are transported to the hatcheries in small plastic or polystyrene boxes containing 5 to 10 L of water per crab. At water temperatures of 30°C and above, seawater ice may be added to the container. For longer journeys of 1 to 5 hours, tanks of up to 1 t capacity are used and aeration or oxygen is provided. If chelae are tied to prevent fighting, crabs can be carried in this way at high densities (one crab per 20 L of water) with negligible mortality.

Spawners are easily injured during capture and post-capture handling. Crabs with a damaged egg mass are usually rejected as broodstock, but loss of one or even both chelae does not necessarily affect spawning ability.

On arrival at the hatchery, the crabs are painted or tagged with an identifying number and are held in tanks until the eggs are ready to.hatch.

Maintenance of broodstock

Facilities. At the JASFA Tamano hatchery, broodstock crabs are held communally in an indoor concrete tank with 10 cm of sand on the bottom and running water 50 cm deep. Because the females and their eggs are in continual contact with the substrate, it must be kept in optimum condition. This is achieved by directing the flow of water and detritus down through the sand, which rests on a false bottom. The water exchange rate is quite high: 500%/day. The 25 m^2 tank is divided into three, and the flow rate through each compartment is about 20 t/day.

In some centres, broodstock are held in outdoor tanks. Adequate cover is essential not only for weather protection but also to screen out sunlight. Indoor tanks in glass-roofed buildings must also be covered. This prevents the growth of diatoms and other algae in the sand and on the eggs. Algal growths interfere with egg development.

As crab production is scheduled early in the season, the Tamano hatchery raises the water temperature in the broodstock tanks. In March-April the temperature is gradually increased from about 10° to 20°C over a period of 8 to 12 days. This encourages feeding and egg development. From May until the end of the production season in late June, it is maintained at about 23°C. In the Fukui Prefecture hatchery, where the crab season extends into late August, refrigeration facilities are available for cooling water in broodstock tanks.

The crabs are usually held at densities of 1 to 3/m^2. The Fukui hatchery is able to maintain densities of up to 10/m^2 with no problems from fighting or cannibalism. This is made possible by removal of part of the movable finger (dactylus) on the chelipeds of all crabs. Feeding is not affected as the crabs are given pieces of chopped fish which are easily manipulated. In addition the crabs are markedly less aggressive when in the berried state. Survival during broodstock maintenance at Tamano is almost 80% (JASFA 1981).

Feed. Ideally, broodstock should be given live food *ad libitum* so that the tank is not fouled by decaying uneaten food. Tamano provides short-necked clams *Tapes philippinarum*, maintaining 3 to 5 kg of live clams in each tank of 10 to 25 crabs. Price and availability of this species are problems in other centres, and the meat of clams, oysters, mussels, mackerel, horse-mackerel or sand-lance is given instead.

Monitoring egg development. In early spring, the JASFA Tamano hatchery receives female crabs before their eggs have been extruded (spawned). Spawning normally occurs after 10 to 20 days' rearing at 20° to 22°C for crabs caught in March, and after 5 to 10 days for crabs caught in April (JASFA 1980). From late April, most female crabs are already berried; that is, the eggs are held under the abdominal flap before hatching.

In all centres, broodstock are selected for their general health and activity and condition of the egg mass: it must be firm, rounded, of yellow-orange colour and free of attached organisms.

In handling berried crabs, considerable care is taken to minimise damage to both handler and crab. A convenient harness is fashioned on each crab by tying wire around the long spines of the carapace and forming a loop to which the crab's number is attached. This loop projects above the sand when the crab is buried and so individuals are easily identified and can be caught using a long hook.

Embryonic development from spawning to hatching usually takes from 20 to 25 days (SISFFA 1978) and is checked daily. The eggs gradually change colour from orange to brown to black. Eventually, the dark eyespots and beating heart of the embryo can be observed microscopically. Later, distinctive reddish-purple points that are probably the antennae appear, signalling the start of hatching in three days.

Hatching procedures

When hatching is imminent, as indicated by the state of embryonic development described above, the female crab is placed in a darkened or covered fibreglass-reinforced plastic (FRP) tank (0.5 to 1 t). Moderate aeration is provided. The Hiroshima Fisheries Experimental Station also provides a slow exchange of water. At Tamano, rotifers (Brachionus plicatilis) are added, at a concentration of 30/ml, as food for the newly hatched larvae.

Normal hatching usually occurs between 8 p.m. and midnight and always before sunrise. Next morning, the spent female is returned to the broodstock holding tank and the larvae are counted and transferred *to the rearing tank. Egg hatching rate is usually close to 100%. If* any abnormalities are observed, such as lack of phototactic response or unusually small size (less than 0.65 mm width), all of the larvae of that batch are rejected.

The number of zoea$_1$ larvae (Z_1) produced depends on the size of the female crab, with 400 g crabs producing about 1 m Z_1, 700 g crabs 2 m Z_1 and 1 kg crabs 3 m Z_1 (SISFFA 1978 and Fukui 1981a). Crabs will spawn three or four times in one season, but because the quantity and quality of the eggs and larvae decline with each spawning in captivity, most broodstock are used only once. The Fukui hatchery is able to use the second spawning of some of its broodstock. Time between hatching and the next extrusion of eggs is from 1 to 3 weeks (Fukui 1981a).

In general, the larvae from different females are not reared together, because of problems that may arise from differences in growth rates and moulting rhythms of genetically different larvae. However, for large rearing tanks (for example, the 200 t tanks at Tamano), two or more females may be needed to provide enough larvae. Each year, the hatcheries must buy many more spawners than actually *needed, to ensure larvae will be available when required during the* season. In 1980 the ratio of spawners used to broodstock held was 9:97 at Tamano, 18 (including 3 repeats):75 at the Fukui hatchery, and 5:45, 2:15, and 2:12 for the Fishery Experimental Stations of Hiroshima, Saga and Ehime Prefectures respectively (Gazami Seed Production Research Conference 1980).

Larval rearing

At 20°C to 25°C Portunus trituberculatus passes through four zoeal stages (Z_{1-4}) of 3 to 4 days each and one megalopa larval stage (M) of 5 to 7 days before metamorphosing to the first juvenile crab stage (C_1).

Production facilities

Rearing tanks. There is considerable variety in the capacity and design of tanks used for rearing crab larvae. Prefectural Fishery Experimental Stations, for which seed production is not a primary function, have relatively small total rearing capacities ranging from 75 t (Ehime) to 300 t (Hiroshima). The two major crab production centres are specialised as hatcheries, with the JASFA Tamano Centre having four 200 t tanks for crab larval rearing and the Fukui Prefectural Fishery Farming Centre, twelve 75 t tanks.

Tanks are made of reinforced concrete, have rectangular, round or octagonal shapes, range in size from 10 t to 200 t, and are located either outdoors or inside a glass-roofed building. Tanks of 75 to 100 t would seem to be the most convenient size. They require only one spawner to provide larvae, are more labour efficient than smaller units, and, in cases of mass mortality, result in more acceptable losses than in larger tanks. Round tanks are desirable because of the absence of corners where larvae, food and detritus can accumulate. However, they utilise floor space less efficiently than rectangular tanks.

Seawater supply. The Tamano hatchery is located on the northern shore of the central part of the Seto Inland Sea. Water movement through this semi-enclosed basin is very restricted. So, although turbidity caused by waves, tides or currents is not a problem, coastal reclamation, urban and industrial pollution, and agricultural run-off throughout the Seto Island Sea have resulted in continual silting and eutrophication (accumulation of mineral and organic nutrients).

However, mild eutrophication is not regarded as a problem and is believed to have had a beneficial effect on fisheries (Tatara 1981).

Seawater intake for the Tamano hatchery is through two 20 cm diameter PVC pipes extending 16 m offshore. For larval rearing, water is passed through a sand filter, which reduces the concentration of suspended solids larger than 10 u to 2 to 5 ppm. The filter has to be cleaned by backwashing for 2 hours every 5 days.

Water quality management

Temperature. Two methods are used to heat the filtered rearing water *at Tamano. Two days before the addition of Z_1 larvae, the rearing* tanks are filled to three-quarter capacity and the water is directly heated to 23°C by steam forced through pipes suspended in the tanks. When water exchange is started after a few days of rearing, clean pre-heated water is drawn from a 200 t reserve tank, which is also heated by the same steam boiler (128 000 kcal/hour). The greenhouse-like effect of the glass-roofed rearing shed helps to maintain rearing water temperatures, while the direct heating system is also used for brief periods during rearing for fine temperature control.

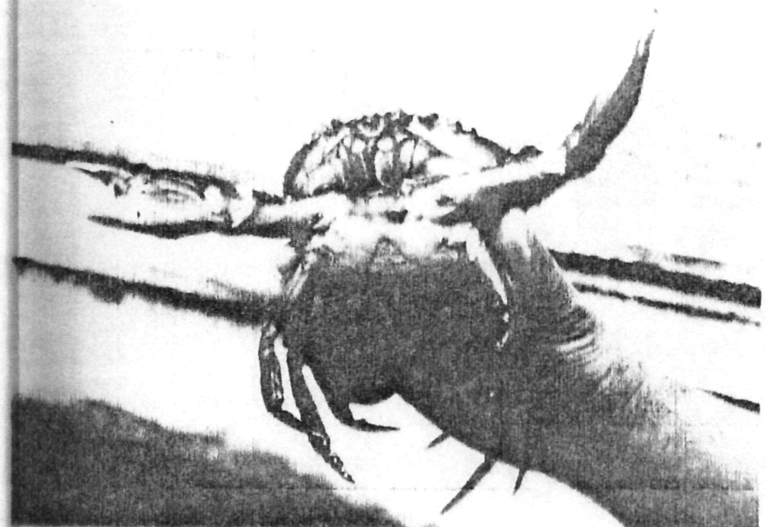

Plate 1. Cultivated mud crab, *Scylla serrata*, in Taiwan.

In most other locations, heating is not necessary because production starts later in the season. In outdoor tanks, water temperature can rise to 33°C in summer without obvious ill-effects on the larvae.

Salinity. No attempt is made to control salinity at any of the hatcheries and rearing water is commonly in the range of 30 to 33 ppt. During the rainy season, salinity in unroofed outdoor tanks often drops to 27 ppt, but this is apparently within the tolerance range of the larvae.

pH. pH of the rearing water is normally around 8.1, but can vary from about 8.6 at the start of culture to a low of 7.7, which may occur with water deterioration due to detrital decomposition. In hatcheries where phytoplankton is also grown in the rearing water, pH may rise to about 9.3 during periods of maximum photosynthesis and cell reproduction. The optimum range is believed to be 8 to 8.5 (Nanbu 1976).

Oxygen. As with pH, dissolved oxygen levels (DO) increase with photosynthesis and algal blooming and peak in the late afternoon. DO supersaturation of the water is common, but if it exceeds 140%, vigorous aeration must be applied to prevent losses due to 'gas sickness'. This is the occurrence of bubbles under the larval carapace caused by oxygen coming out of solution after passing into the body. According to Nanbu (1976), aeration rates of 15 to 20 L/t/min will keep DO below 130%, even at dense phytoplankton concentrations.

Light. It has been discovered that adequate light is essential for normal larval development, in addition to being a prerequisite for larval rearing with phytoplankton. The Hiroshima Experimental Station found that indoor rearing using artificial light (3 000 lux and less, for fluorescent) resulted in large mortalities in the zoeal stages. The Tamano hatchery originally had an FRP roof which admitted only 30% of natural light. This was replaced by clear glass, which admits 80% of sunlight. Long periods of overcast weather can inhibit phytoplankton growth to the extent that the larval culture fails. On the other hand, high light intensities of up to 250 000 lux in mid-summer cause the drastic increases of pH and DO mentioned previously. To help counteract this, outdoor tanks may be covered by screens of black netting.

Water circulation. Circulation is achieved through water exchange, aeration and mechanical stirring. It serves to maintain DO levels, evenly distribute larvae and food, and accelerate decomposition of detritus and leftover food.

Water exchange at the Tamano hatchery begins at the Z_2 stage with about 10% of rearing water being replaced daily. Other centres try to maintain populations of phytoplankton and zooplankton food species in the water and practise standing-water culture throughout the zoeal stages. From the beginning of megalopa when all hatcheries give prepared frozen feeds instead of live food, 20 to 50% of tank volume must be replaced daily.

The usual method of aeration has been to use compressors, although the trend is now toward blowers. The Tamano hatchery uses a Rootes blower (15 kW, capacity 10 m^3 air/min) to move air through circular perforated PVC pipes (diameter 25 mm, perforations 1.5 mm) on the floor of the 200 t rearing tanks. Ideally, aeration should be supplied evenly throughout the tank, but placement of airhoses or air stones is dictated by tank construction.

The optimum aeration rate depends on the type of tank, rearing density, condition of phytoplankton population, type of food (live or dead) and use of organic matter as food or fertiliser. Most hatcheries do not measure air flow rate but merely provide enough aeration to produce good water movement. Nanbu (1976) found the following rates to give adequate water movement with least damage to larvae: Z_1 stage, 5 to 10 L air/t water/min; Z_{2-4} stages, 10 to 15 L/t/min; and megalopa stage, 15 to 20 L/t/min. Use of organic matter necessitates higher rates of 30 to 40 L/ton/min (I. Takahashi, Hyogo, pers. comm., 1978).

The Tamano crab hatchery was the first to use a mechanical stirrer or 'agitator' to assist water circulation. The apparatus has a blade (0.2 x 8 m) attached near the bottom of a central rotating shaft. During the first three zoeal stages, the rate of rotation is one revolution per minute. This is increased to 1.5 rev./min for Z_4, and 2 rev./min for the M and C stages.

Microbiological water treatment. Most centres rely on water circulation and the maintenance of fairly dense populations of the green flagellate phytoplankton *Chlorella* sp. for water conditioning. The algae remove potentially toxic nitrogenous metabolites (ammonia, nitrite) and carbon dioxide, while providing oxygen and possibly antibiotics. Marine bacteria and yeast are also believed to help control levels of dissolved organic matter, ammonia and nitrite (Yasuda and Taga 1980a), and to add vitamins to the water (Gandhi and Freitas 1964 and Strickland 1965, in Gundersen 1976; Siepmann and Hohnk 1962, *in* Hoppe 1976).

Chlorella is continuously mass cultured in separate outdoor tanks and is pumped to the larval tanks as required to maintain a 'healthy' green colour in the water (about 10^4 cells/mL). If the *Chlorella* concentration falls and is not replaced, a diatom bloom (*Skeletonema*, *Chaetoceros*) usually follows. Instead of continually replacing *Chlorella*, some centres encourage the natural blooming sequence by adding organic matter (for example, liquefied clam meat, marine-G, and soycake) as fertilisers. Marine-G is a fertiliser used in the culture of the alga *Porphyra* (nori) and consists mainly of fish liver extract with some added nitrates and phosphates. Soycake is a sedimentary by-product of soy sauce manufacture.

In contrast, the Tamano hatchery does not utilise phytoplankton at all for water conditioning. Instead, water exchange is instituted from Z_2 and a so-called 'microbial flock' of bacteria and yeast is added to the rearing water. By decomposing organic matter and utilising dissolved organic carbon and possibly other larval metabolites, the 'flock' assists in water conditioning and nutrient renewal, and is also intended to be a food source. Twenty to 25 L of 'microbial flock' is added daily to the 200 t rearing tank while the water is being heated before the start of rearing. Then, 25 L of 'flock' is added daily throughout the zoeal stages. This was reduced to 10 L in 1981.

In both phytoplankton and 'flock' systems, the water conditioning organisms are eaten by zooplankton, which are provided as food for the crab larvae. 'Flock' provides some nutrient recycling and is an additional food item for the zoeae themselves. Protozoa are also thought to be involved as intermediate food sources. Thus, simple food chains sustained by regular inputs are established in the rearing tanks.

Extraneous organisms in the rearing tank. At Tamano, daily observations are made of diatom and protozoa levels in the rearing water. Although they are mostly harmless at low densities, extra water exchange is considered necessary if they exceed 5 000 cells/mL. Diatom genera commonly occurring during rearing include *Chaetoceros*, *Eucampia*, *Nitzschia*, *Rhizosolenia*, *Coscinodiscus*, *Thalassiosira*, *Leptocylindrus*, *Bacillaria*, *Skeletonema*, and *Grammatophora*.

Organisms that grow on the larval carapace, such as the diatom *Licmorphora*, the ciliata *Vorticella*, and filamentous fungi, often occur at low temperatures and in deteriorating water conditions. They tend to inhibit moulting activity and increase mortality due to cannibalism.

On the walls of the rearing tank, there are often many barnacles, ascidians, and the green algae *Entermorpha* and *Ulva*. These rarely cause any problems apart from necessitating the scouring of the walls with a high pressure water hose after harvest. This usually takes two man-hours for a 200 t tank.

Occurrence of colonies of hydrozoans can be a problem as they compete with the crab larvae for *Artemia* nauplii and often, after detaching from the tank walls, interfere with larval movement. Their numbers can be reduced by handing a net in the water for a day or two (Maguire 1979).

Dinoflagellate species (for example, *Gymnodinium*, *Noctiluca* and *Heterosigma*) occasionally appear in a hatchery water supply. Red Tide outbreaks have often occurred in the Seto Inland Sea causing failure or suspension of larval rearing.

n recent years an increased emphasis on water quality control reatly reduced the incidence of serious problems caused by rable organisms in the rearing water.

ng regimes. Table 1 shows feeding regimes for several eries. The provision of rotifers (Brachionus plicatilis) at ntrations of 3 to 10/mL throughout the four zoeal stages, is rd procedure. A modification of this can be seen at the Fukui ery where, for 2 to 3 days before the Z_1 larvae hatch out, ers are cultured in the rearing tank. After the initial ation, the rotifers multiply rapidly, feeding on Chlorella in ter. More are added only if numbers decline suddenly. In the rotifers have been frozen and stored for use in extreme ges. At Tamano, small-size rotifers (150 to 180 u) are cultured e early zoeal stages, and medium size rotifers (160 to 200 u) e Z_3 and Z_4 stages. Microbial flock is provided for all zoeal

a supplement to the diet of rotifers, newly hatched nauplius of the brine shrimp Artemia salina are given from Z_2 or Z_3. ring price and unpredictable hatching rate of eggs have caused al reduction in the usage of Artemia as a larval food. The hatchery provides them only when the rotifer supply is ate, and survival rates have not noticeably declined. Iwamoto 1973) found that a diet of rotifers alone was adequate for all tages except Z_4.

me hatcheries also feed the zoeae on liquefied organic matter ing of blended fish or clam meat, soy cake and/or marine-G. xture also serves as fertiliser for diatoms which bloom in the water.

om Z_3 or Z_4, macerated meat of euphausid or other small shrimp , and the short-necked clam Tapes philippinarum is given. At frozen clam meat is imported from Korea and small shrimp from n northern Japan. The frozen blocks of meat are sliced and in heavy-duty commercial machines, then washed and sieved two nets (mesh opening size 860 u and 140 u) attached to a The larger particles of meat are then blended at high speed ter before being sieved again. Final yield of meat in this ge is 35 to 40% of the original.

eral other species have been tried unsuccessfully as food in , including oyster larvae, fresh mussel and pearl oyster meat, ines. These are found to be unsuitable because of either the preparation required or problems with fouling of the water. ability of copeponds, artificial feeds, and other alternatives ia and Brachionus is currently being investigated.

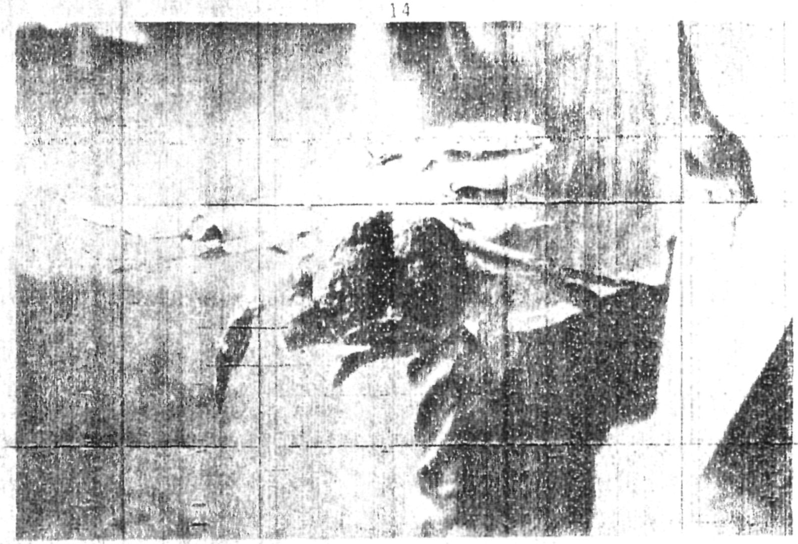

Plate 2. Berried blue swimming crab, Portunis trituberculatus, just prior to egg hatching, Japan.

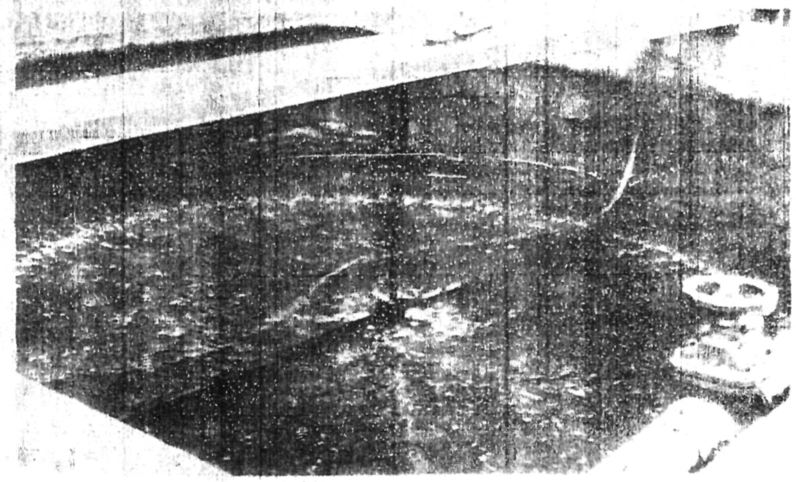

Plate 3. 200 cu.m. tank for larval crab rearing. Water circulation is provided by the rotating blades of the 'agitator' and aeration.

Rotifers and brine shrimp are given once or twice daily, while the meat ration is spread over 3 to 6 feedings per day to prevent fouling.

Culture of Chlorella sp. Most of the Chlorella produced by the hatcheries is used in rotifer cultivation. Because the rotifers are also fed to other species being grown, including red sea bream (*Pagrus major*) and prawns (*Penaeus japonicus*), the daily requirement for rotifers, and hence *Chlorella*, can be huge. Tamano has four 50 t tanks for *Chlorella* production, while Hiroshima and Fukui have four 100 t tanks and five 100 t tanks respectively.

The *Chlorella*-rearing water ('green water') is enriched with commercial fertilisers, usually superphosphate, urea, ammonium sulphate and EDTA, in varying proportions depending on the hatchery. At Tamano, the following amounts are added per tonne of filtered seawater diluted to three-quarter salinity (about 22 ppt):-

$(NH_4)_2SO_4$	-	50.0 g
$Ca(H_2PO_4)_2$	-	7.5 g
$CO(NH_2)_2$	-	2.5 g
EDTA	-	1.5 g
marine-G	-	2.0 g

For more rapid cultivation, potassium nitrate (KNO_3) and potassium phosphate (KH_2PO_4) are also added (the proportions of the other ingredients are altered in this case).

Although *Chlorella* is the main alga present, contamination by other flagellate species including *Chlamydomonas*, diatoms (especially *Chaetoceros*) and protozoa sometimes occurs. Different strains of *Chlorella* appear at different temperatures and localities. The normal cell size is 2 to 3 u.

Isolation of *Chlorella* from the mass culture, to establish a new mono-specific culture, is performed four times a year at Tamano. Beginning with agar plating, the isolated plankton is cultured in a light room for 2 to 3 months before being transferred to outdoor 6 t tanks. These three tanks are used in continuous rotation to provide inoculations for the mass cultures. Initial concentration in the starter tanks is 1m cells/mL. After 7 to 10 days, it reaches 10m cells/mL and the culture is pumped to a 50 t tank. After three days, at a concentration of 20m cells/mL, the *Chlorella* is pumped to a holding tank from which it can be harvested freely for rotifer and larval rearing. Mass culture is not continued for longer than 3 days because of the increasing pH of the water. When the pH approaches 10 the cells weaken and photosynthesis cannot occur. In an emergency,

Table 1. Typical feeding regimes for *Portunus trituberculatus*.

Hatchery and Z_1 stocking density			Stage (inclusive) Z_1 Z_2 Z_3 Z_4 M C_1 C_2
Ehime* 40/L	rotifer	5/mL	____________
	brine shrimp	200/L	----------
	soy cake	1 g/t	....
	blended fish	2 g/t	....
	clam mince	7.5 g/t	- - -
	shrimp mince	7.5 g/t	- - -
Hiroshima* 25-30/L	rotifer	3-5/mL	____________
	brine shrimp	50-300/L	-------
	copepod	50-150/L	_._.
	clam mince	1-4 g/t	- -
	shrimp mince	50/120 g/t	- -
	marine-G	0.5-1 g/t	,,,,,,,,,,,,,
Okayama* 15-30/L	rotifer	3-6/mL	____________
	brine shrimp	200/L	----
	soy cake	1 g/t	....
	marine-G	0.6 g/t	,,,,,,,,,,
	clam-shrimp juice	2 g/t	======
	clam-shrimp mince	6-60 g/t	- - - -
	artificial feed	1-3 g/t	+++++++++++++++++++
Hyogo* 20-30/L	rotifer	5-20/mL	____________
	brine shrimp	200-1200/L	---------
	marine-G	0.5-1 g/t	,,,,,,,,,,
	clam juice	1 g/t	======
	clam mince	10-25 g/t	- - -
Tamano[1] 10-20/L	rotifer	3-10/mL	____________
	brine shrimp	100-300/L	----
	microbial flock	125 mL/t	----------
	clam mince	20-90 g/t	- - -
	shrimp mince	25-125 g/t	- - -
Fukui[2]	rotifer	10/mL	____________
	(brine shrimp)	20-200/L	(--)
	shrimp mince	10-40 g/t	- - - -

* Gazami Seed Pdn. Res. Conf. 1980
1. Jasfa 1980
2. Fukui 1980, 1981b

CO_2 gas is sometimes bubbled into the water to increase photosynthesis.

As the tanks are outdoors, there is no temperature control. Peak production occurs in May and June, before the summer rainy season. Outdoor tank temperatures at this time are 15^o to 20^oC.

The original tanks at Tamano were round, 40 t canvas structures. These have been replaced by 50 t rectangular concrete tanks with a 10 t capacity stepped terrace over which the algae are pumped to increase penetration of sunlight. Aeration is provided by Rootes blowers through a circular perforated pipe on the tank floor.

Culture of microbial flock. A mass culture of yeast and bacteria is prepared in 2 t of natural seawater with 3 kg of glucose, 320 g urea and 130 g potassium superphosphate, at 32^oC. The pH of this culture rapidly drops to about 4 and it is judged ready for use by the fourth day. The exact species composition of the 'flock' is unknown, but yeast are generally present at concentrations of 10^{7-8} cells/mL and small pin colony-forming bacteria at 10^{8-10} cells/mL (Yasuda and Taga 1980b). Occasionally, pathogenic species such as Vibrio sp. occur. It has been suggested that this can be prevented by using 'green water' instead of natural seawater for culturing flock. Vibrio rarely occurs in 'green water', possibly because of the high pH (K. Yasuda, pers. comm. 1982).

Culture of Rotifers, Brachionus plicatilis. Chlorella is the initial food species used in the mass culture of rotifers. It is supplemented with baker's yeast. Although Chlorella is nutritionally superior to yeast alone, it is extremely difficult to provide sufficient quantities for a rapidly multiplying rotifer population. Nevertheless, rotifers fed on yeast are deficient in certain essential fatty acids (w3 HUFA) and must be given a nutritional 'boost' of Chlorella before being fed to larvae (Kitajima et al 1980 a and b, in Hirata 1980).

At the Fukui centre, there are twenty-four 16 t tanks specifically for rotifer cultivation. Starting densities for rotifer and Chlorella are 100 to 150/mL and 10 to 20m/mL respectively, and the initial volume is 5 t. On the second day, another 5 t of Chlorella culture is added, followed by 2 kg yeast (in water) on the third day and 1 kg yeast on the fourth. On the fifth and final day of culture, five more tonnes of Chlorella is given to provide extra nutrition. Average concentration of rotifers at harvest is 300/mL with a maximum of 700/mL.

Rotifer production is speeded up at Tamano. Three 12 t tanks are used in continuous rotation in a 3-day cycle. On day one, Chlorella at 10 to 20m cells/mL and rotifers at 200/mL are added. Most of the Chlorella is consumed within half a day, so yeast is added (1.5 g/m rotifers). Twenty-four hours later, yeast is again given, at a rate of 1.2 g/m rotifers. Forty-eight hours from start of culture, the

rotifers are harvested by draining, at an average concentration of 600/mL. Before being fed to the larvae, the rotifers are held in a 1.5 t tank with 15 to 20m cells/mL of Chlorella for 4 to 10 hours. On day three, the rotifer rearing tank is cleaned and prepared for the next culture.

Different strains are produced at different temperatures and temperature in the tanks is controlled according to the size of rotifer required. At 30^o to 34^oC, rotifers of 150 to 180 u size are cultured for the Z_1 and Z_2 stages. At 25^o to 28^oC, they are 160 to 200 u and are fed to the Z_3 and Z_4 stages. The 200 to 300 u strain appears at temperatures below 26^oC, but is not deliberately cultured.

The salinity of the rotifer-rearing water is similar to that of the Chlorella-rearing water (26 ppt). Vigorous aeration is provided. Faeces are removed by air-lifting the rearing water through simple filters containing a synthetic fibre commonly used in air-conditioner filters. The rotifers are able to pass through the material easily. Mats made of the same fibre are hung around the walls of the tank. Settling tanks have also been used at other centres to remove faeces (Hirata 1980).

At the end of the hatchery production season in September-October, the fertilised resting eggs of the rotifers are collected and held in a refrigerator until the beginning of the next season in March.

Culture of the brine shrimp, Artemia salina. Artemia eggs are hatched in small conical tanks with strong aeration. The Tamano hatchery uses a Brazilian brand of eggs (1981 price 28 000 yen/kg) with an average hatching rate of 60%. Four hundred grams of eggs are placed in a 250 L tank, producing 7 000 to 10 000 nauplius larvae in 24 hours. When aeration is stopped, the unhatched eggs float while the nauplii sink to the bottom of the tank. A simple faucet attached to the conical bottom allows easy removal.

Using Chlorella as food, brine shrimp larvae are also being raised to 1 mm size, when they are given to megalopa as an experimental supplementary food.

Larval monitoring and handling

Stocking and counting. As shown in Table 1, initial stocking densities of 50/L and above were common, except at Tamano. The Tamano hatchery has always begun with much lower densities of 10 to 20/L and cited higher survival as a result.

After hatching in small tanks (1 t), numbers of Z_1 larvae are first estimated by counting several 100 to 200 mL samples. The larvae are then transferred by siphon or bucket to the adjacent rearing tank. However, estimates of larval numbers and survival are somewhat unreliable, because there are no really accurate methods of sampling ırvae, especially when distribution is uneven. Altnough Tamano has vercome this problem to a certain extent through the use of the jitator, there are still large fluctuations in estimates of larval ımbers. Nevertheless, the method is quite adequate for determining ppropriate management procedures.

At Tamano each larval stage is sampled twice - once during the ay, once at night. Using a long 50 mm diameter valved PVC pipe, 11 amples of a few litres each are taken from midwater around the erimeter and middle of the tank. In most other centres, only the ıitial larval and final crab numbers are estimated.

rovision of shelter for megalopa. Two or three days after the etamorphosis from the last zoeal stage to the megalopa stage, the ırvae develop a benthic mode of behaviour and spend most of the time ı the walls and floor of the tank. Megalopa is also the first stage ossessing pincers and mortality from cannibalism greatly increases. iis is especially so during moult periods, when the soft newly-oulted larvae and juveniles are very vulnerable.

To accommodate these developing tendencies, most rearing centres rovide extra benthic area by hanging netting in the tank. These helters' range in sophistication: from fish nets simply strung cross the tank (Hiroshima) to a series of framed 50 x 100 cm nets, iich are slid into position by a convenient system of ropes (Fukui), o a more complex system of eight (9 m x 90 cm) nets suspended from ırs attached to the central rotating shaft of the agitator at Tamano.

However, shelters are inconvenient in that they require extra ıbour input for installation and maintenance and have the major isadvantage of disrupting water circulation and food dispersion. For iis reason, the Fukui hatchery replaced its frame-net shelters by imple nets strung lengthwise parallel to water flow. Tamano ispensed with shelters altogether. To help combat cannibalism, water ovement is increased and large excesses of food are given during ıulting periods.

ırvival and production. Table 2 shows annual production and survival ıring rearing for several hatcheries. In both respects, Tamano is e leading crab hatchery in Japan, with Fukui a close second.

Table 2. Annual production and survival.

Centre	Harvested crab stage	Final survival (%) range	(Av)	Total annual production	
Tamano[1] 1978	C_1	18-44	(26)	5 200 000	
Tamano[2] 1979	C_1	14-42	(26)	6 828 000	
Tamano[3] 1980	C_1	30-60	(43)	5 857 000	
Tamano[4] 1981	C_1	29-71	(42)	4 180 000)	) 5 970 000
	C_2	14-22		1 790 000)	
Fukui[5] 1979	C_1, C_2	6-42	(16)	2 527 500)	) 1 820 000
	C_{2+3}, C_4	1-15	(6)	292 000)	
Fukui[6] 1980	C_1	7-45	(28)	2 721 000)	) 4 198 000
	C_{1+2}	7-41	(14)	1 477 000)	
Okayama[7]	C_1	15-40	(27)	1 481 000	
Hiroshima[7]	C_1	10-23	(15)	1 250 000	
Hyogo[7]	C_2, C_4	6-16	(11)	585 000	
Nagasaki[7]	C_2	4-29	(14)	454 000	
Ehime[7]	C_2, C_3	1-5	(3)	72 000	

Sources:-
1. SISFFA 1978
2. *Tamano, pers. comm.*
3. JASFA 198[illegible]
4. JASFA 1981
5. Fukui 1980
6. Fukui 1981b
7. Gazami Seed Pdn. Res. Conf. 1980

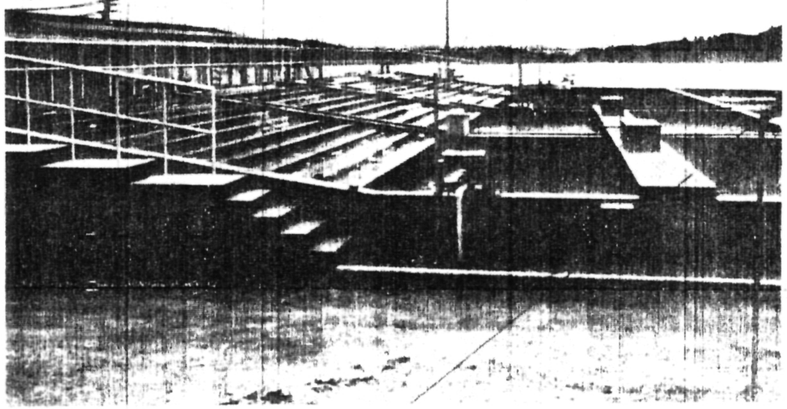

Plate 4. 60 cu.m. terraced tanks for Chlorella cultivation.

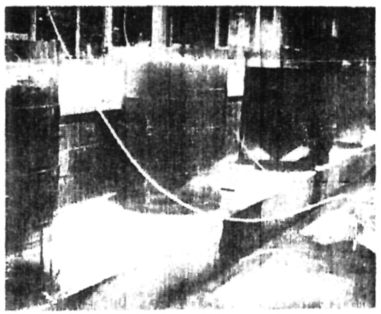

Plate 5. Mass culture of Artemia nauplii.

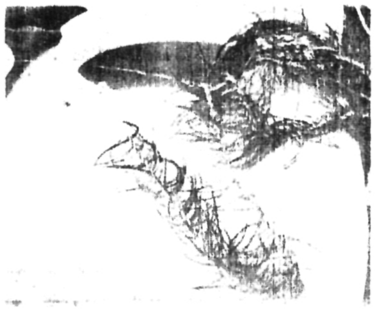

Plate 6. Artificial weed shelters and plastic tank used for transporting juvenile crabs to release site.

At Tamano, the first major mortality, 30% on average, occurs between Z_4 and M stages. This is mainly attributed to cannibalism on newly moulted megalopae (JASFA 1980). The Z_4-M metamorphosis usually occurs over 2 to 3 nights, and the greater the proportion of larvae moulting on the first night, the lower the mortality.

In the four production runs at Tamano in 1981, the level of Z_4-M moult synchronisation was 51%, 80%, 86% and 90%. Corresponding mortality between Z_4 and M was 52%, 26%, 8% and 23% respectively (JASFA 1981). Fukui staff have observed great variation in moulting rhythms. The estimated percentage of M stage larvae present on day one ranges from less than 5% to 80%, and on day two, from 20% to 80%. By day three, all larvae are M stage (Cowan 1980). Unfortunately, the corresponding mortality rates are unknown because actual counts are made only on the Z_1 and final C stages at Fukui. Experimental work has indicated that mortality approaches 40% when only 30% of Z_4 larvae moult simultaneously, and decreases to 25% when 80% of Z_4 moult simultaneously (Cowan 1980). Mortality from cannibalism is greater during the M-C_1 metamorphosis and later moulting periods. This has hampered attempts to rear the juvenile crabs for a longer period. It is most likely an effect of developed prey-capturing ability (for example, larger chelae) and increasing asynchrony in moulting. Often three sucessive crab stages are present at the same time in the rearing tank.

Asynchronous moulting, resulting from genetic differences, variability within the rearing environment, and the hindering effect of diatom, ciliate and fungal growth on the larval carapaces, can cause mortality from cannibalism even when food, larval density and shelter are at optimum levels. Although a certain degree of cannibalism is unavoidable, it can be reduced by rearing larvae of different females separately and by keeping rearing conditions as optimal and uniform as possible.

Sudden mass mortalities of 50% or more sometimes occur during Z_1, followed by a steady decline throughout the rest of rearing. Closer observation of the quality of newly hatched larvae has helped eliminate this problem at Tamano. No major disease problems have yet been found to occur during crab larval rearing, in contrast to prawn larval rearing.

Harvest and transport (Tamano). At 6 a.m. on the day of harvest, siphoning out of the rearing water is begun. A 520 u net screen is placed around the siphons. After about 2 hours when water volume has been reduced to 40 to 50 t, drainage pipes at the bottom of the tank are opened and the water flows into the harvest nets. The crabs are then transferred by dip-net to several 1 t tanks to await counting.

The number harvested is estimated by measuring wet weight of the juvenile crabs, unless there is a lot of debtritus in the water. In this case, the crabs and detritus are dispersed as evenly as possible using a large plunger, while another person takes three 500/mL samples for counting.

The crabs are transported to the intermediate rearing and releasing sites in closed 1 t PVC tanks, at 15^{0} to 19^{0}C, with aeration via a low pressure compressor or oxygen cylinders. Lengths of 'kinran' (nylon rope interwoven with thousands of short strands) are provided as refuge. Kinran were originally designed for use as egg collectors in commercial goldfish breeding. The tanks containing the harvested crabs at an average density of about 150/L are transported by truck or boat to sites up to 15 hours away. Mortality during transportation is claimed to be negligible (JASFA 1980).

Seed production costs

In 1978 culturists from the various hatcheries estimated their rearing costs per harvested C_1 crab as: Tamano 1.46 yen, Horoshima 2 to 3 yen, Hyogo 1 to 2 yen, and Fukui 3 to 4 yen. Neither the JASFA Centres nor the Prefectural Fishery Experimental Stations sell their harvested juveniles. The Fukui hatchery, being a Prefectural Fishery Farming Centre, was selling its juvenile crabs to local fishery co-operatives for 1 yen each, with governmental subsidies for seed production making up the difference.

Production costs in 1980 at Tamano were made up of these items (salaries and miscellaneous running costs excluded):-

Item	Quantity	Total cost (yen)
Female crabs	97 (34.6 kg)	212 170
Food		
rotifers (150-180 u)	656 x 108	163 900
rotifers (160-200 u)	199 x 108	59 700
brine shrimp	39 cans (11.7 kg)	323 700
frozen clam (before mincing)	948 kg	956 975
frozen shrimp (before mincing)	3 470 kg	711 350
live clams	144 kg	43 500
glucose	20 kg	76 000
Water and heating		
electricity	-	1 703 641
water	1 816 m^3	164 370
oil	21 450	1 743 750
Fixtures (pump)	1	185 000
Materials (nets, hoses, etc.)	-	542 640
Wear and tear	-	135 811
Overall cost per crab (C_1 + C_2) = 1.2 yen	Total	6 946 507

Female crabs with packed ripe ovaries are a luxury food item in Japan. Early in the breeding season, the price of spawners reaches 5 000 to 6 000 yen/kg. As soon as the eggs are extruded, the price drops to around 2 000 yen/kg.

Food prices, especially Artemia and short-necked clam meat, have been dramatically increasing in recent years. However, in 1981 the Tamano hatchery was able to import frozen clam meat from Korea at 750 yen/kg, much cheaper than the overfished Japanese resource.

Water heating and food were by far the major expenses, equalling 52% and 32.5% of the total respectively. Although no direct income is received through sale of seed crabs, the hatchery receives a proportion of the annual JASFA membership fees of local fishery co-operatives (500 000 yen) and a prefectural government subsidy (5m yen/year). The remaining operating expenses are covered by the central national government.

Experimental production of Scylla serrata seedlings

Since 1979 the Tamano hatchery has also been attempting to mass produce seedlings of Scylla serrata, using methods similar to those used for Portunus trituberculatus. The rearing method is gradually being adapted as the differing requirements of Scylla are recognised. However, because of the general scarcity of basic data on Scylla larval biology, its mass production is as yet far from successful.

Broodstock management

Scylla serrata supports small fisheries in Okinawa, southern Shikoku and Lake Hamana. Landings at Lake Hamana in the last 5 years have been in the range of 5 to 40 t (Anon 1976-80; Yamakawa 1978). To ensure sufficient spawners are available, the Tamano hatchery imports female crabs from Taiwan.

The crabs are captured from natural stocks (not pond-reared), tied, packed in cartons and carried as hand luggage by plane from Taipei to Osaka. They are then transported by rail or road to Tamano. The journey from Taipei takes less than 8 hours and survival is 100%. It was undertaken twice in 1981, with 27 crabs being carried in March and 7 in May. Forty female crabs were also obtained from L. Hamana, but all of these failed to spawn.

At the hatchery the crabs are held in two 5 t capacity covered outdoor tanks. Half of the bottom area of the concrete tanks (that is, 5 m^2) is covered with sand, which also functions as a water filter, as described in Chapter 2, p. 5. Food is placed in the bare half of the tanks, thus keeping the sand relatively free of detritus.

Live clams (Tapes philippinarum) are provided ad libitum as food.

Water exchange rate is 100 to 400%/day. Water temperature in March and April is maintained at 15°C. In May this is gradually raised to 23° to 25°, to accelerate egg development.

Scylla apparently cannot tolerate crowding to the same degree as P. trituberculatus, especially unberried females of different sizes. The crabs have been held at densities of 1 to 3 m^{-2} but at the higher density, fighting and cannibalism resulted in a 50% mortality rate over 50 days, despite the provision of tubing shelters. Division of the tanks into individual compartments is not considered a practical solution because of the difficulty in cleaning the substrate.

Egg development is monitored in the same manner as described previously (Maintenace of broodstock). Embryonic development from spawning to hatching takes 16 to 17 days at 23° to 25°C. During this period the fmale crab does not eat at all. To reduce the risk of damage to the egg mass, the berried crab is removed to a covered 0.7 t FRP tank 5 days before hatching. Moderate aeration is provided and the water is changed almost completely every second day.

The time of hatching is quite predictable for Scylla: 7 to 8 a.m. at 23° and 5 to 6 a.m. at 27°C. To date, all crabs have been in the size range of 200 to 250 g (11 to 12 cm carapace width), producing 800 000 to 1 500 000 Z_1 larvae each. Egg hatching rate is close to 100%.

Experimental overwintering of juveniles and broodstock has been attempted to reduce the dependency on imported crabs. The crabs have been held in tanks on land and in compartmented baskets hanging in the sea, but survival has been negligible. This is believed to be a result of fungus infestation, insufficient pre-winter feeding and stress caused by violent water movement.

Larval rearing

At 27° to 28°C, Scylla passes through four zoeal stages of 2 to 3 days each, a Z_5 stage of 3 to 4 days, and a megalopa stage of 7 to 8 days before metamorphosing to C_1.

Through trial and error, the standard rearing method for P. trituberculatus larvae is being adapted to Scylla serrata. Not all of the changes made have proved suitable; for example, in 1981 low salinity 26 to 28 ppt) rearing was tried, but no positive effect was demonstrated. This is not surprising as several studies have suggested that Scylla zoeae are not estuarine in nature (Brick 1974; Hill 1974; Ong 1964).

Production and seawater supply facilities are identical for both species and have been described in Chapter 2, p. 8.

As Scylla is commonly found in warm-water areas, rearing is carried out at 27° to 28°C. At these temperatures, diatom and protozoan populations rapidly increase. This is prevented by maintaining high levels of Chlorella in the water and high rates of water exchange. Ten to 15 t of 'green water' is added every day during the zoeal stages, to produce a maximum concentration of 0.5 to

1m cells/mL. Water is exchanged at a rate of 25%/day during zoea, increasing to 40% after megalopa, when *Chlorella* is no longer added. The resulting diatom and protozoa levels are generally lower than 1 000 cells/mL during zoea (comparable to levels occurring in *Portunus* rearing), but can reach 20 000 cells/mL after megalopa (cf. 5 000 to 10 000 cells/mL). *Chlorella* also helps to maintain water quality (oxygen and metabolite regulation), therefore microbial flock is not required.

The presence of *Chlorella* inadvertently affects the larval feeding regime. Whereas *Portunus* zoeae are provided with rotifers every day to maintain an approximately constant level of 10 rotifers/mL, during *Scylla* rearing, rotifers are added only once, at the beginning of Z_1. Subsequently, the rotifers feed on *Chlorella* and multiply rapidly. This system is therefore similar to that in use at the Fukui hatchery. However, occasionally *Chlorella* can be grazed to the extent that water quality suffers; thus continual monitoring of the levels of all organisms is critical.

Artemia nauplii are provided during Z_1 and Z_2 in very small amounts, and then from Z_3 through Z_5 at the standard ration of 100 to 300/mL. As it was suspected that this was insufficient nutrition for Z_5, larger *Artemia* (1 mm length, 3 to 4 days old) are being tried as a supplement. From megalopa, clam and shrimp meat is provided in standard combined accounts of 150 to 200 g/t.

Survival rates from Z_1 to C_1 are still very low for *Scylla*, ranging from about 4 to 9% (compared with 30 to 70% for *Portunus*). Various theories have been advanced by technicians to explain the low survival. Major mortalities have occurred during Z_1 (presumably due to poor quality of the newly hatched larvae); during Z_3 and Z_4 (believed caused by deteriorating water conditions); at the Z_5-M metamorphosis (possibly a result of inadequate nutrition); and at the M-C_1 metamorphosis (inadequate nutrition and poor water conditions due to accumulating detritus). Besides weakening the larvae, these factors delay moulting, which increases the incidence of cannibalism.

Total production of juvenile *Scylla* in 1981 at Tamano was only 300 000. All were used for restocking.

CHAPTER 3

THE POST-LARVAL RESTOCKING PROGRAMME

Introduction

As one of the cornerstones of the Japanese fisheries restocking programme, production and liberation of post-larval *P. trituberculatus* have been increasing year by year. In 1978, about 10m first-stage juvenile crabs (C_1) were produced in 10 prefectures and 7.9m were released directly, or after intermediate rearing, at 47 sites in nine prefectures on the Seto Inland Sea and at 10 other sites on the Pacific coast, Japan Sea coast and in western Kyushu. The JASFA Tamano Centre alone supplied seedlings to seven prefectures and this was supplemented by the output of two prefectural hatcheries, six prefectural Fishery Experimental Stations and one fishery co-operative. Most of the actual restocking is carried out by the Fishery Experimental Stations and by fishery co-operatives under the guidance of hatchery staff.

Among the most extensive and well documented restocking trials have been those performed by the Hiroshima Fishery Experimental Station. The programme began in 1971 with small-scale releases; it then proceeded to comparative trials in open and closed bays in 1974-76 and to large-scale restocking in 1977-79.

In many prefectures, especially in the early years, enthusiasm for the restocking programme ran high and many releasing projects were stated before necessary baseline surveys and ecological studies had been carried out. This king of 'blind restocking' still occurs, although the psychological and political results are easier to determine than any biological and economic benefits.

Preliminary surveys by the Hiroshima Station have recorded the physical characteristics of releasing areas, such as depth profiles, substrate composition, rainfall and runoff, water temperature and salinities, tides and currents; biological features, including faunal composition, crab breeding seasons and grounds, and distribution of larvae and juveniles; and information on the crab fishery - catch statistics, seasons, fishing grounds, trends in catch per unit effort (CPUE) and estimates of the crab resource present (Hiroshima Pref. 1977).

The first attempts at restocking began with direct release of the megalopa stage. As understanding of post-larval ecology increased, it was realised that the juvenile crab stages have a much better chance of survival, especially if they are reared until the benthic habitat is fully developed. This led to the present search for the most effective method of intermediate culture.

Direct restocking is still feasible in certain locations with suitable environments, such as Hiroshima. It has been found that the C_1 stage exhibits almost no benthic behaviour. In nature, it drifts for 7 to 10 days at the sea surface, clinging to seaweeds and seagrasses, especially the eelgrass (Zostera sp.). The coast of Hiroshima Prefecture has some of the largest eelgrass beds in the Seto Inland Sea and the time of maximum abundance coincides with the appearance of juvenile crabs.

On average, one juvenile crab can be found in every 0.5 to 2 kg of eelgrass (Hiroshima Pref. 1977). Burrowing ability develops in C_3 and, from this stage on, the juvenile crabs settle in the intertidal zone as soon as it is reached. Up to C_3 or C_4 (9 to 20 mm carapace width), the crabs live in tidal pools and can tolerate moderate water movement, although they are dispersed by heavy rainfall. From C_5 to C_8 (25 to 50 mm), the crabs move actively throughout the intertidal zone; and from C_8 to C_{12} (50 to 130 mm), are found in depths of 5 m or more. At a size of about 10 cm carapace width, they begin to migrate offshore for overwintering and mating (Seibu Region 1980).

In the Seto Inland Sea, the spawning season generally extends from late April or early May to late August, with a peak in June and July. Wild juvenile crabs (C_2 stage and later) begin appearing inshore in July and live in the intertidal zone for about one month. By September, the final batch of young crabs has moved offshore, where they are caught first by the gill net and set net fisheries and later by demersal trawl fisheries. Up to August-September, the catches mainly consist of large (about 15 cm) crabs hatched the previous year. From then on, first-year crabs of 10 cm size become predominant.

Methods of releasing

Direct release

In direct restocking trials, the C_1 seed crabs are usually pumped or siphoned through a large diameter flexible hose into buckets from the tanker in which they are delivered to the release site. The buckets are then carried by hand or boat a few hundred metres out from shore and the contents simply broadcast into the open sea.

According to studies in Hiroshima Prefecture (Inoko et al 1979a, 1979b), 5% of C_1 released in a small bay survived and settled on the beach after 10 days. Survival after 30 days was 3.5%. In an open bay, survival was less readily determined: only 0.5% of released C_1 were discovered in the beach zone after 16 days (MAFF and JASFA 1980). Almost all studies have demonstrated the rapid disappearance of C_1 seedlings from restocking sites, mainly by passive dispersal on the non-benthic C_1 crabs and by predation.

Ideally, direct-release sites should be sheltered, with a gently sloping, sandy-muddy sea floor, substantial seagrass beds and no strong currents. In less-than-ideal conditions, direct restocking is

gradually being replaced by intermediate rearing and release into artificial shelters.

Intermediate rearing

In terms of the degree of management required, the experimental intermediate culture methods can be divided into three categories: onshore facilities, semi-closed inshore facilities, and open inshore facilities.

Onshore facilities, such as large (50 to 150 t) canvas or concrete tanks and outdoor ponds, are closed systems requiring water exchange and provision of shelter and food (krill or clam meat). Stocking density of C_1 seedlings is in the range of 1 000 to 3 000/t. Survival after 1 to 3 weeks' rearing to C_{2-4} is generally 20 to 40% and has reached 56% (MAFF and JASFA 1981; Seibu Region 1980). Cannibalism and deterioration in water quality are the main causes of mortality.

After harvesting, the crabs are released directly into the sea.

Semi-closed inshore facilities permit natural water movement through net walls or screens, but the crabs cannot escape and predators cannot enter. The most common structures used are the 'kakoi' net enclosures. These may consist of a simple net and pole fence enclosing an area of about 2 000 m^2 or a smaller metal-frame net pen of 100 to 200 m^2. To reduce cannibalism 'kinran' shelters (Chapter 2, p. 18) are often provided. Stocking density is 100 to 500/m^2 and survival to C_{2-4} is 29 to 39% (op. cit.). Food is provided.

Another method in this category uses agricultural onion sacks (40 cm x 70 or 90 cm, 1.5 mm synthetic mesh construction). These are packed with kinran or cedar branches and are submerged in the sea for several days to allow settlement of food organisms, for example, Amphipoda. C_1 seedlings are then added (125 to 500/sack) and the sacks placed in shallow water. Two-week survival is 18 to 33% (op. cit).

An artificial tidal lagoon of 16 000 m^2 has also been constructed in Yamaguchi Prefecture for intermediate culture. A screen gate permits water exchange. Predators are removed but no food is provided. In the 1979 trial, survival to C_{3-4} was 27% (Seibu Region 1980).

In all the above methods, the net screens or walls are opened to allow the juvenile crabs to disperse after 1 to 3 weeks.

Open inshore facilities are constructed so as to allow the crabs to disperse freely, while still providing a substrate and some protection from predators.

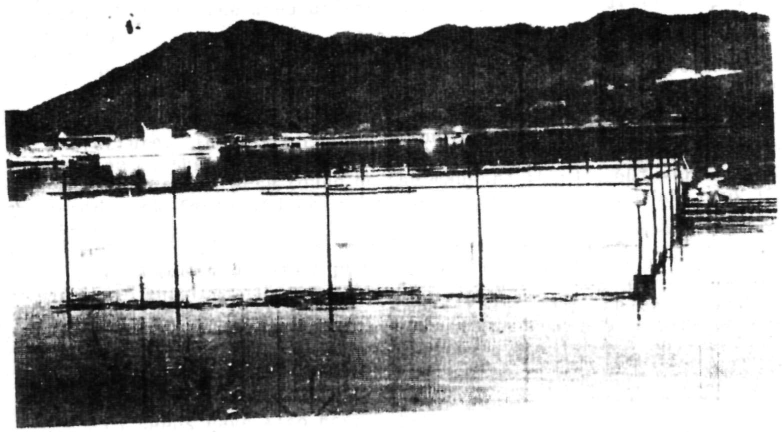

Plate 7. Net pen for intermediate rearing of juvenile crabs.

In an attempt to simulate seagrass beds, tests are being conducted on artificial shelters or 'mabushi', in which kinran or cedar branches are suspended from floating rafts and standing racks. The structure may be surrounded by a net leaving the bottom open and is submerged for several days before receiving the seedlings. Cedar branches have been found to attract a better settlement of natural food organisms than the nylon kinran.

The effectiveness of mabushi in increasing survival is difficult to determine because, as with direct release, it is almost impossible to distinguish between mortality and loss due to dispersion. Nevertheless, in trials by three prefectural stations, settlement/survival in the surrounding few hundred square metres was found to be between 5 and 31% two days after release (MAFF and JASFA 1981; Seibu Region 1980). After 5 to 7 days, up to 25% of the crabs were still in the area of the mabushi, but thereafter disappeared rapidly.

Most of the loss of crabs from the mabushi is presumed to be merely migration to the beach zone. This assumption is strengthened by the finding of a two-day survival of 76% in trials in Fukuoka Prefecture. There, to reduce dispersal, a low (40 cm) net fence was erected on the sea floor 1 m out from the mabushi. While 30% of the surviving crabs were found on the mabushi itself, 60% were retained inside the fence and only 10% were found outside (MAFF and JASFA 1981).

Instances of very poor survival have been attributed to insufficient food, strong water currents especially near river mouths, wave movement, heavy rain immediately after release, Red Tide occurrences, shifting of the raft, and too sparse a density of kinran lines. Predation is rarely considered a problem but obviously must contribute to mortality in any open system.

C_1 seeds have also been liberated on man-made tidelands. This method was first used in prawn restocking and is designed to reduce the high initial mortality caused by predation. See Kurata and Shigueno (1976) for a detailed description. Although shelter and even food have been provided on the tidelands, release of the C_1 seedlings has not resulted in settlement of more than a few percent after three days (MAFF and JASFA 1981; Seibu Region 1980). Unlike the burrowing juvenile prawns, C_1 crabs are more affected by strong currents and predation by fish at high tide. No improvement over restocking on natural beaches at low tide has been demonstrated.

Various other structures, such as intertidal net cages containing kinran and hanging-oyster-culture wire baskets with kinran, have been tested as open, intermediate rearing systems, but without success.

A common problem in most systems is that the larger juveniles often remain behind after harvesting or opening of the enclosure. Cannibalism on smaller crabs stocked afterwards can cause considerable losses.

For survival, offshore facilities and net enclosures at sea are most successful, while the open mabushi system at least appears to be an improvement over a direct restocking in most cases. However, financial considerations (cost of construction and land, labour input for water quality maintenance, feeding and harvest) will undoubtedly continue to stimulate the search for an effective intermediate rearing system that requires minimal management.

In open locations, survival of restocked C_{2-4} stage crabs is much higher than for C_1. For example, in Fukuoka, 45% of C_2 survived 4 days after direct release on a natural beach and 87% survived 3 days after release at a mabushi site (cf. 76% for C_1) Seibu Region 1980).

Recovery of restocked crabs

Estimation of the contribution of restocking to commercial catches of crabs is still fraught with difficulties, 15 years after the start of the programme. A fundamental stumbling block is the inability to easily distinguish the natural wild population from the hatchery recruits.

Mark-recapture studies

Tagging studies are not particularly useful, because of the lack of a suitable tag for small juvenile crabs. In experiments involving larger (9 to 20 cm width) crabs, it was found that some kinds of tags are lost when the crabs moult; for example, marks painted on the carapace. Others were found to interfere with feeding, movement or moulting activity; for example, swimming leg removal and tags near the leg base. Arrowhead and anchor tags placed near the rear edge of the dorsal surface of the carapace or in the seventh sternum segment have been found to last through ecdysis and cause no ill effects (Takaba and Hirata 1979; Seibu Region 1980). In a two-year investigation, Takaba and Hirata (1979) recovered 1.6 to 6.3% (average 3.2%) of crabs tagged and released in Hiroshima Prefecture. In the western end of the Seto Inland Sea, recapture rates of 1 to 22% (average 7%) were obtained in a separate two-year study involving 940 crabs (Seibu Region 1980). This kind of data is more useful for comparison rather than as an approximation of recovery rates for seedlings.

Liberation of hatchery-bred Scylla juveniles into Lake Hamana promises to show results through a form of mark-recapture study. The artificial recruits are hatched from Taiwanese broodstock at the Tamano centre. These spawners were obtained at sea and are of the easily recognisable 'oceanica' type (reduced frontal spines, Chapter 1) that at Lake Hamana is caught outside the lake, but never inside. Releasing began in the summer of 1981 and restocked crabs started to

appear in catches in late autumn (October to December). The 1982 season began in April, and by May 80 to 90% of the catch was estimated to be restocked. Shizuoka Fishery Experimental Station researchers are optimistic that the final recovery rate will be at least 40%, similar to that for prawns restocked in Lake Hamana (H. Fushimi pers. comm. 1982).

A method of visually recognising artifically bred Portunus trituberculatus, however, does not yet exist. Therefore use is made of the following indirect methods for determining recovery rates.

Size-frequency distribution analyses

At the Tamano hatchery, the major supplier of seeds, female crabs are captured at the beginning of the spawning season (March to April) and are held at elevated temperatures to accelerate egg development. The larvae are also reared in heated water and juvenile crabs can be produced as early as mid May. In contrast, wild C_2 juveniles do not appear inshore till July. Early restocking thus results in a size difference between hatchery-bred and wild recruits, which is claimed to be discernible up to 15 cm size (Seibu Region 1980).

Crabs caught in a shallow restocked channel near Tajima, Hiroshima Prefecture, in July, were 7 to 11 cm in size. Crabs caught in August in an unstocked bay 12 km away were only 5 cm. Even up to late October, when the channel crabs were 18 cm, they were still 2 to 3 cm larger than crabs caught elsewhere (MAFF and JASFA 1981).

However, difficulty in distinguishing restocked crabs was reported in Saga Prefecture (MAFF and JASFA 1981). This may have been because seedling release was not carried out till mid June and late July. Takeda (1981) reported that high summer temperatures may cause size differences to disappear by September. Accelerated growth (that is, increase in moulting frequency), combined with the variation in individual growth rates and the natural lengthening of intermoult periods in later stages, may mean that the wild recruits 'catch-up' (attain the same moult stage and size range as the restocked crabs) during the fishing season.

Nevertheless, it is claimed that, providing the fishery is limited to a well-defined area, season and method, size composition of the catch can be used to estimate contribution to the fishery and recovery rate of restocked crabs, as shown in these tables:-

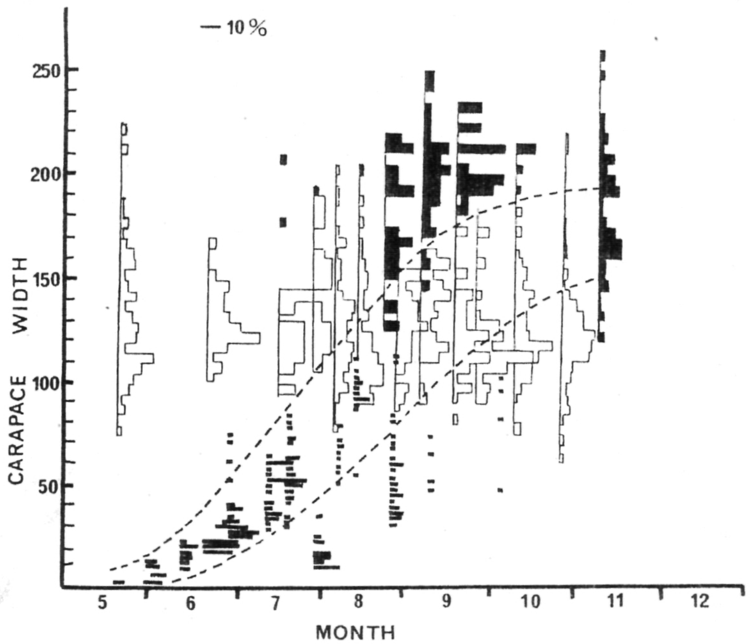

Figure 2. Monthly size composition of catch.*

Gill net and set net fisheries

Trawl fishery

Release site and inshore sampling

Restocked group

Source: modified from MAFF & JASFA, 1981

Location	Total no. of first-year	No. of restocked crabs caught	% Contribution to catch
Oita (a)	23 130	19 512	84
Oita (b, c)	14 188	11 617	82
Fukuoka (d)	50 853	25 058	49
Yamaguchi (e)	12 433	10 803	87
Yamaguchi (f)	13 737	11 074	81

Location	X No. seeds received (10^3)	Y No. seeds released (10^3)	Z Catch (10^3)	Z/X % Recovery	Z/Y % Recovery
a, b, c	1 400	780 *	31.1	2.2	4.0
d	908	547 *	25.1	2.8	4.6
e	340	92	10.8	4.5	11.7
f	500	87	11.1	2.2	12.7

(* includes mabushi or direct release)

(a =Choshu; b= Matama; c = Kokouchi; d = Minoshima; e = Shokusei; f = Akiho)

Source: modified from Seibu Region (1980)

Changes in total catches

The effect of restocking theoretically should be most easily observed in places where a crab fishery did not previously exist. This was the case in Etajima Bay, where no crabs had been caught for several years before the first large-scale releases by the Hiroshima Fisheries Experimental Station in 1974 (Inoko et al 1979a). Five hundred thousand C_1 were released and 3.5% of these were found to have survived and settled on a nearby beach within 30 days. Using De Lury's method relating the CPUE to accumulated catch and accumulated effort, the total initial crab resource before fishing was estimated to be 2 289. This means survival of crabs between release and start of fishing 4 months later was 0.5%. The total commercial catch was 1 498, which was 0.3% of the released C_1, 9% of the older juveniles that settled in the beach zone, and 65% of the resource available.

Similarly, survival and recovery of restocked crabs were estimated for waters off Buzen, Fukuoka Prefecture, where no significant fishery existed before 1978 (MAFF and JASFA 1981). In 1978, 167 000 seedlings were liberated either at a mabushi site or in the intertidal zone, and 545 000 were released in 1979. In 1978, survival to the start of fishing was 29%; and 79% of these were caught, producing an overall recovery rate for released seedlings of 23%. The figures for 1979 were 26%, 64% and 17% respectively.

Appearance of Scylla in Seto Island Sea catches would be an obvious demonstration of the effect of restocking. However, since releasing began in 1980, no recoveries have been made. Although this may be partly attributable to the small scale of restocking attempts and crabbing methods that are more suited to Portunus, the lack of suitably muddy estuarine habitats for Scylla in the Seto Island Sea is probably an important factor.

In many areas where existing crab fisheries had declined, recent increases in annual catches have also been cited as possible evidence of the effectiveness of restocking. In Okayama Prefecture, catches declined from over 25 t in 1965 to almost zero in 1969. In 1971 when restocking began, the catch was 13 t. By 1979, 1.5m seeds were being released annually and the catch had risen to 107 t (Okayama Pref. 1980).

In Hiroshima Prefecture, annual catch peaked in 1956 at 270 t, then declined drastically as shown in Figure 3. Large-scale restocking began in 1974 with the liberation of 86 000 C_1 seeds, increasing to 260 000 in 1979. The upturn in the fishery would appear to be correlated with the beginning and growth of restocking, but such a simple cause and effect relationship cannot be assumed.

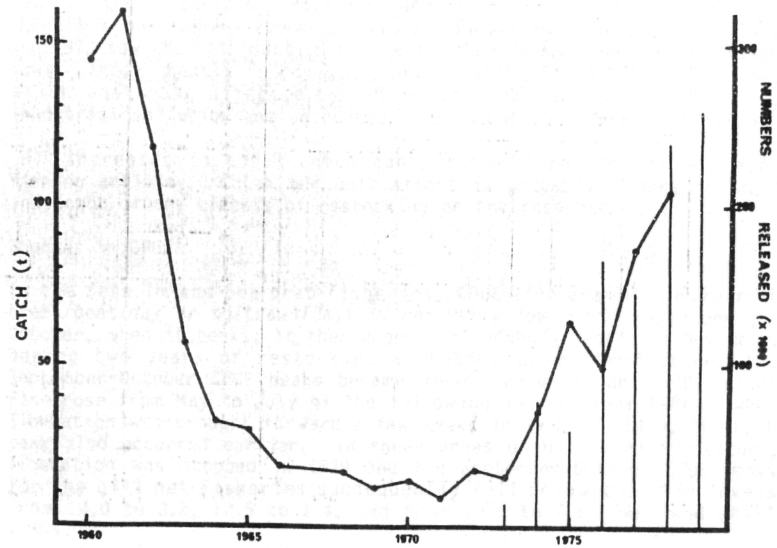

Figure 3. Annual catch and restocking of crabs in Hiroshima Prefecture.

Source: MAFF & JASFA, 1980

In some local Hiroshima fisheries, catches actually dropped in a year of intensified restocking effort. In Hiuchi Nada, a huge bay, part of which extends into Hiroshima and Okayama Prefectures, restocking did not begin in force till 1978. However, the fishery had started to recover by 1974, when the catch of 311 t was double that of previous years (Takeda 1981). Restocking in the adjacent prefectures may have been responsible, but fisheries resources are influenced by many different factors. Natural fluctuations in the environment, and therefore the fishery resource, can be significant. In addition, 1971 and 1973 saw the introduction of coastal development and antipollution laws. These greatly improved the environment of the Seto Inland Sea, which was being affected by extensive foreshore reclamation and industrial pollution and undoubtedly contributed to increased catches.

Increases in total catch can also be a result of increased fishing activity. Catch per unit effort is probably a more reliable indicator of any effects of restocking on the resource.

Changes in CPUE

In the Seto Inland Sea crab fisheries, CPUE (for example, number of crabs/boat/day or kg/trawl/day) is generally low until September and October, when it peaks; it then drops off suddenly again in November. During two years of restocking at Kakio, Ehime Prefecture, the September-October CPUE peaks became more pronounced and CPUE values also rose from May to July of the following year (Takeda 1981). When liberation was brought forward a few weeks in 1978 and 1979, the CPUE peak also occurred earlier. In three areas of Hiroshima Prefecture, liberation was stopped in 1979 and the September-October CPUE peaks for the gill net fisheries subsequently fell below the 1978 levels from 14.0 to 3.2, 12.5 to 1.4, and from 13.5 to 7.6 (MAFF and JASFA 1980).

Economic feasibility

Estimates of recovery rates are still very approximate and cannot possibly take into account all factors affecting the restocked crabs. Although restocking has apparently added to the commercial catches in some places, the real test is whether the increased value of the landings is greater than the costs of producing and releasing the seedlings.

Cost-benefit analyses would be premature at this stage, but a tentative model, relating rearing and releasing costs, market price, recovery rates and break-even points, has been developed (Seibu Region 1980).

Restocking costs for three different methods were estimated as shown below:-

Cost of production per crab (Japanese yen)

	Fixed costs	Variable cost	Total
Direct release	0	C_1 seeds:3.0	3.0
Canvas tank	tank, pump and blower:2.0	C_1 seeds:3.0 feed, labour, wear and tear:1.2	6.2
Mabushi raft	raft, net, etc.: 3.9	C_1 seeds:3.0 labour, use of vessel:0.4	7.3

Market price depends on sex and size, with 10 to 15 cm (100 g) crabs fetching about 80 yen each; 15 to 20 cm (250 g) crabs, 250 yen; and 20 to 25 cm (500 g) crabs, 1 000 yen. The value of each restocked crab caught also depends on the recovery rate:-

profit on each seedling = market price x recovery rate - restocking cost

As can be seen in the model, at a market price of 250 yen/crab, the above methods of restocking would become economically viable at recovery rates of 1.2%, 2.5% and 2.9% respectively.

Four actual cases (Chapter 3, p. 34) were included in the model. Based on the calculated recovery rates and the prevailing market prices, the value of production for each seedling was between 3 and 6 yen. For example, in Kokouchi (c), the cost of restocking was 4.59 yen and value of production was 4.52 yen (market price 205 yen x recovery rate 0.0222); so the restocking project there was not far from profitability.

Restocking is expected to become more economically feasible with rising market prices and continuing technical improvements to lower production costs and increase survival.

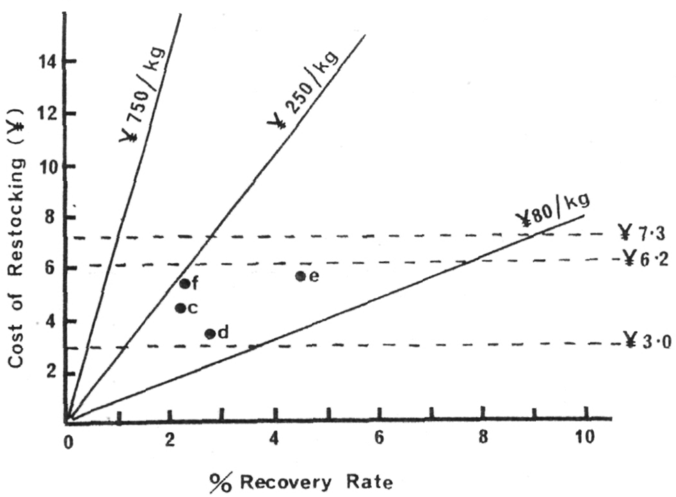

Figure 4. Relationship between value of production per seedling, market price and recovery rate.

Source: modified from Seibu Region (1980)
(c = Kokouchi, d = Minoshima, e = Shokusei, f = Akiho)

CHAPTER 4

CULTIVATION OF CRABS (Scylla serrata) TO MARKET SIZE IN TAIWAN

Introduction

The mud crab Scylla serrata is fished and cultivated all along the west coast of Taiwan, including the Pescadore Islands (Penghu), and in the north-east county of Ilan. The crabs are mainly caught close inshore using gill-nets and baited traps and pots. Apart from three exceptional years from 1976-78 when total production, including aquaculture, soared to 2 000 t, annual mud crab landings for the last 15 years have generally ranged between 200 and 700 t (TFB 1980). Maximum value of mud crab production was NT490 million in 1976 (2 016 t).

Fishery production of other portunid species in Taiwan, mainly Portunus pelagicus, P. trituberculatus, P. sanguinolentus and Charybdis feriata, has been twice to 25 times that of Scylla, although they are worth considerably less (maximum value of annual catch: NT159 million for 7 960 t in 1979).

Annual aquaculture production has increased from 180 t in 1976 to 562 t in 1979. Actual production is likely to be much higher than these official statistics of the Taiwan Fisheries Bureau, as not all production is reported. In 1979 mud crabs officially ranked 13th in terms of aquaculture production tonnage and 15th in value (NT71 million). The major species cultured in Taiwan are eels, milkfish, oysters, jumbo prawns, tilapia and carp.

There was a small quantity of other portunid species produced by aquaculture in 1979 (8 t), but the estuarine habit, less aggressive behaviour and higher value of Scylla serrata make it a far more popular candidate for cultivation.

Unlike Japan, where prawns and other species are reared to market size entirely by monoculture, the crab farming industry in Taiwan is based on polyculture. Scylla may be grown with one or more of the following species: grass, jumbo or giant tiger prawns Penaeus monodon, kuruma prawn P. japonicus, sand shrimp Metapenaeus monoceros, the milkfish Chanos chanos, and red alga (Gracilaria sp.). Of the three varieties of mud crab recognised by growers, the 'white crab' is believed to be most suitable because it supposedly grows larger, is less aggressive and more tolerant of a wide range of salinities than either the 'sand crab' or the 'red-legged crab' (Chen 1976).

In complete contrast to Japan, which has a highly developed crab hatchery system but no on-growing, Taiwan does not yet have mass production of seedlings. Growers are still forced to rely on seedlings collected from the sea. Larval rearing trials are underway, however, and hatchery-scale production is expected to begin within 2 or 3 years.

Experimental hatchery trials

National Taiwan University, Taipei

Larval rearing experiments have been conducted by Dr Hon-Cheng Chen and colleagues of the NTU. Optimal salinity and temperature ranges for the zoeal stages are 25 to 30 ppt and 26^{0} to 30^{0}C respectively (Chen and Jeng 1980). As food organisms, rotifers were found to be adequate for the zoea$_1$ stage only, with sea hare veliger larvae or brine shrimp nauplii necessary for later stages and the copepod Tigriopus for the megalopa stage. Female spawners did well on live freshwater snails. An inexpensive and novel form of shelter for the megalopa and juvenile crabs was provided by plastic artificial Christmas trees in the rearing tanks!

According to Dr Chen (pers. comm. 1981), a private experimental hatchery in Tainan, using NTU methods, is currently able to produce 100 000 crab$_1$ stage seedlings per month, at densities of 6 000/t and maximum survival of 60%.

Tainan Fish Culture Station, Taiwan Fishery Research Institute

Research at the Tainan Fish Culture Station (Director, Mr Y.Y. Ting and Mr M.N. Lin) has aimed at understanding and controlling the whole life cycle of the cultured mud crab. Juvenile crabs produced at the station are held in outdoor ponds for 4 months till mature, at a size of about 10 cm carapace width. After mating, spawning of laboratory held crabs occurs in about 4 months, compared to 1 month for pond crabs. To shorten this period, artificial maturation through unilateral eyestalk ablation was being tried. Of 10 females ablated, all had produced healthy eggs within two weeks. There were seven successful hatchings with normal Z_1 larvae. If successful, this technique, which is commonly used on prawns and other species, will greatly quicken the development of a crab hatchery.

Broodstock are held in an outdoor pond with a sand bottom and running water. An average of 1 or 2 Z_1 larvae are produced by a 10 to 12 cm spawner. The Z_1 larvae are fed brine shrimp nauplii whisked in a blender for a few seconds. Living whole nauplii are given to the later zoeal stages, minced fish to the megalopa and crab stages, and live oysters to the spawners.

Survival throughout the zoeal stages is reported to be 90 to 100%, but during megalopa and the crab$_1$ stages, this drops to 20% because of cannibalism. Contrary to the findings of most other studies (Ong 1964; Brick 1974); Fielder and Heasman 1978), the zoea larvae at the Tainan lab consistently pass through six, and not 5, stages before metamorphosing to megalopa. This would seem to indicate less-than-ideal rearing conditions. Yatsuzuka (1962) observed that an

extra zoeal stage occurred in three species of crab (Neptunus trituberculatus, Eriocheir japonicus and Sesarma dehanni) in which growth and development were retarded. Prawn larvae may also delay metamorphosis but continue to moult in the absence of adequate food (Wickins 1976). Zoea$_1$ were occasionally killed by a chitin-destroying bacteria which attacks the carapace spines. Infection can be prevented by 20 ppm of sodium sulphamonomethoxine in the rearing water (Ting et al 1981).

Experimental seedling production has also been attempted by a private hatchery on Penghu, but has been frustrated by continuing mortality believed caused by inadequate light during the zoeal stages and excessive cannibalism during megalopa.

Seedling collection

Distribution

Berried female crabs have been captured off the west coast from about 22.5^{0}N to 24.5^{0}N and around Penghu, apparently heading for waters of 6 to 12 m depth for hatching their eggs (Chen, NTU, pers. comm. 1981). The megalopae migrate toward estuarine nursery grounds and have been found inshore along almost the same range. Exceptions are:-

(a) an area of high turbidity near the estuary of a large, fast-flowing river;

(b) estuaries affected by serious industrial pollution; and

(c) Penghu, where there are no rivers (Chen op. cit.).

Surprisingly, a small crab seed collection operation does exist on Penghu, but it is restricted to the warmer months (May to October). In winter, the cold China coastal current flows south through the Taiwan Strait. However, in summer, monsoonal surface drifts and a branch of the warm Kuroshio current both swing north-east through the Taiwan Strait from south-east Asia (Chu 1971). Presumably, early juvenile stages, as well as larvae, are carried to Penghu, but the megalopae larvae cannot survive the lack of suitable estuarine waters.

The major crab fry collection area, usually providing 60% to 70% of the total annual catch, is Chiayi, in the west of the main island. Penghu is 48 km offshore.

The officially recorded total annual seedling catch was about 1.3m in 1976, 1.8m in 1978 and 1.9m in 1979 (TFB 1977, 1979, 1980). Dr Chen believes the industry requires at least 12m /year. In 1980-81, a serious shortage of crab fry was widely attributed to drought conditions, which produced intolerably high salinities (about 40 ppt) in the estuarine areas. The shortage is also believed to have been caused by the effectiveness of new fry catching methods that catch megalopae as well as juvenile crabs. So few escape the nets, that the breeding populations of a year later may be drastically reduced. In 1982, Hai Ou, in the far south-west, was the only collecting area able to supply sufficient quantities of fry to growers along the west coast.

Methods

Hai Ou. The crab fry are caught in the river mouths or close inshore, drifting with longshore currents. If particularly abundant, they can be gathered in the traditional triangular push-nets used for collecting milkfish fry. Otherwise beach seine nets are used. About 100 men are engaged in seedling collection, each having up to 10 nets operating. In peak seasons only two or three nets are required and these can catch 60 000 to 70 000 crab fry/day. In 1980-81 however, maximum daily catch for six nets was 2 000 (Farmer a, Appendix 1). Fry are collected from the nets every morning by boat, sorted from milkfish and other species, and carried to nearby nursery ponds. Crab fry can be caught all year round with a peak in spring and summer. Only the megalopae and early juveniles, up to $crab_{3-4}$ stages, can be caught using these methods.

Penghu. Several seedling collectors operate on Penghu, catching crab and other species, especially grouper, for which a large market exists in Hong Kong.

One operator (b) utilises three nets that are set up 30 to 40 m offshore in a bay 10 km long and 5 km wide at the mouth. The nets are set every day at high tide and are removed at low tide. In good years, 2 000 to 3 000 crabs can be gathered in less than 2 hours, but 500 to 600 is average. The fry-catching season is shorter here (May to October), suggesting a dependence on seasonal currents.

Larger seedlings, (2 to 3 cm and over) are captured at night using an underwater light in water up to 0.5 m deep. The bottom is sandy and the crabs can be easily seen and caught by hand. Adult crabs up to 20 cm wide are also caught in this way.

All the seedling crabs caught on Penghu are sold to dealers on the main island. Small juveniles are placed in oxygen-filled plastic bags containing netting as refuge. The bags are then packed in cartons and air-freighted to Taiwan. The flight takes only 20 minutes. Larger seedlings first have their chelae tied with synthetic twine and are then packed in large boxes with layers of grass soaked in seawater. The operator mentioned above ships up to 30 000 larger seedlings per season and 25 000 smaller seedlings per week to Taiwan. The small size fetched NT5 each in 1981 compared to NT2.5 in 1980. Best prices were obtained from areas of high demand: Chiayi, where most farms are concentrated, and Ilan, a hot spring area where high water temperatures accelerate growth so that pond stocking and harvest are more frequent.

Nursery farms

Nursery farms in the Hai-Ou area usually consist of four or five small ponds (15 to 20 m^2) with concrete-covered brick walls, mud floors covered by 5 to 10 cm of beach sand, and 20 to 50 cm of seawater. No aeration is provided, but natural seepage of water through the pond bottom is replaced daily. To control water temperature in summer, water exchange, through pump and siphon, is carried out, varying from 30 min/day to one complete exchange per day. The ponds may also be shaded.

Unsealed pond floors that allow some seepage are believed to result in better bottom conditions and water quality than concrete floors.

Most of the Hai-Ou ponds are immediately adjacent to the beach, behind a sea wall and above MSL. One small 2 hp pump is adequate for pond filling. Because of a nearby river, the salinity of the sea is low, about 21 ppt. Some operators gradually decrease the salinity of the nursery pond further, to 10 ppt over a 2-week period.

The seedlings are stocked in the nursery ponds at densities of 2 000 to 3 000 m^2. Depending on demand, they may be held for up to 2 weeks. Survival is 50 to 70%.

The crabs are fed blended trash fish, about 1 kg/30 000 seedlings/day, depending on the amount of unconsumed food remaining.

At a width of 1 cm and over (C_{2-3}), the fry are harvested by hand nets and carried immediately without water to nearby grow-out ponds. Transport to distant farms is in plastic bags of oxygenated water. In a typical journey $2^1/_2$ hours north to Chiayi, survival is claimed to be almost 100%.

Each nursery farm usually has dozens of regular customers, buying up to 100 000 fry each time, at NT1.50 to 5 each (1981). Larger seedlings of 2 to 3 cm that are caught and sold without going through nursery rearing fetched NT7 each. In Chiayi, seedlings bought from southern nurseries for a few NT, were being reared for 2 weeks longer and sold for NT12. Seedling scarcity in 1981 had apparently doubled the normal prices, providing an even greater incentive for hatchery development work.

Nursery pond operation is often carried out in conjunction with other crab farming activities, such as polyculture, monoculture, intermediary dealing and selling of feeds. One Hai-Ou operation (a), who had an 80 m^2 nursery and a 1 ha prawn-crab ongrowing farm, obtained 15% of his income from the nursery, 25% from sales of market-size crab and 60% from prawn sales. Another farmer (c) with 80 m^2 of nursery holding ponds and almost 4 ha for prawn-crab polyculture was able to obtain up to 50% of his income from the nursery business. He

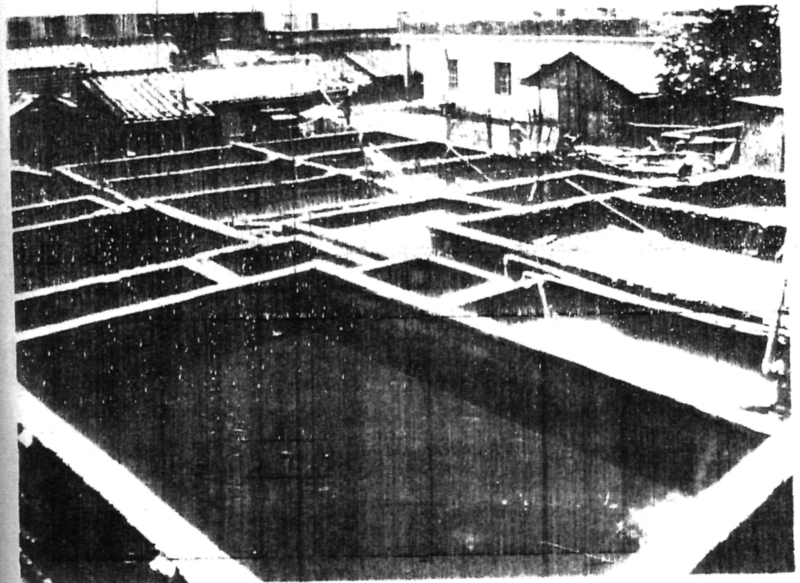

Plate 8. Complex of nursery ponds for juvenile crabs, Taiwan.

did this by acting as a middle-man between seedling suppliers in the south and farmers in the Chiayi area.

Polyculture to market size

Species

Prawns, crabs, milkfish and Gracilaria are commonly cultured together in various combinations of two, three or all four species. Traditionally, milkfish was the primary species in polyculture. In recent years falling demand, comparatively low market value and the development of improved techniques for breeding and culturing prawns have quickly led to the displacement of milkfish by prawns as the major crop. On many farms milkfish are raised only for private consumption, for use as baitfish or as foragers to control blooms of algae (Filamentous algae (for example, Enteromorpha and Chaetomorpha sp.) can completely overgrow the Gracilaria plants in winter). Nevertheless, total annual production of milkfish is still around 30 000 t, six or seven times that of prawns.

Similarly, falling prices of Gracilaria have resulted in production declines in some places. However, because it continues to grow without attention once the plants have become established in a pond Gracilaria culture can still return a profit. The plants also serve as refuge for prawn and crab fry and help maintain oxygen levels in the water.

The main prawn-crab area is south of Kaohsiung, while polyculture of crabs with milkfish and Gracilaria is predominant north of Kaohsiung.

Pond construction

Polyculture farms range in size from less than 1 ha to over 200 ha. Individual pond sizes also vary greatly, although the shape is always rectangular. The larger ponds, ranging from 0.5 to 2 ha, have dikes of mud or sand about 2 m high. Being susceptible to gradual erosion and subsidence, and major damage by typhoons, the dikes are usually reinforced by one or more of the following methods: sandbags, bamboo fences, heavy vegetation, bricks, concrete planks and concrete covering. The most common pond size of this type is 1 ha, and there are typically 1 to 4 ponds/farm.

Dikes can also be constructed of brick with a covering of concrete. This type of pond is smaller, commonly 0.5 ha, but ranges in size from 0.2 to 1 ha. Farms often have both types of pond, with the larger sizes used for polyculture and the smaller ones for monoculture of crabs or prawns.

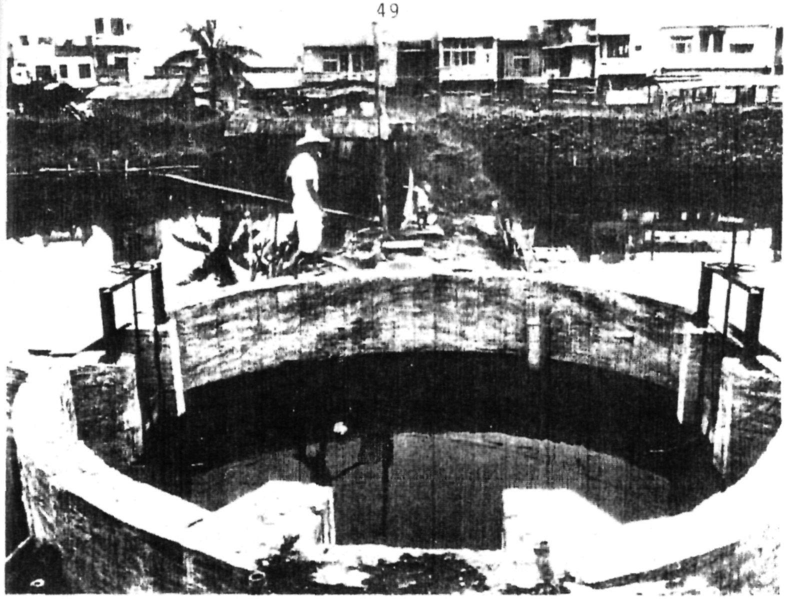

Plate 9. Heavily vegetated dikes and modern sluice gate system, Taiwan.

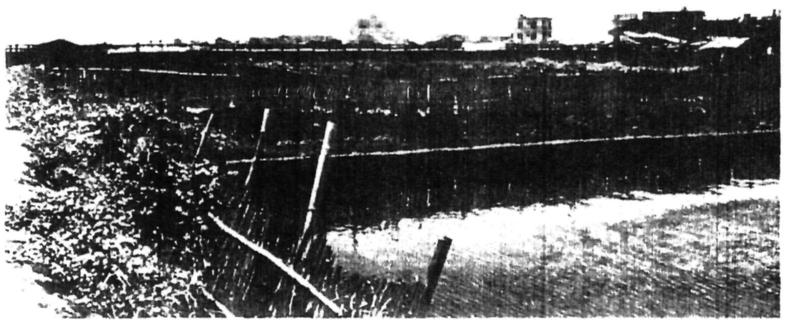

Plate 10. Fences of bamboo and other materials are used to prevent crabs escaping, Taiwan.

Sluice gates are made of concrete with removable wood or stainless steel boards. Ponds of two or more hectares require three or four gates to be efficiently filled or drained by tides, while one or two suffice for smaller ponds. Bottoms are of sand or mud or a mixture. While 100% mud or clay is more impermeable to water, addition of a good proportion of sand prevents the crabs from digging burrows in the pond floor. Burrowing in the mud dikes, which must remain as compact as possible, is more difficult to stop. Fences of bamboo, brick or concrete boards are one solution, which, however, is not always successful. The fences also prevent the crabs escaping. Brick concrete dikes have vertical inner walls and do not suffer these drawbacks.

Pond floors are typically level or slope slightly toward a drain or sluice gate. Although some farms can be found at elevations between MHT and MLT that permit utilisation of tidal movements for filling and draining ponds, most are not so conveniently situated. The average tidal difference on the west coast of Taiwan is less than 1 m (Chen 1976). Unless pumps are used, ponds with floors close to MHT cannot be filled and those more than a few centimetres below MSL can rarely be completely drained. Subsidence of ponds due to excessive pumping of underground water, has become a serious problem in the Hai-Ou area.

Water supply

In some areas, farms extend several kilometres inland, along the reach of tidal estuaries. PVC pipes 15 cm in diameter are used to carry water from the pumps at the source, often hundreds of metres to the ponds. Pond water is commonly 1 to 1.5 m deep. For farms using tidal exchange, even very large farms of 4 to 5 ha, one small pump of 1 to 5 hp is sufficient and may not even be used, except in emergencies. Farms at extra high or low elevations need three to five pumps, as do farms specifically growing Gracilaria, which requires particularly clean water for maximum photosynthesis. One farm (d), which relied completely on underground water because of industrial pollution in the nearby estuary, had eight pumps.

Underground water in many areas is saline and can be pumped directly to the ponds. This source is used especially at neap tides when tidal exchange is inadequate or when estuarine water is unsuitable because of pollution or excessive dilution after heavy rain. For the same reasons, estuarine water is usually pumped only at high tide, when salinity is highest, and concentration of pollutants lowest.

Fresh underground water, where available, is used to dilute seawater to appropriate salinities for rearing, especially in times of drought. Farms without access to freshwater have experienced severe crab and prawn mortalities in drought conditions of high temperatures, high salinities and hot dry winds. Because it is often oxygen deficient, freshwater is first aerated by pumping it over stepped terraces. High iron concentrations in some areas preclude its use and river water is the only alternative. As much as possible, pond water is maintained at a low salinity, ranging from 5 ppt to no more than 21 ppt, with 10 to 12 ppt most common.

Water quality maintenance

Paddlewheel-type aerators are used when there is no wind, and in very hot or cold weather. They are operated all night, especially in mid-summer when water temperature may reach 30°C. Because the animals are being fed at maximum rates, water quality can quickly deteriorate at these temperatures. At such times, water exchange through pumping is also increased. In winter, pond water temperatures occasionally fall below 10°C. The crabs become inactive and growth ceases. To prevent sudden temperature drops, water depth is increased. Normal rates of water exchange vary from replacing a few centimetres every few days to two-thirds pond volume every 2 weeks or total exchange every month or so. Water quality is the determining factor, and a close watch is kept for any signs of fouling or abnormal behaviour in the cultivated species.

A common practice among crab farmers in Taiwan is to clean the ponds and to allow them to dry out for a few weeks after harvesting. This:-

(a) prevents the build-up of noxious reduction layers (containing hydrogen sulphide and ammonia) in the mud of the pond bottom;

(b) temporarily eliminates competitors and predatory species such as the small shrimp Palaemon orientis, gobies and tilapia from the pond and permits the spreading of lime to kill the eggs of these pest species; and

(c) in the case of polyculture with milkfish, permits the application of fertiliser, usually rice-bran powder, to encourage the growth of benthic blue-green algal and diatom food species.

However, some ponds which are difficult to drain are not dried out for several years at a time. Increase in bacterial populations in such conditions is known to cause at least one disease in crabs. The responsible organism is an unidentified chitin-destroying bacteria which produces small ulcers in the carapace. Injured and moulting crabs are particularly susceptible and die within 1 month of infection (Chen, N.T.U. pers. comm. 1981). In experimental hatchery trials, berried crabs taken from the polyculture ponds were often affected by epiphytic bacteria on the eggs, which greatly reduce hatching rates. This problem was overcome at NTU by placing spawners in water containing 10 ppm malachite green or methylene blue for 5 minutes. Lime is sometimes added directly to pond water to reduce bacterial levels.

Feed

Type of food and feeding methods for polyculture are fairly well-established. Interviewed farmers generally agreed the most suitable and convenient feeds for prawns are artificial pellets and trash fish or small shrimp; for crab, live snails and trash fish; and for milkfish, algae and artificial feed or rice-bran powder.

The preferred food for crabs, especially for fattening, is the fresh and brackish water snail (Cerithidae spp.). The crabs will eat fish, but apparently will not touch the available pelleted food unless starving. Athough other crustaceans are part of the natural diet of mud crabs, few farmers reported cannibalism to be a problem. Adequate food is always provided and stocking densities are low (0.5 to 1 crab/m^2). Predation by crabs on prawns during culture has been observed only when the very small prawn seedlings are moulting (C.F. Liu, Tungkang Marine Lab, pers. comm. 1980). For this reason, prawns are stocked from a size of 2 to 3 cm (total length), when their swimming speed is too fast for capture by the crabs, even during moulting. Pest species of shrimp gathered from the ponds at harvest time are also utilised as food.

The amounts of the various foods provided daily are not calculated precisely; for example, as a percentage of total biomass present. Rather, after an initial 'appropriate' amount of food is placed in the pond, rations are varied depending on rate of consumption, as estimated roughly by eye. The following pattern is most usual.

Trash fish or shrimp, intended for both prawns and crabs, is provided freely, usually at 4 to 5 g/m^2/day. Some farmers (f, g) gave up to five times this amount. If prawns are the main species in a polyculture crop, artificial pelleted food (protein content 38 to 45%) is also provided. The most common maximum daily pellet ration is about 400 g/1 000 prawns (about 2% of body weight at that time) or 4 to 10 g m^2. If other species are of equal or greater value in a polyculture crop, pellets are not given.

Live snails are always provided at a rate of 10 to 15 g/m^2/day for crabs, and the soft-shelled species can also be consumed by the prawns. Milkfish first feed on the algae grown in the pond and are later given pellets (protein content 24 to 29%) at a rate of about 4% of body weight/day. Alternatively 1 to 4 g rice-bran powder/m^2 may be given every few days. Where the milkfish crop is unimportant, no supplementary food is provided at all. As a minor crop in polyculture, milkfish stocking rates are low: 0.1 to 0.4 fish/m^2.

Prawn pellets are given 2 to 5 times/day, along the edge of the dikes. Snails and pieces of fish are provided once or twice daily beside the dikes, or are spread evenly over all the pond. Milkfish pellets are given at one place in the pond, usually once a day. At one farm (d) an automatic feeder delivered pellets continuously over a 12-hour period each day.

There are several brands of pelleted prawn feed in Taiwan, ranging in price from NT37 to 43/kg. Milkfish pellets are NT16 to 18/kg. Trashfish can be bought for NT7 to 25/kg, snails for NT5 to 6/kg, and rice-bran powder for NT8 to 10/kg.

Stocking and harvest

The table below summarises information gathered from 14 polyculture farms on stocking densities, size and price of seedlings of prawns, crabs and milkfish.

Species	Size (cm)	Price (NT each)	Stocking density (per m^2)
crab	0.5-1	1.5-5.0	0.5-1.0
	2-3	7.0-15.0	
prawn	2-3	0.6-2.5	10-25 (prawns as main crop)
			1-5 (prawns as secondary crop)
milkfish	2-3	2.5-3.5	0.1-0.4
	10-15 (overwintered)	10-25	

Most prawn fry are bought from private hatcheries south of Kaohsiung. Crab seedlings are obtained directly from fishermen or nursery farms, or indirectly, through dealers. Small milkfish fry are gathered in scoopnets and sold to farms for rearing either to market size or to intermediate seedling size over winter. Except for observing activity levels as an indicator of seedling health, there is no selection of seedlings on the basis of quality. Gracilaria cuttings are obtained from nearby farms where the plants are already established (NT8/kg). The cuttings should be straight, firm and elastic with many shoots.

The table below compares grow-out period, estimated percentage survival, size and price at harvest for all four species:-

Species	Harvest size or other criteria (range and average	Grow-out period (months)	%survival (range and average	Price (NT/kg) (range and average
prawn	25-50 g (35 g)	3-4 (summer) 5-6 (winter)	50-90 (70)	300-500 (390)
crab	. 8-9 cm . hard carapace . female crabs fertilised	3-4 (summer) 5-6 (winter)	30-70 (40)	. males and unmated females: 135 * . ripe females: ** S 80-100 each M 160-180 each L 180-210 each
milkfish	. 15 cm (bait, seed) . 300-1 200 g (600 g)	3-5 4-12+	80-100 (90)	10-25 80-150 (120)
Gracilaria	heavy dense growth	20-45 days	-	22-28 (25)

* includes weight of wet rope (about 2/3 total)
** S = 8-9 cm, M = 9-10 cm, L = 10-11+ cm carapace width

Early spring and mid-late summer are the two major stocking times for prawns and crabs. However, as the supply of crab fry is less reliable than that of prawns, crabs are also stocked in the ponds throughout the growing season, as they become available. The resulting range in size and state of maturity means that harvesting of crabs is also conducted on a continuous basis, in addition to a final major harvest at the same time as the prawn crop. The presence of predatory fish species in some ponds has necessitated the use of intermediate rearing enclosures for the small crab fry. Fish poison is spread inside the net before stocking the crabs. Tea seed cake at 50 ppm will kill gobies and tilapia without affecting crabs and prawns.

For bait and seedling production, milkfish fry are stocked three times a year in February, April and July-August. For rearing to edible size, stocking may be carried out several times, beginning in March with overwintered fingerlings. During intensive rearing of milkfish, where they are the main crop, it is possible to have eight or more partial harvests of 200 to 300 g size fish between May and November (Chen 1976). However, in all cases surveyed for the present study, there were no more than 3 harvests/year. In some cases, the milkfish are not fed at all, and are left in the ponds for 1 or 2 years before harvesting.

Gracilaria cuttings are spread evenly throughout a pond and are often weighted down with nets or bamboo sticks. Low barriers dividing the pond may be used to prevent the plants being piled up in one corner by strong wind. Once firmly established in a pond, Gracilaria may be trimmed at harvest and does not have to be replanted each time.

Harvest Methods. Prawns are harvested either by hoop-net traps positioned beside dikes, by nets on sluice gates, or by hand-held dip nets. A mild electric shock of 4 to 5 V over 4 seconds is often used to force the prawns off the bottom.

Crabs are caught in the hoop-net traps, by dip nets at feeding time, or are netted near sluice gates as they swim against the incoming current. Baited lift nets are also used. Concrete pipes may be placed in the pond and checked daily for inhabitants. The main catching method, however, is by hand. With or without gloves (usually two pairs), the farmer moves slowly through the water, watching and feeling for crabs of suitable size and condition. Two or three crabs are harvested every day throughout the growing season using these methods.

Gracilaria is simply uprooted or trimmed by hand, while milkfish are harvested using gillnets in the main pond or in a catching pond. Water is allowed to enter at high tide so the fish swim against the current into a small pond where they are easily netted.

Yields. The practice of continual stocking and harvesting of crabs during polyculture, combined with a lack of day-to-day records, makes it extremely difficult to estimate crab production from the ponds. The rough estimates of minimum yield for crabs mentioned below were obtained by considering stocking density and estimated survival rates. Densities are assumed to remain fairly constant.

The surveyed farms fall into four loose categories, based on the percentage contribution of each species to the annual income of the polyculture ponds (H = high %, M = moderate %, L = low %):-

1. Prawn (H) culture with some crabs (L), 5 farms. Well-managed farms of this type produced yields of prawns similar to that obtained by monoculture; that is, 8 to 10 t/ha/year in 2 to 3 crops, providing 60 to 80% of pond income/year. The annual yield of crabs (20 to 40% of income), although secondary, is roughly estimated to have been at least 8 000 to 9 000 crabs/ha.

2. Prawn (M) and crab (M) culture with some milkfish (L), 3 farms. On these farms, most of the annual income (80 to 100%), was produced about equally by prawns and crabs, with a maximum of 20% coming from milkfish reared as bait. The ponds yielded 2 to 4 t prawns/ha in two or three crops, an estimated 5 000 to 8 000 crabs/ha, and less than 1 t/ha/year of milkfish of 300 g size and over (or about 5 000 bait-size fish/ha/year).

3. Gracilaria (M) and crab (M) culture with some milkfish (L) and prawns (L), 4 farms. These farms had well-established Gracilaria plants in their ponds and so did not have any expenditure for new cuttings. Thus Gracilaria culture was still profitable despite the low prices, providing 50 to 60% of annual farm income, at yields of 10 to 20 t/ha. The crab crop was second in importance (20 to 50% of income), with an estimated yield of 5 000 to 6 000 crabs/ha. Prawns and milkfish were both minor crops (0 - 10% of income), annually yielding 200 to 400 kg/ha and less than 1 t/ha, respectively.

4. Milkfish (M) and crab (M) culture, 2 farms. Only two farms produced milkfish as a major crop (50% and 90% of income). In the former case, annual milkfish yield was about 4 t/ha and the estimated crop of crabs was about 7 000/ha.

Post-harvest

After capture, the crab pincers are tied with moistened rice-straw rope. Farm are regularly visited by middlemen who buy the daily harvest of crabs. Mature female crabs with fully-packed ripe ovaries fetch the highest prices and are sold directly, or through other dealers, to markets and restaurants throughout all of Taiwan. In most cases, the eggs are not fully developed and these crabs are held for a few days or weeks of 'fattening' in specialised monoculture ponds. Male crabs and females with no eggs are the least valuable and are sold by weight.

Harvested Gracilaria is cleaned of detritus and spread out on a clean surface for sun drying. The ratio of wet to dry weight is from 7 to 10:1. The crop is exported or sold to agents for the local agar industry. After the major harvests, prawns and milkfish are loosely packed in ice and trucked to market.

Monoculture fattening of female crabs

Introduction

Monoculture of crabs in Taiwan is actually a short-term operation involving the holding and fattening of female crabs, rather than the growing of crabs to market size. It exists and is profitable only because the 'red crabs' - females with internal orange-red eggs packed to the very edge of the carapace - are a highly prized gourmet food, fetching around NT500 in Taipei restaurants for a 12 cm crab.

The monoculture farmers usually function as intermediary dealers for all types of mud crabs, whether fished or farmed. Males and unfertilised females are resold immediately to local markets and other farms. Ripe female crabs are held for just 1 or 2 days before being sold to the general public and restaurant agents. Underdeveloped females are held until their ovaries are fully developed (1 month usually, but up to 3 months during winter in Chiayi). The state of ovarian development can be determined by holding the crab up to a strong light. The eggs are visible through the carapace when mature.

Description of ponds

Crab monoculture farms are typically small, with 5 to 15 ponds of 50 to 600 m^2. Dikes are concrete-covered brick or reinforced concrete. The bottom is mostly sand and is built up around the edges to provide an area of shallow water where the crabs can survive sudden drops in DO levels. Water depth in the centre of the pond is usually 50 to 60 cm, being increased to 1 m or more in winter. Salinity, as in the polyculture ponds, is mostly 10 to 15 ppt, although one farmer (h) utilised tidal water of 25 ppt without any ill-effects on the crabs.

Optimum water quality is maintained by:-

(i) water exchange - in summer, pumping is continued all day, or, where possible, tides are utilised to exchange most of the pond water every few days;

(ii) aeration through paddle-wheel or compressor; and

(iii) cleaning of ponds and spreading of lime after harvesting.

Stocking, feeding and harvest

Female crabs of 8 to 12 cm size are stocked at densities of 2 to 4m^2. This may be decreased to about one crab/2m^2 during summer. Crabs are stocked almost daily all year round, with a peak in late summer and autumn. Farmers try to stock crabs of similar egg development in the same pond, so harvesting will be simplified.

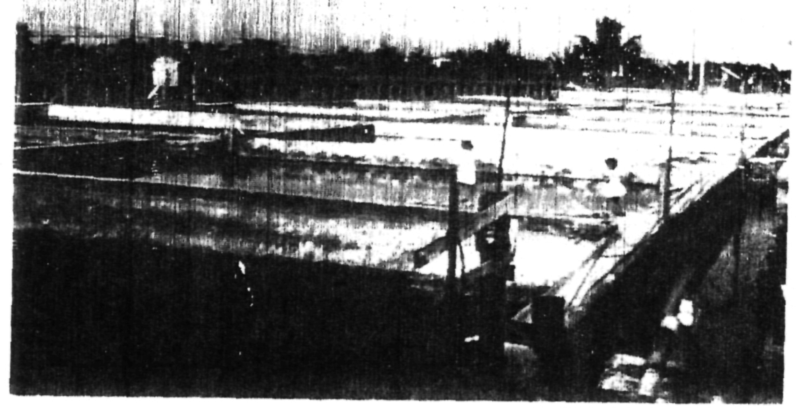

Plate 11. Monoculture farm for female crabs, Taiwan.

In addition to sex, size and egg development, crab quality is determined by the condition of the membrane of the claws; that is, rounded plump membranes indicate a healthy crab, while crabs with dry, rough membranes are rejected.

The crabs are fed once a day on pieces of trash fish (up to 200 g/crab) and, if available, live snails are provided every few days at about 100 g/m^2. Small shrimp are sometimes given for a few days before harvest (20 g/crab) as a final nutritional boost.

Survival is commonly 70 to 90%. During harvest, water flow is stopped and the level lowered. The crabs are caught by hand (usually without gloves), tied with wet straw rope and packed in straw baskets for transport by train or truck to the major cities. They are capable of surviving in this state for 6 to 7 days in winter and 2 to 3 days in summer. The matured crabs are usually sold for NT20 to 40 more than their buying price.

Organization of the crab farming industry

Taiwanese fish-farmers, unlike their Japanese counterparts, tend not to participate in self-help co-operatives. Fishery co-operatives and associations exist in all centres visited, but fewer than half of the farmers interviewed were members. Although the associations provide medical insurance, loans, technical consulting and sometimes training courses, most farmers believed there were few benefits for members.

The Tungkang Fishery Association operates the local fish market, taking a 5% commission on the sale of fishery products, but none on farm produce. The association loans are low interest (7% yearly, about half that of banks). However, few farmers used these loan services and the largest amount borrowed was NT800 000. Special government loans are also available, mainly through the Joint Commission on Rural Development. There was little enthusiasm for these either, probably because application procedures are complicated; for example, three guarantors are needed, and use of the money is supervised.

The main government financial support for the farms is indirect and substantial: no income tax is levied on farm profits. In some cases, no land rates are paid, because ponds are constructed inside levee banks or on privately reclaimed land which is not officially registered. Land rates varied from less than NT2 000/ha/year to almost NT10 000/ha/year.

Extension services, providing technical and biological advice, are available from several regional laboratories of the Taiwan Fisheries Research Institute. However, most crab farmers tend to rely on the experience of friends and family when seeking advice. In contrast to prawn farming, in which techniques developed at the laboratories have been widely disseminated and adopted, there has been little long-term research done on improving crab-farming methods.

Recent research has concentrated on developing crab hatchery techniques.

Nearly all farmers understandably declined to reveal their annual farm incomes, except for these four cases (the figures should at best be regarded as modest estimates):-

(a) a 1.8 ha Type 2 polyculture farm - NT1.5m;

(b) a 2 ha Type 3 polyculture farm = NT1m plus;

(c) a 1 ha shrimp and crab monoculture farm - NT200 000, which was unprofitable; and

(d) an 8 000 m^2 Type 1 polyculture farm, which brought in NT400 000 for crabs alone in the first 5 months of 1981.

Problems and prospects

The most urgent problem facing crab farmers in Taiwan today is the unpredictable and inadequate supply of seedlings. Application and development of results of crab hatchery research at government institutions should overcome this shortage within 2 to 3 years.

Other complaints were associated with the effects of poor water quality at the source: freshwater scarcity, high temperature and salinity during drought, industrial pollution, high iron content in underground freshwater, and seawater turbidity during the typhoon season. Problems were also caused by inadequate husbandry and resulting infestation by pathogens (black-gill disease fungi, ectocommensal protozoa and ectozoic algae on prawns, and chitin-decaying bacteria in crabs). Muscle necrosis occasionally occurs in crabs during high temperatures and low DO levels in summer. The main response to outbreaks of disease is to change and/or deepen pond water. Ectocommensal protozoa in prawns was being treated with 10% saponin added to the pond after reducing water depth to 30 cm. A concentration of 5 ppm is maintained for at least 4 hours.

Mud crab behaviour poses some minor problems. Fighting is minimised by using low stocking densities and high food rations. Shelters are considered unnecessary. Despite the use of bamboo, brick or concrete fences around the inside edge of the mud dikes, the crabs sometimes manage to burrow under the fences, into the dikes and out, especially near sluice gates. Apart from providing an escape route for the crabs, this eventually leads to the collapse of the dikes. Crabs in short burrows are routinely hooked out and the holes filled. According to farmers, crab escape is only a problem during the breeding season, and when water temperature changes suddenly or water quality deteriorates.

Pest species of shrimp, the eggs of which easily enter through the inlet screens, compete with the cultivated species for food, and are a major problem in most ponds. Lime or calcium carbonate is used to kill the eggs.

Poaching is a serious problem, which is largely overcome by the construction of living quarters for the owner/manager at the pondsite, or by the use of guard-dogs, usually Dobermans.

Crab culture in Taiwan is neither a traditional, large-volume, subsistence-type industry such as milkfish farming, nor yet a high-profit, rapidly-expanding sector like prawn culture. The constant luxury value of ripe female crabs has ensured that crabs have always been an important secondary crop in polyculture, providing a substantial proportion of annual income. However, technical problems (for example, seedling supply), the disparity in price between male and female crabs and lack of an export market at present combine to keep aquaculture production of mud crabs on a small scale compared to other species.

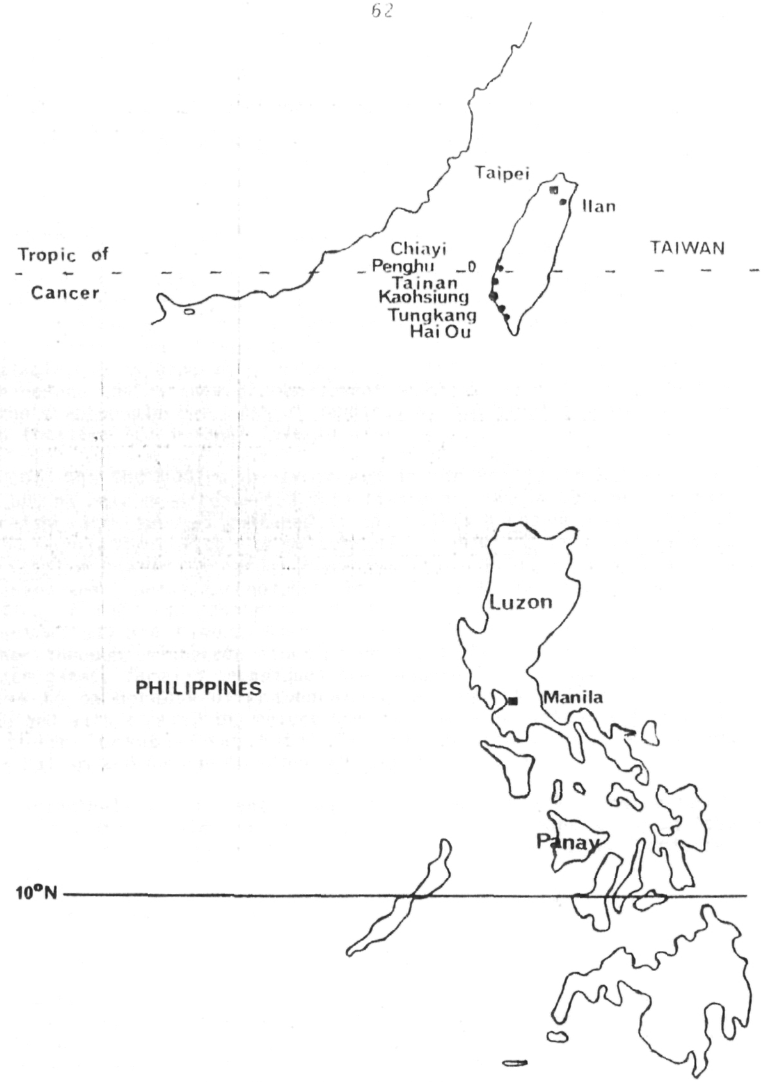

Figure 5. Crab farming areas visited in Taiwan and the Philippines.

CHAPTER 5

CULTIVATION OF CRABS (Scylla serrata) TO MARKET SIZE IN THE PHILIPPINES

Introduction

As elsewhere in Asia, Scylla serrata is a highly valued delicacy in the Philippines. Mud crabs are caught in commercial quantities in the extensive mangrove swamps and estuarine waters by means of gill nets, baited traps, fish traps and hooks. Although few statistics are available, it is generally believed that intensive and indiscriminate fishing and the absence of management measures have caused a decline in the crab population. Annual landings by municipal fishing craft in 1976 totalled 109 t (BFAR 1976).

Of the 400 000 ha of mangroves in the Philippines, more than 170 000 ha have been converted into fishponds. As in Taiwan, the main brackish water species cultured is the milkfish Chanos chanos (90% of total population) with the culture of jumbo or tiger prawn Penaeus monodon increasing greatly in recent years because of advances in hatchery and rearing technology. In contrast to Taiwan, however, the raising of mud crabs as an important component of a polyculture crop is not widely practised. Although crabs occur in almost all ponds, either through deliberate stocking or accidental entry of fry through sluice gates, farming techniques are comparatively undeveloped. This seems to be because of inadequate knowledge of mud crab biology, combined with a resulting reluctance to farm crabs intensively because of their "troublesome habits": destroying dikes, escaping, cannibalism and damage to other species during harvest.

Nevertheless, incidental rearing of crabs is a long-established, sometimes profitable practice in the Philippines and at least four entrepreneurs have even started crab monoculture farms (Lapie and Librero 1976).

Polyculture to market size

Pond construction and water supply

Typically, the ponds in which crab farming is practised were originally constructed in mangrove swamps for rearing milkfish. Adaptations were often made to ponds as prawn culture spread and one or two modifications for crabs are usually made.

Mangrove areas are convenient for fishpond operation because the tidal fluctuation is utilised for water supply and pond drainage. According to Rabanal (1978), the best sites are those with:-

(a) minimum tidal amplitude of 1 to 2 m daily and 3 m maximum annually (smaller amplitudes do not permit adequate water renewal and drainage, while greater amplitudes tend to produce great pressure on dikes at high tide);

(b) soil composed mostly of clay for water retention and dike strength;

(c) proper elevation in relation to tidal fluctuation (too high or too low sites have to be excavated or filled in to allow proper draining and filling of ponds, and the use of pumps is not widespread; and

(d) vegetation that can be easily cleared. Legally, a mangrove buffer zone of 20 m must be left beside rivers and 100 m on the sea side.

In milkfish farms that combine nursery and rearing operations, about 5% of the farm area is devoted to small nursery ponds (0.5 ha or less), 20 to 30% to transition ponds (1 ha) and the rest to large rearing ponds (up to 20 ha), canals and dikes, etc. (SEAFDEC 1980). The fish are transferred from one set of ponds to the next as they grow and as the algal food in the ponds ('lab-lab') is consumed. Farms are commonly 10 to 50 ha in total area. Dikes are almost exclusively constructed of mud-clay, main gates are concrete, and secondary gates (one/pond) are wooden. Pond floors are levelled and usually have to be treated with lime to combat the acid-sulphate soils typical of mangrove areas. After drying, the ponds may be spread with organic fertilisers to encourage growth of 'lab-lab'. Inorganic fertilisers, usually ammonium sulphate and urea, are also used, mainly for the second and subsequent crops.

In converting to prawn-milkfish polyculture, the farmers are recommended to make several adaptations to the rearing system (SEAFDEC 1980). To facilitate management, the rearing ponds should ideally be no larger than 1 ha. As water depth has to be increased to 1 to 1.5 m, compared to 20 to 30 cm for milkfish, dikes need to be strengthened through widening by a couple of metres. The greater activity and carnivorous feeding habit of prawns necessitate stricter water-quality management to maintain clean water with optimum DO levels. Tidal water exchange is increased; two gates (inlet and outlet) are constructed at opposite ends of the pond to achieve flow-through of water; pumps may be used to increase water circulation; and aeration devices are sometimes installed.

Farmers who intentionally stock crabs with prawns and/or milkfish often construct an overhanging fence of bamboo around the inside edge of the dikes. This is to prevent the crabs escaping, especially berried females trying to migrate out to sea for hatching.

The tendency of the crabs to fight, dig burrows and seek shelter is usually provided for by constructing mounds of soil in the ponds, leaving tree stumps uncleared and the pond floor unlevelled. For this reason, crabs are best stocked in new, undeveloped ponds. The mounds are also used by the crabs to remain near the surface during times of low DO levels. Maintaining water depth of at least 1 m or excavation of deeper troughs down the middle and along the sides of the ponds to provide refuge from high summer temperatures also reduces burrowing activity.

Salinity in the fishponds of northern Panay usually ranges between about 10 ppt and 20 ppt, but often reaches 30 ppt in the dry season. Water that is lost through evaporation and seepage is replaced every day at high tide. The western Visayas (including southern Panay) and northern Luzon have a very pronounced dry season (November-April). One farm on Manila Bay experiences salinities of 20 to 35 ppt during the wet season, and the ponds are converted to salt beds during most of the dry season. Ponds in the western Visayas lie idle from February to May.

Seedling supply

Crab seedlings are collected in rivers and along the shore by baited lift-nets and traps, set-nets and triangular push-nets. In many cases, fry are carried passively into ponds with the tide. They are available all year, with October-December being the peak season. The best time for catching is believed to be at high tide and during changes in lunar phase (Grino 1977).

On one small creek in northern Panay, 20 fry collectors were operating. One collector, who supplied 10 different farms, had 45 lift-nets that he baited with small shrimp and frog meat and checked every day on the rising tide. His daily catch of crab seedlings (2 to 10 cm size) averaged about 100. This brought in only ₱15 and was supplemented by fishing. Fry of all species are usually supplied through concessionaries, who are awarded exclusive rights by the local municipalities to buy all fry caught along their stretch of coast. Prawn fry (average size 15 mm, ₱0.15 to 0.25 each) and milkfish fry (average size 1.5 cm, ₱0.02 each) are gathered in various push nets, fry seines and trawls, and stationary net traps. Since 1979, prawn fry have also been supplied by a few commercial hatcheries.

In general, crab fry are stocked at a larger size than in Taiwan. Although seedlings as small as 0.5 cm and as large as 10 cm are sometimes stocked, the most common size is 2 to 3 cm, which sells for ₱0.15 to 0.35/piece. To prevent mortalities due to fighting during transport, the pincers of the crabs are often removed. This practice is suspected of increasing immediate post-stocking mortality however, due to feeding difficulties and predation by larger crabs, and is being discouraged (Robles 1978).

Stocking

Pond stocking densities reflect the greater emphasis on milkfish and lower technical level of crab farming in the Philippines. Despite an increasing trend to convert partially or entirely to the more profitable prawn export crop, milkfish is still a very valuable subsistence crop in this country.

The most common crab stocking density is about 1 000/ha, only one-tenth of densities in Taiwan, although the present level of technology is believed capable of supporting at least 5 000/ha (Lavina 1980). Stocking is sometimes carried out on a continuous basis, but usually is done once at the start of each growing season (May to August).

Conventional intensive culture of milkfish begins with nursery rearing of fry at densities of 30 to 50/m^2. After 1.5 months, the 1 to 3 g size fingerlings may be transferred to a transition or 'stunting' pond where they are held for several months at extremely low food levels. Thus fingerlings are always available for stocking, and the stunted fingerlings are believed to grow faster. Alternatively, they may be stocked directly in the grow-out ponds at 2 000 to 3 000/ha. Higher densities are possible with stock manipulation; that is, transferring the fish to larger ponds as they grow (initial density 10 000, final density 2 000/ha) or stocking three different size groups together (1 000/ha for each group) and harvesting selectively (Lijauco et al 1978).

As is now the case with crabs, prawn fry were initially stocked in the milkfish grow-out ponds at about 1 000/ha and little extra management was provided. Medium density polyculture operations now stock from 500 to 1 000 milkfish/ha and 5 000 to 10 000 prawns/ha.

Feeding

A huge variety of organic material, intended as supplementary feed for crabs, is thrown into fishponds in the Philippines. It is believed that the mud crab will eat almost anything and sometimes the crabs are left to scavenge by themselves for food in the pond. In contrast to Taiwan, where it is recognised that non-starving crabs will eat only two or three types of food (snails, fishmeat, shrimpmeat), mud crabs in the Philippines have been provided with decaying leaves, twigs, and roots, grass, legumes, algae, rice bran, corn bran, frogs and toads, fowl entrails, dead domestic animals, water buffalo hide, kitchen trash, sea snakes, sea cucumbers, trash fish, mussel meat, and crushed oysters and snails. Trash fish from the ponds, mainly tilapia, is the most common feed.

As might be expected, there are no strict feeding regimes: food is provided every few days at the most, enough to keep the crabs 'quiet'. Some farmers feed only on the rising tide in order to minimise fouling.

Milkfish feed on 'lab-lab', a naturally grown complex of algae, microbes and minute animals. This is sometimes supplemented with rice bran. Prawns also feed on 'lab-lab' organisms, supplemented daily or every two days by wet feed such as trash fish, shrimp heads, livestock hide and entrails. the SEAFDEC nutrition department recommends a balanced combination of protein sources, such as fishmeal, shrimphead meal, soybean meal and leaves of the 'ipil-ipil' plant, Leucaena leucephala (SEAFDEC 1980). Leucaena, a leguminous tree widespread throughout the tropics, is high in protein and is used as cattle, poultry and pig feed in the Philippines. Its leaves must first be soaked in water for at least 24 hours to remove a potential toxin, mimosine. SEAFDEC is also experimenting with a dry pellet feed for prawns. One promising laboratory formulation has a feed conversion rate of 2 to 3:1, but as yet is too expensive for commercial application.

Harvest

This table compares grow-out period, estimated percentage survival, size and price at harvest:-

Species	Harvest	Grow-out	% Survival	Price (₱/kg, 1980)
Milkfish	200-500 g	3-4 months	90%	4-6
prawn	30-60 g	4-6 months	50-60%	35-75
crab	200-500 g	4-8 months	40-70%	mixed sex: 25-45 females: 7-8 each

Despite the higher temperatures of the Philippines, both prawn and crab grow-out periods are longer than in Taiwan. With crabs, growth to minimum market size of about 200 g or 8 cm usually takes about 6 months. Less than optimal food levels are obviously an important contributing factor. The 4 to 6 month grow-out period for prawns applies to tiger prawns in salinities of 10 to 25 ppt; at higher salinities, growth of Penaeus monodon is retarded (Primavera and Apud 1976).

For this reason, pond operators are recommended to grow banana prawns P. merguiensis or Indian prawns P. indicus, during the dry season.

Although female crabs with ripe gonads are considered a delicacy, surprisingly few farmers bother to harvest the crabs at the optimum time. Some farmers specifically harvest before the crabs become berried and start escaping from the ponds to migrate to sea.

The fluctuation in prices for prawns reflects the dependence on export markets, particularly Japan. Huge demand in 1979 forced prices up to ₱60 to 75/kg, but by early 1980 they had fallen to ₱35/kg due to increased production and the shift of Japanese buying to other suppliers. By mid-1980, there had been a slight recovery to ₱50/kg.

Methods. Crabs are harvested from time to time during the growing season by baited lift-nets, bamboo cages, traps and gill nets. Dip nets can be used at high tide as the crabs swim against the incoming water. At the time of total harvest, the crabs are netted at the sluice gates and are also caught by hand after the pond water is drained.

Milkfish are sometimes partially harvested using gill or seine nets, but the catching pond method is cleaner, more convenient and less disturbing to the fish (Chapter 4, p. 53). This method is also used for total harvest of fish and for harvesting prawns. Traps and bagnets are also used for catching prawns.

Post-harvest. Milkfish are killed quickly after harvest by placing them in a large tank with crushed ice and a little water. They are then size-sorted and packed in boxes or baskets with ice and trucked to local markets. Some fish are canned, smoked or deboned and command a higher price.

Harvested prawns are washed and packed whole with crushed ice in boxes for the local market. Prawns intended for export are headed and sent to the nearest processing plant where they are sorted, weighed, blast-frozen and packed in cartons for shipment.

Crabs are mainly sold through the local market and private sales. Air shipment of live crabs from northern Panay to Manila, where the price is ₱15/kg higher, has been attempted, but was frustrated by excessive mortality of crabs during and after the one-hour flight.

Productivity

Average yield of milkfish farms in the Philippines is about 650 kg/ha/year (range 300 to 1 000 kg/ha) (Lijauco et al 1978). Milkfish-prawn-crab polyculture ponds are more productive, averaging 577 kg fish, 52 kg prawns, and 111 kg crabs/ha (SEAFDEC 1980). Intensive stocking can yield 4 to 10 times this quantity of prawns. In terms of value, the major proportion of polyculture farm income is contributed by the prawn and/or milkfish crops with the crab crop rarely worth more than 10% of the total. The few crab monoculture farms were found to have an average yield of 339 kg/ha/year (Lapie and Librero 1976).

Organization of the industry

Organisation of Philippine fish farmers into co-operatives began as recently as 1974 when SEAFDEC started monitoring traditional farming methods. The first group of co-operating farmers formed an association to receive training and seedlings, while making their facilities available for research. This set a precedent for the creation of regional fishpond operators associations throughout the country, which later united into a national federation. Even so, a survey of 1 500 fishpond and fishpen operators by Librero and Nicolas (SEAFDEC 1980) found that the number of associations was inadequate and few operators were members. Of those who were members, two-thirds believed that they did not get any benefits from the associations.

A number of national and international organisations and special programmes are involved in research and extension work. The main ones are SEAFDEC (South East Asian Fisheries Development Centre), an international organisation with mainly Japanese support; BFAR (the Philippine Bureau of Fisheries and Aquatic Resources); and PCARR (the Philippine Council for Agriculture and Resources Research). Several universities co-operate in the programmes. Substantial funding is provided by various international aid agencies; for example, UN Development Program, US-AID, and the Canadian International Development Research Centre. Credit is readily available through commercial and rural banks, savings and loans associations, and the government Land Bank and Development Bank. Most foreign loans come from the World Bank and Asian Development Bank. However, as in Taiwan, these low-interest institutional sources are often passed over by fish farmers in favour of private lenders. Some of the reasons given are inadequate loan size, excessive collateral requirements and transactional costs (SEAFDEC 1980).

Despite the proliferation of extension services, Librero and Nicolas found that only 25% of pond operators and 41% of fishpen operators were reached by government extension workers. The extension programme is hampered by a lack of appropriately trained workers, insufficient baseline data on all aspects of aquaculture, less than ideal co-ordination between the various overlapping agencies, and the predominance of small producers in widely dispersed locations.

Research on mud crab biology and grow-out techniques is occasionally conducted at the SEAFDEC Tigbauan and Leganes Stations. Experiments have concentrated on moulting, reproductive behaviour and larval feeding, and on comparisons of different crab densities and feeds during grow-out. In the latter experiment, juvenile crabs were provided with trash fish, canned mussel meat, decomposing potato peel and filamentous algae. Only the algae failed to support the crabs over a 30-day period (Lijauco and Prospero 1980, pers. comm.).

Problems and prospects

Most problems hindering development of the crab farming industry are those of the fish-farming industry in general; that is, insufficient supply and high cost of fry; inadequate transfer and application of new technology; unstable production; price fluctuations; lack of infrastructure facilities, especially for marketing and transport; low level of private investment; and insecurity of farms. In the

provinces, individual thieving and armed poaching raids by bandits are serious threats around harvest time.

Although newly-established hatcheries are helping meet the demand for prawn fry, techniques for artificial breeding of milkfish are not yet commercial. Crab hatchery development is not a likelihood for the foreseeable future.

To a greater degree than in Taiwan, the Philippine aquaculture industry is viewed as a source of cheap protein for the poor. For this reason, the continuing culture of milkfish and other low-priced species is officially encouraged, despite the greater profits than can be gained by conversion to prawns. Like prawns, mud crabs are a luxury species whose value lies in the ability to generate income through the export or restaurant trades. This potential is, at present, almost totally unrealised. Nevertheless, there is a long tradition of casual rearing of crabs in Philippine fishponds, and expansion of the industry is merely awaiting the dissemination and application of new and existing biological and technical information.

CHAPTER 6

RELEVANCE TO THE AUSTRALIAN SITUATION, with particular reference to Queensland

Background

There are three commercially important crabs species caught in Australia. The sand crab or blue swimmer (Portunus pelagicus) occurs all around the coast north of Victoria; the mud crab Scylla serrata is found in the north between Broome and Sydney; and the spanner crab Ranina ranina is believed to be restricted to the northern half of Australia. The mud crab fishery is largest in Queensland, and in 1980-81 was worth \$429 300, while the value of the sand crab catch was \$1 517 000 (Matilda and Hill 1981). The recently commenced spanner crab fishery is estimated to be worth about \$250 000 (A. Pashen, QDPI, pers. comm. 1983).

Sand crabs and mud crabs are caught with baited pots and dillies, and sand crabs also appear in otter trawl nets. Fishing activity for both species is concentrated in southern Queensland. Demand for mud crab has been increasing steadily; between 1971 and 1981, the average wholesale price for mud crabs in the peak season increased 500% to around \$4.25. Adjusted for inflation, the price increase was around 100% (Hill 1982). Monthly prices fluctuate with supply, which in southern Queensland peaks in summer and autumn while landings are low from June to October. The wholesale price for mud crabs in October 1982 (winter) averaged \$9.80 (Anon. 1983a) and, in March 1983 (summer), was up to \$6.12 (Anon. 1983b). Meanwhile, in Brisbane retail outlets and restaurants, large mud crabs fetch \$25 to \$30 each, even in summer.

Although the Queensland sand crab catch is still slowly increasing and exceeded 500 t in 1980-81, the mud crab fishery is believed to be fully exploited. In some regions of southern Queensland, mud crab populations appear to have been fished beyond their regenerative capacity (Heasman and Fielder 1977) and the number of professional crabbers has declined by 40% in recent years (B. Hill, pers. comm. 1982). Landings slowly increased and stablised at about 200 t between 1974 and 1978, after which they declined to about 140 t in 1981 (Hill 1982). More recent Queensland Fish Board data show a continued decline, but recording of catches was affected by organisational problems in Q.F.B. from 1980-81, and this data is not a reliable indicator of trends. Large numbers of crabs are known to be passed directly from Queensland fishermen to retail outlets in New South Wales. Illegal fishing of the protected females and undersize males (less than 15 cm) width) continues, despite increased penalties and inspections by the Queensland Department of Harbours and Marine Boating and Fisheries Patrol. In July 1981 alone, more than 1 000 crabs were confiscated while being shipped interstate (Anon. 1981).

In New South Wales, regulations allow the sale of all mud crabs that are 8.6 cm shell 'length' (127 mm width) and over.

With the aim of establishing criteria for efficient management of the mud crab resource, the Queensland Fisheries Service in 1978 began studying various aspects of mud crab biology, capture and marketing. The University of Queensland has also conducted extensive research on mud crab biology.

There has always been considerable interest in farming the mud crab in Queensland, but general ignorance of both its biology and appropriate cultivation technology has prevented the initiation of any serious ventures. Some of the factors that would be involved in establishing a crab farm in Queensland are considered below and are compared to the situations existing in Japan, Taiwan and the Philippines.

Before setting up any aquaculture venture, there are biological, socio-economic and legal aspects to consider.

The hatchery phase

Both Scylla serrata and Portunus pelagicus, which are similar to the Japanese species P. trituberculatus, possess many biological characteristics that are desirable in cultivated species. For the hatchery phase, these are:-

(a) Ease of breeding in captivity. Portunus and Scylla will spawn and hatch eggs naturally in controlled conditions. Spawning of fertilised Scylla can also be induced by ablation of one eyestalk as has been shown by studies in Taiwan (see Chapter 4, p. 43) and Queensland (N. Gillespie, QDPI Fisheries Research Branch, pers. comm. 1982). It is extremely advantageous to establish a hatchery to supply crab seed, instead of relying on the gathering of wild fry, as practised in Taiwan and the Philippines. In addition to overcoming natural fluctuations, a hatchery allows selective breeding, manipulation of the breeding season and, in Queensland, would overcome prohibitions on the taking of undersized crabs. Authorised capture of spawners, by licensed hatcheries only, could be readily monitored.

(b) High fecundity. Individual female crabs of both species can carry several million eggs.

(c) Hardiness of larvae. At the Tamano hatchery in Japan, survival of Portunus larvae has gradually risen over the years as knowledge of larval-rearing ecology increased; it now averages 40%. The same trend is expected for survival during Scylla rearing, which now averages under 6% in Japan and about 20% in Taiwan.

The larval rearing methods described in Chapter 2, p. 7 and 26, and Chapter 4, p. 43, may have to be adapted to Australian conditions. Production facilities in general could be scaled down to meet the smaller initial demand for crab seeds. In the tropics, summer and spring larval rearing should require no supplementary heating. In more southerly locations, glasshouses would be a more economical alternative to oil-burning heaters.

For water conditioning, it would be advisable to grow the flagellate Chlorella, especially as Chlorella is most efficient at preventing protozoan outbreaks during high temperature rearing. Control of protozoan populations is more difficult at high temperatures when using microbial flock for water treatment. The larval diet of rotifers, brine shrimp and macerated shellfish meat would have to remain essentially the same in Australia. Artificial feed for crabs and satisfactory alternatives to Brachionus and Artemia are not yet available. Instead of the short neck clam (Tapes sp.), meat of Australian bivalves such as pippies and cockles and of other molluscs and crustaceans would suffice in the post-larval diet. Minced fish is a less satisfactory alternative.

Because of the expertise required and the substantial capital outlay involved in the construction and operation of a commercial hatchery, seed supply would ideally be the responsibility of government fisheries departments or large private organisations. In addition, capture of female crabs could be more readily supervised with a centralised hatchery system.

Restocking

If hatchery production exceeds demand by prospective farmers, it may be possible to initiate fishery restocking, especially in those regions suffering from excessive fishing pressure. This kind of activity could only be carried out by a non-profit organisation. In the absence of Japanese-style fisheries co-operatives that have jurisdiction over designated fishing grounds, disputes over the ownership of restocked crabs are bound to occur. Problems caused by migration out of the restocking area are less likely with Scylla and Portunus. When not breeding, mud crab populations are firmly bound to particular mangrove estuaries (Heasman and Fielder 1977). Portunus is generally found further offshore and is much more mobile. Migrations of up to 40 km have been recorded in Japan (Seibu Region 1980).

Nevertheless, from an economic viewpoint, construction of a hatchery is more justifiable when production costs can be covered by sales to crab farmers.

he pond phase

esirable biological characteristics for the grow-out phase of quaculture include rapid growth; tolerance of a wide variety of nvironmental conditions, and adaptability to crowding.

Rapid growth. In Japan, P. trituberculatus can be captured and marketed within 4 months of releasing the early juvenile stage. In crab ponds in Taiwan and the Philippines, Scylla serrata reaches marketable size (8 to 9 cm) in 3 to 6 months. In the waters of southern Queensland, Scylla does not reach legal size (15 cm) till the third year from the egg. Even in north Queensland, the natural grow-out period is 2 years (B. Hill pers. comm. 1982). This could conceivably be reduced by manipulation of the breeding season. Elevated temperatures and eyestalk ablation can be used to induce maturation of gonads and fertilised eggs. Larval growth is also accelerated at high temperatures. Crab seeds would then be available for stocking in early summer or even earlier if mating was also artificially induced.

While it would not be economical to use supplementary heating for the grow-out ponds, passive methods of water heating using glasshouses or pond covers may be feasible. Floating bubble-plastic 'pool blankets' have been found to raise pond temperatures 6 to 9°C in winter (Wisely 1980).

An adequate diet is essential for rapid growth. Scylla is primarily a predator on slow-moving or sessile molluscs and crustaceans (Williams 1979). Such live or freshly killed food should constitute a large part of its diet under culture (as in Taiwan), rather than mostly dead and decaying animal or plant matter (as in the Philippines).

Tolerance of a wide variety of environmental conditions. Adult Scylla are euryhaline, being able to tolerate salinities from almost fresh up to about 60 ppt (Hill 1979), but, except in times of drought and flood, such extreme salinities are unlikely to be encountered. Feeding, and therefore growth, ceases at about 12°C (Hill 1980), and activity ceases below 10°C. Pond water temperatures may fall to this level in the south. Fatal drops in temperature are avoided in Taiwan by increasing pond water depth in winter. If water exchange and circulation are insufficient during summer, high water temperatures and the consequent risk of fouling and low DO levels can cause muscle necrosis and death in crabs. Brief critical periods can be endured if there are shallow areas in the pond for retreat. The mud crab can survive several days in a minimum of water.

This quality is an advantage in the transportation of mud crabs to market. Research at the Queensland Department of Primary Industries' Fisheries Research Branch has shown that at below 20°C the crabs can survive for up to a week out of water in a sealed container with high humidity (air saturation over 90%) (N. Gillespie, pers. comm. 1982). At lower humidities and temperatures around 30°C, survival time decreases to four days. In Taiwan, crabs tied with wet straw rope can survive out of water for 6 to 7 days in winter and 2 to 3 days in summer.

Disease has so far been less of a problem in crab culture than in prawn culture, and can be controlled by good water quality management.

. Adaptability to crowding. Both Scylla and Portunus will fight and cannibalize when crowded to any great degree. Maximum observed density of Scylla in nature is 81 crabs/ha (Hill 1975). Nevertheless, Taiwanese polyculture ponds are stocked with up to 1 juvenile mud crab/m^2; and in monoculture ponds, female crabs can apparently tolerate densities of up to 4/m^2. Only the supposedly less aggressive 'white crab' variety is cultured in Taiwan. In Japan, it was found that female Scylla broodstock can be held at 1 crab/m^2, but at 3/m^2, fighting becomes a serious problem. Such behaviour decreases while the crabs are in berry. Stocking density in the Philippines is commonly 1 000/ha.

Portunus broodstock can tolerate densities of 1 to 3/m^2, increasing to 10/m^2 if part of the claws is removed. Cutting of claws is not practical in the on-growing situation however, because, with the frequent moulting of juvenile crabs, the claws would soon be regenerated. Brick or tubing shelters are used in Japan; and in the Philippines, earth mounds and tree stumps serve as shelter. Neither method is used in Taiwan because it interferes with harvesting.

Mud crabs are not strictly territorial. They remain buried during most of the day and are active mainly at night while searching for food. The provision of sufficient suitable food is undoubtedly why ponds in Taiwan can be stocked at a rate ten times that of the Philippine ponds and more than 100 times the density of crabs in nature.

It should be possible to use comparatively high stocking rates in Queensland ponds, to help offset the effect on annual yields of the long growing season required to reach minimum legal size. Polyculture could conceivably be used to boost total annual yield of the ponds, with other species occupying the vacant niches; for example, herbivores such as mullet. However, species that are now raised with Scylla in Asia (for example, milkfish, prawns, algae and tilapia) in Australia have the disadvantages of either low market value or substantial fisheries production. Further research is needed on the possibility of growing other valuable brackish-water species together with crabs.

Even though cultivation of mud crabs may be biologically feasible, legal and socio-economic factors will ultimately determine whether it can succeed.

Legal aspects

Compared to other areas studied, Queensland possesses many legal impediments to the development of a crab farming industry.

As discussed previously, the problem of fishing regulations that prohibit the capture of female and small male crabs can be overcome by establishment of a hatchery. As for the female portion of the aquaculture crop, special permits for interstate and overseas marketing would be necessary. If the permit was held by a centralised body, which supervised stocking and harvesting, monitoring by authorities would be simplified. Although the potential for illegal stocking of wild crabs in the ponds would exist, such activities would be discouraged by:-

(a) size and behaviour differences between hatchery-bred and wild stock that might be recognisable at harvest or might increase the level of aggression and cannibalism;

(b) close supervision of farming activities;

(c) stringent conditions for the granting and renewal of farming licences; and

(d) appropriate penalties.

Illegal trafficking in edible-size crabs should not be facilitated by the special permit system, especially if an identifying brand is used for farm grown crabs.

The prospective crab farmer seeking a suitable site in Queensland not only has to consider physical features such as elevation, soil structure and chemistry, water supply, tides and climate (Chapter 4, p. 57 and Chapter 5, p. 63, but also is confronted with a whole range of restrictive legislation dealing with coastal resource use.

In Taiwan and the Philippines, tidal flats have been extensively cleared for construction of fishponds. Very little Crown land is available for leasehold in Queensland, but should a potential site be found, application may have to be made to the local shire council, Water Quality Control Board of Queensland, Department of Primary Industries, Lands Department, Water Resources Commission and Department of Harbours and Marine, depending on the site and type of proposal (DPI 1981). Permits are needed for any construction below HWM (under the Harbours Act 1955-76) and for any road construction, vehicle use, excavation and draining (Beach Protection Authority Act 1967). The Department of Tourism and Housing requires structures to be cyclone-proof. A treatment plant must be provided to ensure effluents discharged from the project do not adversely affect the environment (Queensland Clean Waters Act). Mangroves and other marine plants are protected species (Fisheries Act 1976) and special permission is required for their removal. There are 4 600 km^2 of mangrove forests in Queensland. They have been acknowledged as an important resource that serves as nursery ground for many commercial species, as well as stabilizing the shore and reducing erosion. General government policy is to protect the tidal wetlands, and various areas of the State have been set aside as Habitat Reserves and National Marine Park.

It is, therefore, highly unlikely that an aquaculture proposal based on intertidal ponds would be approved, and, according to the Queensland Department of Primary Industries (1981), proposals should preferably be based on the use of freehold or leasehold land above the level of high water spring tide.

Such locations may suffer some drawbacks, especially of higher cost and availability of land, inability to use tides to fill and drain ponds, necessity for extended intake and outlet channels, pumping costs and lack of suitable substrate. However, there could be several advantages in locating away from the intertidal zone, such as simplified excavation and construction, the ability to drain and clean ponds at any time, the ease of access and proximity to power, water and telephone lines, more acceptable living environment for staff, and the possibility of locating farms closer to the central hatchery and its attendant facilities.

Socio-economic aspects

The feasibility of any crab farming venture will also depend on social and economic factors, which should be examined thoroughly before investment is made. These include costs of land, water, power, construction, labour, transport and materials; for example, crab seeds and feedstuffs.

Apart from the initial outlay, carry-on finance is likely to be limiting to the independent entrepreneur who cannot write off losses and continue to pay employees' salaries during the development period. Investment incentives and other government assistance that is available to new industries could be helpful.

The high cost of labour in Australia compared to costs in Asia is often cited as a major obstacle to aquaculture development. However, farmers in Taiwan and the Philippines also keep their use of hired labour to a minimum for the same economic reason. Instead, most of the daily maintenance and routine work is performed by the owner and/or his family, who usually live on-site. During busy periods, such as harvesting, assistance is provided by a more-or-less loose association of owner-operators and their families.

The organisation of individual owner-operators into co-operatives is an alternative to relying on the involvement of government or large private corporations and would greatly facilitate the development of an aquaculture industry in Queensland. A large production unit consisting of a hatchery and associated farms could significantly benefit from a central pool of equipment and services; for example, seed supply, pond construction, purchase of materials, co-ordinated harvesting and marketing, financing, technical consulting and training of staff. Government assistance, supervision and extension services would also be simplified.

Although the marketing channels through the Fish Board and private sales would seem to be well established, further research should reveal significant potential for diversified marketing of cultivated crabs; for example, inland cities, off-season sales, contract agreements with restaurants, caterers and supermarkets, on-farm selling to the general public, and export interstate and overseas. Development of such new markets would reduce the risk of a general price drop due to increased supplies, and competition with the established fishery would be minimised.

Queensland's current regulations and traditional consumer preference for large-clawed three-year-old male crabs would necessitate out-of-state marketing of the smaller male crabs and females. However, a recent government review (Hill 1982) recommended marketing of female crabs be permitted for a trial period. Female mud crabs with ripe ovaries fetch premium prices throughout Asia. Australia's Asian population and restaurants could be a potential ready-made market.

Establishment of crab farms could also be affected by social conditions. Coastal land and waters are subject to many competing uses; for example, aquatic recreation, commercial fishing, oyster farming, extractive industries, real estate development, waste disposal, passage of vessels and conservation. The siting of farms above the intertidal zone should overcome objections from most of these quarters, provided that external facilities (for example, intake pipes) and activities (for example, effluent disposal) are not disruptive. On the other hand, proximity of some of these activities would not be desirable from the aquaculturist's viewpoint. Water pollution, damage to facilities and poaching would be ever-present dangers.

It should be apparent from the above discussion that crab farming in Queensland is not a suitable investment proposition for those seeking quick returns and minimum risk. Potential investors would be well advised to keep abreast of developments in crab hatchery research in Australia and overseas, for successful mass production of juvenile mud crabs will be the basis of any future industry in Queensland. It would then be desirable to undertake detailed feasibility studies followed by pilot-scale projects before establishment of commercial farms.

As with any new industry, careful planning is essential. With an extra degree of caution to cover the unpredictability of the natural environment, especially when it is not fully understood, the potential for a mud crab farming industry in Queensland should eventually be realised.

CHAPTER 7

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