Marine crustacean farming : present status and perspectives

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Abstract

For centuries, several species of prawns and crabs have been raised from wild-caught juveniles in coastal brackish-water fish ponds in various countries of south east Asia. The Indonesian "tambaks" are well known examples of such traditional practices. In western countries, since the turn of the century, advances of marine biology and fast increase of marine fisheries enabled the development of large-scale production and release of larval stages of American and European lobsters in a fruitless attempt to restock natural populations. After the Second World War, the increasing demand for crustaceans in United States and Japan was satisfied by opening new prawn fisheries all over the world. A major breakthrough was achieved with the development of hatchery technologies for the penaeid prawn *Penaeus japonicus* (Hudinaga, 1942 in Japan) and the caridean prawn *Macrobrachium rosenbergii* (Ling, 1969 in Malaysia), which occurred during the first decades of the second half of this century. Together with the increasing market demand in developed countries for sea food, this led to a considerable interest of both public agencies and private investors in marine shrimp and prawn culture. In western countries, a large number of pioneering commercial ventures, often based on assumptions not scientifically founded, failed. Nevertheless, the aquaculture production of prawns mainly based on wild-caught juveniles increased in South-East Asia and Central America during the 1980s. This overall positive trend should not hide important failures which occurred at a local scale, such as the Taiwanese crisis of 1988 due principally to environmental degradation, resulting in severe disease problems and a near collapse of the farming activity. Following the early period of hatchery technology development, the major scientific achievements were related to food requirements and formulation of compound diets for larvae, juveniles and adults and to a better knowledge of diseases caused by bacteria and several viruses which have been identified from hatcheries and intensive farming ponds. Additional new technological advances have emerged from recent research in the fields of physiology (endocrinology) and genetics. By far, the major part of the world production of marine crustaceans relies on penaeid prawns and, to a lesser extent, on *Macrobrachium* species. However, some other species of marine crustaceans have potential for aquaculture.

The economic aspects of marine crustacean aquaculture should be considered together with those of the fishing industry: market prices are rather similar, depending on the quality of the product. The balance between market demand and production is an important constraint which, in turn, establishes the success of prawn farming. Since the early 1980s, crustacean aquaculture has increased tremendously in both Asia and America: the world production for 1991 approximated 700,000 tons, with more than 600,000 tons from penaeid prawn culture.

Keywords: Crustaceans, shrimps, prawns, crabs, lobsters, aquaculture, exploitation, Penaeidae.

L'élevage des crustacés marins : état actuel et perspectives.

Résumé

Pendant des siècles, quelques espèces de crevettes et de crabes ont été élevées à partir d'individus juvéniles capturés dans le milieu naturel, dans des bassins à poissons d'eau saumâtre de différents pays d'Asie du Sud-Est. Les "tambaks" indonésiens sont des exemples bien connus de ces pratiques traditionnelles. Dans les pays occidentaux, depuis le début du siècle, les progrès réalisés en biologie marine et la croissance rapide des pêches maritimes ont permis le développement de la production à grande échelle de stades larvaires des homards européen et américain, dans une vaine tentative de reconstitution des stocks naturels. Après la Seconde Guerre mondiale, la demande croissante des Etats-Unis et du Japon a été satisfaite par l'ouverture de nouvelles pêcheries de crevettes dans l'océan mondial. Un progrès décisif a été réalisé avec la mise au point des techniques d'écloserie pour la crevette Pénaeidé *Penaeus japonicus* (Hudinaga, 1942 au Japon) et la crevette Caridé *Macrobrachium rosenbergii* (Ling, 1969 en Malaisie), qui sont apparues au cours des premières décennies de la seconde moitié de ce siècle. Parallèlement à la demande croissante du marché des pays développés pour les produits de la mer, ce résultat s'est traduit par un intérêt considérable porté à l'élevage des crevettes marines de la part des institutions de recherche et des investisseurs. Dans les pays occidentaux, un grand nombre de tentatives d'élevage commerciales, fondées sur des considérations non scientifiquement établies, ont échoué. Néanmoins, la production aquacole de crevettes reposant sur la capture d'animaux juvéniles dans la nature, s'est développée en Asie du Sud-Est et en Amérique Centrale au cours des années 1980. Cette tendance globalement positive ne doit pas dissimuler les faillites importantes qui se sont produites à l'échelle locale, comme la crise des élevages de Taiwan en 1988, causée principalement par une dégradation de l'environnement, entraînant l'apparition de problèmes pathologiques sévères et une disparition presque totale de l'activité d'élevage. Après la période pionnière du développement de la technologie d'écloserie, les principaux acquis scientifiques concernent les besoins alimentaires et la formulation d'aliments composés pour les larves, les jeunes et les adultes, et une meilleure connaissance des maladies bactériennes et virales qui interviennent dans les écloseries et les fermes d'élevage intensif. De nouveaux progrès techniques complémentaires ont vu le jour à la suite de recherches dans les domaines de la physiologie (endocrinologie) et de la génétique. De loin, la majeure partie de la production mondiale de Crustacés marins repose sur les crevettes Pénaeidés et, dans une moindre mesure, sur des espèces de *Macrobrachium*. Cependant, quelques autres espèces de Crustacés marins intéressent potentiellement l'aquaculture.

Les aspects économiques de l'aquaculture de crustacés marins doivent être considérés avec ceux de l'industrie des pêches maritimes : les prix du marché sont à peu près les mêmes, et dépendent de la qualité du produit. Le rapport entre la demande du marché et la production est une contrainte importante qui à son tour, détermine les conditions du succès de l'élevage de crevettes. Depuis le début des années 1980, l'aquaculture de crustacés a augmenté considérablement en Asie et en Amérique : la production mondiale pour 1991 avoisine 700 000 tonnes, avec plus de 600 000 tonnes provenant des élevages de crevettes Pénaeidés.

Mots-clés : Crustacés, crevettes, crabes, homards, aquaculture, exploitation, Penaeidae.

HISTORICAL BACKGROUND

One of the most traditional types of aquaculture is the extensive rearing of penaeid prawns on coastal brackish-water fish ponds, that occurs in different countries of South-East Asia, from India to the Philippines, through Malaysia, Thailand and Indonesia. In the Indonesian "tambaks", post-larvae and juveniles of several species of fishes and prawns enter the fish pond freely with tidal flow; during ebb-tide, a gate with small mesh keeps the animals within the pond. The ponds are supplied with brackish-water, and receive some nutrients and plant detritus that enhance natural productivity. After a period of rearing, prawns are easily caught at the entrance of the pond when moving back to the sea. The migratory mechanisms which make the post-larvae enter the pond with the tidal flow and the juveniles return to the sea have been studied in detail for several species such as *Penaeus notialis* in the Caribbean (*see* Hughes, 1969, for experimental studies, and Kurata, 1977 and Garcia and Le Reste, 1981 for general discussion, including large-scale adult migrations in the sea).

The production of such ponds is highly variable, depending on the supply of wild post-larvae and environmental conditions during rearing; it can reach 250 $kg.ha^{-1}$ per crop, *i.e.* 500 $kg.ha^{-1}.y^{-1}$ when two crops are feasible during one year.

With the development of marine biology during the second half of the 19th century, life histories of exploited species such as the lobsters *Homarus americanus* and *H. gammarus* and several species of shrimps and crabs were studied in detail, and the larval stages described. The first indications of over-exploitation of fishing grounds in the North Atlantic and the North Sea led to an attempt to restock depleted populations by releasing in the sea huge numbers of early larval stages. This was done for the lobster by many North Atlantic countries, using egg-bearing wild females, and annual production of more than 15×10^9 larvae at stage 3-4 was reached (a maximum of 17×10^9 larvae were produced in the year 1917). These were released in the sea with no obvious subsequent effect on the fisheries. Nevertheless, this effort was pursued up to the early 1950s in North America, and new approaches based on improved releasing techniques including artificial habitats were developed more recently in France and in the U.K. (Hénocque, 1983; Van Olst *et al.*, 1980).

During the years 1935-1945, several important scientific contributions were achieved: the life cycle of penaeid prawns was analysed in detail by Hudinaga (1942) in the case of *Penaeus japonicus*, and by Heldt (1938) in the case of three Mediterranean species *Penaeus trisulcatus*, *Parapenaeus longirostris* and *Sicyona carinata*, and the morphology of larval (nauplii 1-5 or 6, zoea 1-3 and mysis 1-3) and post-larval stages was described.

In 1943, Panouse demonstrated the accelerating effect of the unilateral eyestalk ablation on both moult cycle length and ovarian development in the case of the caridean shrimp *Leander serratus*. Three decades later, this result was applied to penaeid prawns and became extremely important for the control of spawning of broodstock of several species of penaeids that do not mature or spawn easily in captivity, such as *Penaeus chinensis*, *P. monodon* and *P. vannamei*. Different techniques are commonly used: surgical removal of one of the two eyestalks (extirpation), or of the eyestalk content (enucleation), with different techniques of operation (Liao and Chen, 1983). Concerning the freshwater prawn *Macrobrachium*, Ling (1969) was able to complete the life cycle at laboratory scale in the early 1960s.

RECENT PERIOD

In the beginning of the 1960s, the work of Hudinaga ended in success with the production of the first ton of *Penaeus japonicus* reared in captivity. Offspring were reared from wild females, through 12 larval stages (6 nauplii, 3 zoea and 3 mysis) and 21 post-larval stages (Hudinaga, 1942). The most significant results obtained by Hudinaga are probably the determination of the different food requirements of those stages, beginning with the unicellular algal food required by the zoea. Hudinaga was also the first to develop laboratory culture of the diatom *Skeletonema costatum*. Several decades later, Kittaka (1971) was able to transfer these laboratory techniques to large-scale production, using ponds of 60 to 200 m^3 filled with sea-water enriched by nutrients. Up to 100-200 ripe wild females are placed in these ponds where they spawn; zoea larvae find appropriate concentrations of unicellular algae to feed on. Living food (*Artemia*, zooplankton) is necessary at the end of larval life. Similarly, Fujimura (1966, 1974), working in Hawaii on a few adults of *Macrobrachium rosenbergii* introduced from Penang, was able to develop large-scale hatchery techniques utilizing so-called "green-water" for post-larval rearing. Japanese results were known in western countries a few years after publication by Kittaka (1971). University laboratories, public agencies and private entrepreneurs first tried to transfer directly the Japanese technology and imported ripe females of *Penaeus japonicus* from Japan, generally with poor commercial success. In a second phase, tests were conducted on different species, including indigenous species, while research concentrated on zootechnical problems (hatchery techniques, formulation of compound diets, management of captive brood-stock). After a long screening period of the aquaculture potential of species such as *Palaemon serratus* and a huge number of penaeid species, aquaculture production has increased dramatically since the beginning of the 1980s.

A special mention should be made of restocking programmes. They started at the end of the 19th century, in an attempt to reconstitute overexploited stocks of the American and European lobsters. The techniques were very simple; berried females were kept in tanks and larvae at stage 3 to 4 (which are still pelagic) were released to the sea without any protection. The development of large-scale production of post-larvae of *Penaeus japonicus* encouraged the Japanese authorities to launch an extensive programme of restocking the Seto Inland sea. A network of hatcheries was built specifically for this purpose. Although the programme has been going on for more than twenty years, the economic feasibility of the restocking activity has not yet been clearly demonstrated. Some evidence for the positive impact of restocking had been obtained using chemical analyses (metal content of hatchery produced post-larvae is different from wild post-larvae) and morphological tagging (post-larvae produced in the hatchery are slightly but consistently different from naturally produced ones), with a recapture of 5-8% at market size (New, 1988). Similar programme are developing in other countries for instance in China where 4 billion post-larvae of *P. chinensis* are released annually with a return estimated to be 4.6-8.2% (Rosenberry, 1989).

BIOLOGICAL TECHNIQUES

The following major steps should be considered for most crustacean species farmed:

- obtaining broodstock or seedstock,
- maturation, spawning, hatching, and larval rearing,
- post-larval rearing or nursery phase,
- grow-out culture,
- harvesting and processing.

Broodstock or seedstock are essential to crustacean aquaculture. A conveniently located wild stock can support a large aquaculture industry in different ways: providing wild juveniles for farming and wild females for hatchery operations. One of the best examples is aquaculture in Ecuador, mainly based on the wild stock of *Penaeus vannamei*. Post-larval shrimp are caught by individual fishermen using hand-nets (called "semilleros" in Ecuador). The price of wild post-larvae is much higher than that of hatchery produced post-larvae, due to their better survival rate. Indonesian shrimp aquaculture of *Penaeus monodon* is also largely based on wild seedstock, whereas small and medium-scale hatcheries starting with wild ripe females are developing. The utilization of captive broodstock reared in grow-out ponds is developing for a few large-scale hatcheries, due to the increasing price and availability of wild females. This method applies to those species that breed and spawn easily in captivity.

In hatcheries, security and predictability are necessary conditions for the success of post-larval production. Major biological differences exist between penaeid prawns that spawn a large number of free eggs that hatch a few hours later and caridean shrimps or Reptantia (lobster, crayfish) that bear a smaller number of eggs for weeks or months until hatching time. In both groups, some species mature, mate and spawn easily in captivity, while others require controlled environmental conditions or endocrinological manipulations to breed. Below are some examples of these differences, which are of great influence on the structure and operating costs of the hatcheries:

Species that breed readily in captivity: *Penaeus indicus, P. merguiensis, Macrobrachium rosenbergii.*

Species that require environmental or endocrinological manipulations: *Penaeus chinensis, P. japonicus, P. monodon, P. stylirostris, P. vannamei, Pandalus platyceros, Homarus americanus.*

Environmental manipulations make use of controlled photoperiod and thermoperiod. In the case of penaeid prawns, the effect of photoperiod has been established for *Penaeus japonicus* (Laubier, 1975), and has been extended to other penaeid species. Seasonal inversion is easy to achieve using this technique, which gives very high survival rate. Unilateral eye-stalk ablation is commonly used with either wild or captive females, but it results in lower survival rate.

In the case of captive broodstock, the productivity (% of larvae at 1st stage produced) is in the range of 30-80% for penaeids, 50-80% for *Macrobrachium*, 30% for lobsters and 4-80% for crabs. The average survival during larval life is in the range of 50-80% for penaeids, 30-60% for *Macrobrachium*, 20-60% for lobsters and 4-70% for crabs. During the post-larval and juvenile periods of rearing, the survival is higher, ranging from 70-90% for penaeids, *Macrobrachium* and lobsters, and 20-70% for crabs. Combined survival rate from the egg to the juvenile demonstrates the importance of high fecundity: 10-58% for penaeids (differences in specific behaviour are responsible for this large variation), 10-43% for *Macrobrachium*, 4-16% for lobsters and 0.3 to 39% for crabs. From hatching to harvest, the average figures are as follows: 36% for penaeids, 18% for *Macrobrachium*, 25% for lobsters and 8% for crabs (Lee and Wickins, 1992). In the case of lobsters, cannibalism is a major problem and rearing requires individual chambers.

Studies on prawn nutrition enabled definition of the main requirements for proteins, lipids (steroids, fatty acids) and sugars. The optimal protein content for *Penaeus* species varies from 30% (*P. vannamei*) to 55% (*P. japonicus*). Amino-acid requirements have been determined for several species of shrimp and prawns. Penaeid requirements for the essential fatty acids have been extensively studied in the case of *P. japonicus*, where linoleic acid (18:2 n-6), linolenic acid (18:3 n-3), icosapentaenoic acid (20:5 n-3) and decosahexaenoic acid (22:6 n-3) are essential components and must be present in the diet. Similar results have been obtained for *P. monodon* and *P. merguiensis*. Farmed crustaceans are not able to synthesize sterols de novo from acetate and mevalonic acid, and sterol requirements have been also determined. One per cent of cholesterol in the diet is generally sufficient. Phytosterols have also been used as substitutes for cholesterol in the diet. A few vitamin requirements have been determined: ascorbic acid, choline, inositol, riboflavin, and thiamine. Several reviews have been published on shrimp and prawn nutrition (New, 1976; Akiyama and Dominy, 1989; Chuang, 1990).

A number of shrimp feed formulas have been developed in the past 20 years. The following table shows the formulas of two typical dry compound grow-out feeds (1/5th of water is added to the ingredients prior to extrusion and the moist pellets are dried at 60°C overnight in an oven) and of one semi-moist grow-out food used with *P. monodon* (from New, 1990):

Dry compound grow-out feed for *Penaeus monodon*:

	Formula 1	Formula 2
Shrimp meal	15.00	27.50
Fish meal	30.00	27.50
Extracted soybean meal	15.00	-
Rice bran	15.00	20.00
Bread flour	15.00	15.00
Sago palm starch or corn starch	5.00	5.00
Oil (fish liver and soybean oil in 1:1)	4.00	4.00
Vitamin/mineral mix	0.95	0.95
Vitamin C	0.05	0.05
Total	100.00	100.00

Semi-moist grow-out food:

Fish meal (55% crude protein)	10.00
Shrimp head meal	15.00
Wheat pollards	36.75
Vitamin mix	1.25
Water	37.00
Total	100.00

The main economic constraints of such formulas come from the high quantity of fish meal (average 30%) and shrimp meal (average 15%), which are rather expensive ingredients. With such feeds, the food conversion rate ranges from 1.7 to 2.2. As a result, 300 g of fish meal, corresponding to 1 kg of raw fish, is necessary for 1 kg of feed, which produces 500 g of prawn meat; 2 kg of fish for 1 kg of prawn. Using such feeds, depending on species of penaeid prawn, growth is very fast. The following average figures are considered successful by aquaculturists: from 1 to 18 g for *P. vannamei* in 4.5 months (1g.week^{-1}), from 1 to 30 g for *P. monodon* (2g.week^{-1}) in 4 months.

It must be emphasized that captive broodstock need a special feed including at least 5% of squid meal or head and waste of shrimps for ovarian development.

One of the major achievements of these last ten years was the so-called artificial plankton, *i.e.* microparticulated diets, which diameter ranges from 5-30 to 40-90, 90-150 and 150-250 μm. Microparticulated diets are given at the second zoea stage, together with some microalgae or yeast. Before that development, hatcheries had to produce daily huge quantities of live food, such as the rotifer *Brachionus* and the branchiopod *Artemia* at different development stages.

The technical constraints to the development of penaeid culture, except for the problems of bacterial and viral diseases, are relatively minor. The main ones deal with the control of broodstock and seedstock quality. Research is centred on induction of spawning in wild ovigerous females, induction of maturation in pond-reared adults and wild non-ovigerous females, rematuration and conditioning of previously spawning wild adults and pond stock. Nutritional research concentrates on compound diets for captive broodstock, grow-out feed and microparticulated diets. Growth might also be increased through hormonal treatment. In the field of environmental issues, recent failures in different South-East Asian countries demonstrate the need for a better knowledge of ecotoxicology of cultured species.

The achievement of domestication and the perspectives of selective breeding seem less promising than 15 years ago: it has been shown with several crustacean species that improvements through selective breeding programmes may be limited and may take a long time to achieve. The natural genetic variability of most penaeid prawns is low, and hybridization has not yet been achieved, unlike the lobsters, where it is probably the easiest way to introduce variability. Surgically sex-reversed freshwater *Macrobrachium* have been produced at a laboratory scale (Malecha, 1983), and similar programmes should be tested in other groups.

DISEASES OF CULTURED PENAEIDS

The development of commercial culture of penaeid shrimps has been accompanied by the occurrence of infectious and non-infectious diseases. In the early 1970s, a few diseases had been identified: the fungus *Fusarium*, responsible for black gill disease of *Penaeus japonicus*, which is likely to appear in intensive conditions, chitinolytic bacteria producing erosion of the cuticle and several phycomycetes such as *Lagenidium* and *Sirlopidium*. Fungal zoospores attach to and encyst upon the cuticle of an egg or larval shrimp. The encysted spore then germinates, with the germ tube penetrating the cuticle. The mycelium grows from that point, until the egg or larva is completely filled with hyphae. Several epicommensals are also known.

This situation changed drastically with the increasing use of intensive culture systems that often encourage the development and transmission of many diseases (Lightner, 1983). Several viral diseases of cultured penaeid shrimps are now known, and some of them have been at least partially described. Other viruses have been found in certain other groups of Crustacea. Major groups of viruses represented in Crustacea include Reoviridae, Picornaviridae, Baculoviridae, Paramyxoviridae, Rhabdoviridae and Iridoviridae. While no Chlamydiae occur in penaeids, they are known in crabs and amphiphods. Rickettsiae occur in penaeids as well as in crabs and amphipods (Brock in Sindermann and Lightner, 1988).

The penaeid baculovirus infects the epithelial cells of the hepatopancreas and, less commonly, the anterior midgut. Typically, the disease results in high mortality in the larval, post-larval or early juvenile stages, but it may also be present in older animals. *Baculovirus penaei* occurs in the Gulf of Mexico and on the Pacific Coast of Central America, in several species of shrimps: *Penaeus duorarum, P. aztecus, P. setiferus, P. vannamei* and *P. stylirostris*. *Monodon baculovirus* is known from the Philippines and Taiwan, where it occurs in *P. monodon*. Another *Baculovirus* occurs in *Penaeus japonicus* and causes necrosis of the midgut gland. Another recently discovered virus infecting *P. stylirostris* may be a *Parvovirus*. Many of the viruses can be diagnosed by the demonstration of polyhedral inclusion bodies in the nucleus of the infected cells.

Numerous bacterial diseases have been reported in Crustacea. The majority are of a secondary etiology. The only primary bacterial disease in cultured Crustacea is gaffkemia disease (*Aerococcus viridans* var. *homari*). In other reported cases of bacterial infections, motile Gram-negative, oxidase-positive, fermentative rods have been isolated and identified (*Vibrio, Pseudomonas, Aeromonas*). In shell disease, the erosion and penetration of the cuticle can result in septicemia and death. Other bacterial diseases may occur as localized abscesses in viscera, muscle, gills, or as generalized septicemia. Successful treatment of such infections has been reported by direct additions of certain antibiotics to the water (larval rearing) or to the diet (juvenile or older shrimps).

As said above, fungal infections are frequent in larvae of penaeid prawn. They can be controlled using trifluralin with or without water filtration to prevent the presence of zoospores. *Fusarium solani* may cause heavy losses in intensive culture of prawns. There is no effective chemotherapy against this fungus. Rearing in low density, with well-oxygenated water and sediment, may prevent *Fusarium* infection from developing.

Several epicommensals such as the bacteria *Leucothrix*, the ciliates *Zoothamnium* and *Epistylis*, occur on penaeid prawns. They affect all life stages and can cause significant mortalities.

Other diseases may have nutritional or environmental causes. The black death disease is produced by ascorbic-acid deficiency. The presence of aflatoxin B_1 in the feed causes aflatoxicosis with necrosis of the hepatopancreas, mandibular organs and hematopoietic organs. Gas-bubble disease can occur in penaeid prawns as a result of supersaturation of atmospheric gases in the water, nitrogen and oxygen (dissolved oxygen levels at 250% of normal saturation in seawater of 25°C and 35 ppt may cause oxygen-caused gas-bubble disease). Cramped tail occurs at high temperature and salinity, muscle necrosis occurs after periods of severe stress. Toxic disease caused by diatom or dinoflagellate blooms have also been reported.

For the future of shrimp farming, diseases should be considered as one of the major constraints to progress in semi-intensive and intensive rearing systems. The present practices (repeated introduction of disease-carrying shrimps into a given area, lack of quarantine of imported stocks) could cause a serious threat, not only to cultured animals, but also to shrimp fisheries. Recently, vaccines against vibriosis and other bacterial diseases have been developed. However, the virus problem remains unsolved.

ENVIRONMENTAL ISSUES

Several ecological and environmental impacts can be created by shrimp aquaculture. Apart from the effect on the broodstock, and in special cases on the seedstock, several failures have been encountered with the development of large-scale culture of shrimp. In hatcheries, antibiotics or any effective chemical have been used to help overcome bad husbandry. Typically, therapeutic abuse starts with the use of low concentration of a broad spectrum antibiotic in the early period, continues through increasing the concentration as the resistance of the disease organisms rises, then with a change to another antibiotic, and later to a combination of antibiotics, until all treatments become ineffective. At this stage, the whole hatchery must be chlorinated and "dried out" (Chamberlain, 1988). Such practices may also give rise to more disease-susceptible post-larvae, because many will have developed from weak larvae artificially protected from diseases by the antibiotics. Continuous use of wide-spectrum antibiotics will also encourage the development of lasting resistance in pathogens. Although such practices can be accepted in the framework of preliminary zootechnical trials, they should be strictly avoided during the production and marketing period.

Depending on the topography and porosity of the substrate, groundwater extraction may cause saltwater intrusion into domestic freshwater sources. Such a phenomenon was reported on the Mediterranean coast of Israel some years ago. Nevertheless, excessive extraction of groundwater to lower the salinity in

Table 1. – Examples of crustacean culture options (after Lee and Wickins, 1992).

	Location	Annual yield ($kg.ha^{-1}$)	$Crops.y^{-1}$	Live weight (g)
	In tropical climate			
Extensive culture				
Penaeus monodon	India	1 000-1 500	2-3	26-39
P. vannamei and *P. stylirostris*	Ecuador	240-1 200	2-3	19-22
Scylla serrata	Philippines	399	1-2	> 200
Semi-intensive pond culture				
P. monodon	S.-E. Asia	2 044	2-6	28
P. stylirostris	New-Caledonia	3 000	1 (6 m.)	18-25
P. vannamei	Ecuador	1 150-1 725	2-3 (?)	15-25 (?)
Macrobrachium rosenbergii	Thailand	2 000-2 500	continuous	36
Scylla serrata	Taiwan	up to 1 800	2-3	200-300
Intensive pond culture				
P. monodon	Thailand	4 000-12 000	2	33
P. penicillatus	Taiwan	4 298-12 286	1 (6 m.)	9.5-12.3
Intensive cage culture				
P. merguiensis	Singapore	20-30 000	2	12
Panulirus versicolor	India	up to 1 800	1-1.5	220-310
Super-intensive culture				
P. japonicus	Japan	20-30 000	1	20
P. vannamei ([1])	Hawaii	up to 45 000	3	15.7
	Culture in Mediterranean climate			
P. japonicus	France	210-590	1	15-25
P. japonicus	Italy	189-525	1	25-30
P. semisulcatus	Israel	739-2 740	1	7-21
M. rosenbergii	Israel	up to 2 800	1	20

([1]) Super-intensive methods in Hawaii were developed with *stylirostris* and later applied to *P. vannamei*.

Table 2. – World production of crustaceans from 1958 to 1988 (in 1 000 t) (compiled from Laubier and Laubier, 1988; Lee and Wickins, 1992).

	1958	1966	1978	1985	1988
Freshwater species					
Crayfish	?	?		8.8	52.8-100
Freshwater prawns	?	?	91.3 ([2])	143 ([3])	48.5
Sea water species					
Shrimps/prawns	537	757	1 669.1	1 902.6	2 028-2 484 ([4])
Crabs	197	365	760	887	1 048
Lobsters	36	32	40.5	55.5	64.5
Spiny lobsters	43	59	68	83.8	78.6
Other "lobsters" ([5])	32	45	69.9	71.7	80.6
Total	**845**	**1 258**	**2 698.8**	**3 152.4**	**3 299.7-3 802.9**

([2]) This figure relates to crayfish and freshwater prawns.
([3]) Figures for 1985 production of freshwater fisheries given by FAO are not in accordance with general trend for freshwater fisheries.
([4]) The second figure includes species not identified precisely in the FAO statistics.
([5]) Including Norway lobsters and galatheids.

shrimp ponds occurred over a wide area in Taiwan, and eventually led to a slight land subsidence. Intensification of pond-use and prolongation of the on-growing period to produce larger animals led to reduction of the time allowed for pond bottom rejuvenation. Such practices, coupled with pollution from industry, agriculture and shrimp farm effluents and development of a *Baculovirus* disease, were responsible for a major crisis of shrimp aquaculture in Taiwan. In 1987, production reached 100 000 t of *Penaeus monodon*; it dropped dramatically to 30 000 t in 1988 and then to 20 000 t in 1989, because of high mortality rates and growth inhibition. The first sign of recovery came in 1990, when intensive farms were relocated from the southwest to the northwest and northeast of the country, and farmers lowered densities of *P. monodon* or switched to *P. penicillatus* and *P. japonicus*. In 1991, production reached 30 000 t.

Problems may also come, as in other types of aquaculture, from agricultural waste (manure, pesticides), pollution and chemicals. Some difficulties appeared in Thailand in 1989-90, mainly due to pollution, overstocking and poor drainage. New licensing requirements and stricter pollution control have been instituted by the Government. Still, due to the high level of an antibiotic (oxytetracycline) in farm-raised shrimps from Thailand, the Japanese Health Authority instituted an inspection programme for all shrimps imported from South-East Asia countries (Rosenberry, 1991).

CULTURE OPTIONS

Different culture options have been developed in tropical environments, ranging from extensive to super-intensive culture, through semi-intensive and intensive. Some typical examples of these different practices are given in *table* 1.

Some attention should also be paid to polyculture of several species of penaeids in the same pond (India), to the production of soft-shelled crabs from wild or cultured stocks, and to restocking and stock enhancement programmes.

PRODUCTION TRENDS

World production of crustaceans has increased rapidly since World War II, due to the increasing demand from industrialized countries, in particular the United States and Japan. An important part of this increase has come from penaeid and crab fisheries, as shown in *table* 2.

The increase in production from prawn, shrimp and crab fisheries has been remarkable, with a five-fold growth for the total period of thirty years.

Crustacean aquaculture based on scientific biological technologies is generally considered as a recent achievement, although traditional on-growing of shrimps and crabs in coastal tropical fish ponds goes back several centuries. Even after World War II, during some twenty years following the creation of the FAO, the production of marine crustaceans by farming was not distinguished from fisheries landings in the yearly statistics published by that international organization. Thus, it was rather difficult to assess the contribution of aquaculture to total production. One of the first attempts to measure the production of aquaculture was made by Pillay (1979) for the year 1975 (*table* 3). The figures given for crustaceans (as well as for molluscs) are probably much lower than the actual production.

Table 3. – Crustacean production by aquaculture for year 1975 (from Pillay, 1979).

	t
Penaeid prawns	17 000
Macrobrachium	1 000
Crayfish	2 500
Total	20 500

Table 4. – Crustacean production from aquaculture for 1983 to 1990 (compiled from Laubier and Laubier, 1988; Lee and Wickins, 1992).

	1983	1988-1990
	t	t
Marine shrimps and prawns	116 110	511 454-663 000 ([1])
Freshwater prawns	3 000	10 000-19 387
Freshwater crayfish	?	32 263
Lobsters	0	0 ([1])
Spiny lobsters	0	49
Crabs	?	3 277-7 000
Artemia	?	350

([1]) Yields from restocking programmes, which should be given in number of juveniles released rather than in weight produced, are not included.

At that time, in the case of the primitive types of aquaculture in coastal brackish-water ponds of South-East Asia, it was not easy to distinguish between fishing and farming activity. Moreover, it was often difficult to collect realistic figures of production at the national level: local consumption and lack of organized markets resulted in under-evaluation of aquaculture production.

More accurate estimates were produced and published by FAO some years after the FAO international Congress on Aquaculture held at Kyoto in 1976. Since the beginning of the 1980s, reliable figures are available from national sources and adequately compiled by FAO and specialised organizations. *Table* 4 shows figures of production of crustaceans by farming for recent years.

Within the total period of seven years (1983-90), the production of penaeid prawns by farming has been multiplied by six times, and the production of freshwater prawns (*Macrobrachium* spp.) by a slightly higher figure. Comparison with fishery production for 1990 clearly demonstrates the importance of aquaculture crops, which represents approximately one quarter of the whole shrimp and prawn production from fisheries and aquaculture. The last figures available for penaeid prawns and freshwater *Macrobrachium* for 1991 show similar progress, with 690 100 t for the former and 25 970 t for the latter. Lobster and spiny lobster production remains at a very low level, while crab farming (mainly the mud crab *Scylla serrata* and the swimming crab *Portunus trituberculatus*) is developing in south-east Asia.

During the last fifteen years, marine crustacean aquaculture expanded remarkably in different countries of the world, especially South-East Asia and South and Central America. Science and technology contributed to this fast development, together with the dissemination of old oriental practices from South-East Asia in western temperate countries, where no tradition of marine crustacean farming existed. The specific composition of penaeid world production (*table* 5) demonstrates the importance of three species amounting to 78% of the total, with one species

Table 5. – Specific composition of the world production for 1991 (from World Shrimp Farming 1991).

Penaeus monodon	43%	Asia (China excluded)
Penaeus chinensis	18%	China
Penaeus vannamei	17%	Ecuador

Other important species are: *P. stylirostris*, *P. japonicus*, *P. penicillatus*, *P. merguiensis* and *P. indicus*.

Other farmed species are: *P. subtilis*, *P. brasiliensis*, *P. paulensis*, *P. setiferus*, *P. duorarum*, *P. occidentalis*, *P. schmitti*, *P. californiensis*, *P. semisulcatus*, *P. latisulcatus*, *Metapenaeus monoceros*, *M. dobsoni*, *M. affinis* and *M. brevicornis*.

Table 6. – World aquaculture production of penaeids for 1991 (from World Shrimp Farming 1991).

	% world production	Production (in tons)	Hectares in prod.	kg/ha	Number of hatch.	Number of farms
America	19.4	133 600	174 250	767	207	2 055
Asia	80.6	556 500	819 500	679	4 501	34 340
Total	100	690 100	993 750	696	4 708	36 895

(*Penaeus monodon*) representing nearly half of world production.

An analysis of world shrimp and prawn production for 1991, country by country, has been recently published (Rosenberry, 1991). It shows the importance of South-East Asia compared to America (*table* 6).

Large-scale hatcheries and large farms in smaller number characterize American penaeid aquaculture compared with the Asian one. For 1991, the world aquaculture penaeid production amounted a total of 690 100 t.

Tables 7 and 8 show the aquaculture production of penaeids country per country, in both Asia and America. A special mention should be made for the four leading countries: Ecuador (100 000 t), China

Table 7. – Penaeid aquaculture production in Asia in 1991 (from World Shrimp Farming 1991).

	% world production	Production (in tons)	Hectares in prod.	kg/ha	Number of hatch.	Number of farms
China	26.1	145 000	140 000	1 036	1 000	2 000
Indonesia	25.2	140 000	200 000	700	250	20 000
Thailand	19.7	110 000	80 000	1 375	2 000	3 000
India	6.3	35 000	65 000	538	16	2 500
Philippines	5.4	30 000	50 000	600	250	3 000
Vietnam	5.4	30 000	160 000	188	120	1 000
Taiwan	5.4	30 000	8 000	3 750	800	2 000
Bangladesh	4.5	25 000	100 000	250	0	1 000
Japan	0.6	3 500	500	7 000	40	165
Others	1.4	8 000	16 000	500	25	175
Total	100	556 500	819 500	676 ([1])	4 501	34 340

([1]) Average.

Table 8. – Penaeid aquaculture production in America in 1991 (from World Shrimp Farming 1991).

	% world production	Production (in tons)	Hectares in prod.	kg/ha	Number of hatch.	Number of farms
Ecuador	74.9	100 000	145 000	690	150	1 700
Colombia	6.7	9 000	4 000	2 250	20	30
Mexico	3.7	5 000	5 000	1 000	6	100
Honduras	3.4	4 500	7 000	643	2	25
Panama	3	4 000	4 000	1 000	6	40
Peru	2.6	3 500	4 000	875	3	60
U.S.	1.2	1 600	450	3 556	3	25
Others	4.5	6 000	4 800	1 250	17	75
Total	100	133 600	174 250	767 (1)	207	2 055

(1) Average.

Table 9. – Structure of penaeid aquaculture in Indonesia for the year 1991 (from World Shrimp Farming 1991).

Total production (t)	140 000	Hectares in production	200 000	Production in $kg.ha^{-1}$	700
Number of farms	20 000	Number of hatcheries	250	Species	
% extensive	50	% small scale	55	*P. monodon*	60%
% semi-intensive	40	% mid scale	35	*P. merguiensis*	20%
% intensive	10	% large scale	10	Others	20%

Table 10. – Structure of penaeid aquaculture in Ecuador for the year 1991 (from World Shrimp Farming 1991).

Total production (t)	100 000	Hectares in production	145 000	Production in $kg.ha^{-1}$	690
Number of farms	1 700	Number of hatcheries	150	Species	
% extensive	60	% small scale	25	*P. vannamei*	90%
% semi-intensive	25	% mid scale	50	*P. stylirostris*	10%
% intensive	15	% large scale	25		

(145 000 t), Indonesia (140 000 t) and Thailand (110 000 t).

Detailed analysis of the production structure (number and size of hatcheries and farms) in the two major shrimp producing countries in Asia and America, *i.e.* Indonesia and Ecuador, reveal important differences in the average size of both hatcheries and farms (*tables* 9 and 10). Whatever these differences, it is interesting to underline that national average production per hectare is very similar in the two countries: 700 $kg.ha^{-1}$ in Indonesia, and 690 $kg.ha^{-1}$ in Ecuador.

COST ANALYSES

The following cost analyses figures for cultured penaeid prawns have been compiled by Lee and Wickins (1992) from different published sources related to given situations in certain countries. They should not be considered as reference data, but useful examples of approximate costs of shrimp farming.

Operating costs for a hatchery (*table* 11) comprise the following items: labour (33.1%), depreciation (16.1%), broodstock (11.9%), feeds (11.8%), miscellaneous (9.8%), energy (7.8%), maintenance (7.1%) and chemicals (2.4%). The differences in production costs of post-larvae are remarkably high ranging from nearly 1 to 6, mainly depending on labour cost in the various countries.

Operating costs for a large Ecuadorian farm of *Penaeus vannamei* (*table* 12) comprise the following items: post-larvae or "seed" (23.3%), feed (21.1%), depreciation (18.1%), labour (10.4%), miscellaneous (9.1%), interest (8.8%), maintenance (4.0%), energy (3.8%), land lease (1.4%). Compared with the hatchery operating cost, seed and feed represent nearly 45% of the total, instead of 22% for broodstock and feed in the case of the hatchery, while labour represents only 10% of the operating costs of the farm, instead of 33% for the hatchery.

Differences in production cost of post-larvae (from 1 to 9) and of 1 kg of fresh shrimp (1 to 10) reflect national differences and the effect of farm size.

WORLD CRUSTACEAN MARKET

Interest in crustacean aquaculture was stimulated by the high value of these food products. Demand for crustaceans has grown rapidly in western developed countries and in Japan, while fisheries yields have remained stable or increased at a much slower rate. This situation encouraged farming activity to develop in different countries. The ability of aquaculture production to influence price and market conditions was clearly demonstrated by prawn farming which, within less than 15 years, was able to oversupply world demand and to reduce prices. This, in turn, enabled shrimp and prawns to enter in the mass market of some developed countries.

Marine prawns are mainly consumed in three large areas of the world. Consumption of the total world production (around 2.8 Mt) is dominated by Japan, the USA and western Europe, which account for 85% of this consumption. The Japanese are still the largest consumers of seafood, with around 80 kg per capita and per year, of which 2 kg are shrimps and prawns. Demand is still increasing, and Japan imported 261 000 t in 1988, mainly frozen and headless. A small but expensive section of the Japanese market is for live *Penaeus japonicus* , which are sold at a price that is four times higher than frozen shrimp.

The United States market is influenced by the fisheries of the Gulf of Mexico. The consumption of prawns is 1.3 kg per capita and per year. Importations come from Central America and South-East Asia. Importation from China is increasing.

Table 11. – Operating and investment costs for shrimp and prawn hatcheries (from Lee and Wickins, 1992).

Species	Location	Output (millions per month)	Post-larvae age (day)	Operating cost (US$.y^{-1})	Investment	Production cost (US$ per 1 000PLs)
Penaeus monodon	Philippines	0.05	35	11 000	6 000	18.33
P. monodon	Indonesia	0.25	16	7 700	1 400	2.57
P. monodon	Philippines	0.83	21	112 000	113 000	11.24
P. vannamei	Ecuador	4.58	7	257 000	766 000	4.68
P. vannamei	Ecuador	16.70	7	836 000	1 326 000	4.17
Penaeus sp.	USA Texas	45.00	5	3 311 000	3 562 000	6.13
M. rosenbergii	Tahiti	0.83	-	189 000	336 000	18.98
M. rosenbergii	Fr. Polynesia	1.25	-	196 000	412 000	13.07

Table 12. – Operating and investment costs for penaeid farms (from Lee and Wickins, 1992).

Species	Location	Output (mt.y^{-1})	Output (kg.ha^{-1} crop^{-1})	Stocking density (no.ha^{-1})	Operating cost (US$.kg^{-1})	Total investment (US$)
P. monodon	Indonesia	2.0	1 000	25 000	1.53	281
P. monodon	Australia	7.2	1 200	80 000	11.96	235 400
P. monodon	Thailand	14	1 000	150 000	3.21	30 912
P. monodon	Taiwan	18	6 000	200 000	7.03	78 000
P. monodon	Malaysia	42.0	1 667	67 000	3.98	241 752
P. monodon	Thailand	583	3 600	200 000	4.04	2 608 000
P. monodon	Indonesia	1 152	5 000	375 000	5.5	10 972 168
P. vannamei	Ecuador	11.0	1 100	40 000	1.80	
P. vannamei	USA Texas	51.2	1 066	135 580	11.74	503 522
P. vannamei	Ecuador	369	909	60 000	2.91	576 114
P. vannamei	Ecuador	2 721	853	60-70 000	3.48	5 672 000
P. stylirostris	USA Texas	67.6	1 409	200 000	7.71	503 522
P. japonicus	Japan	50.0	-	-	9.49	660 000

The European market relies heavily on cold-water shrimps (*Pandalus borealis, Crangon crangon*) and importations of warm-water penaeids. The consumption of prawns and shrimps in Western Europe is only 0.5 kg per capita per year. This figure, much lower than Japanese and American figures, has increased in the past few years.

The world market for freshwater giant prawn *Macrobrachium* is a combination of producing South-East Asia countries (specially Thailand, which consumes one-third of its production, and Taiwan) and importation by Japan, USA and Europe.

CONCLUSION

Crustacean aquaculture is a high-risk activity, with good prospects for profit, but also potential for heavy losses. Limitations come mainly from supply of "good quality" seedstock and broodstock, which is probably linked with nutrition requirements not completely understood to obtain high quality broodstock. Wild post-larvae and wild ripe females give better results than post-larvae produced in the hatchery and broodstock reared in growing ponds. Diseases and environmental issues become important constraints. Interaction between chemistry of the water, pond bottom constitution, diet composition, crustacean shell mineralization, internal ionic regulation, is incompletely understood, resulting in the reversible condition known as soft-shell or crinkle-shell.

However, the rise of the production of crustaceans by farming in the past fifteen years is remarkable, especially in the case of penaeids. The demand should continue to expand in the future, as long as the economies of Japan, United States and European countries remain healthy. Scientific achievements such as sex ratio control in *Macrobrachium* or the recent success of spiny lobster culture from the larval stage also look promising.

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