

## Overview of Penaeid Culture Research: Impact on Commercial Culture Activity

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**Abstract** The paper gives a comprehensive review of the state of penaeid culture research, its impact on commercial activity, and the major research efforts required to solve remaining problems. After providing a brief historical perspective and describing the dominant penaeid species under culture, the paper discusses the major components or phases of a production system: constitution of broodstock and maturation, larval and postlarval rearing, pregrowing in nursery systems, and grow-out. The extensive, semi-intensive and intensive grow-out systems are described including applied research on fertilization, water management, feeding, etc. needed to support these systems.

Artificial diets (pellets, microcapsules) in relation to basic nutritional requirements and diseases (nutritional, environmental or caused by pathogens) in the larval rearing, grow-out and other production phases, and their respective research priorities are discussed. Lastly, the need for fundamental research in shrimp physiology, digestion, ecdysis, maturation, hormones, pheromones and genetics to complement applied research is highlighted.

### Introduction

Shrimp culture has shown tremendous development in the last ten years due to a constant increase in shrimp demand and limited supply in the world market. It has appeared clearly to many investors that the gap could not be filled by fishery catches which are on the decline due to overfishing and increasing operating costs. Shrimp farming is becoming a new agricultural industry for both developed and developing countries. Of total shrimp production estimated to be around 1.7 million tons, shrimp culture which produced under 1,000 tons in the late sixties increased to around 58,000 tons (3% of world supply) in 1983 with projections of over 400,000 tons (18% of world supply) in 1990 (Branstetter, 1983; Vondruska, 1984).

If traditional extensive culture in Southeast Asia has emerged from the skill of the local people, recent developments in different countries derive from or are dependent on research results and technological breakthroughs.

The work of Fujinaga in 1933 (Hudinaga, 1935) opened the way to modern shrimp farming but it was only in the early sixties that the first commercial farms were built in Japan. In the beginning, the culture technique was entirely dependent on wild-caught postlarvae or gravid females, water exchange by tidal action, and natural productivity. We are now able to control the whole system — complete constitution of broodstock in captivity through successive generations, mass production of postlarvae at low cost, pregrowing of high quality juveniles, water management control by pumping and aeration, feeding with artificial diet using local products and byproducts, and medium- to high-density growing systems. All the forms of culture exist worldwide from the extensive to the highly intensive ones and yields range from 100 kg to more than 40 ton/ha/yr. At present, most of the

commercial production is harvested from semi-intensive culture in earth ponds with mean yield of around 2 ton/ha/yr relying largely on wild-caught postlarvae.

In most cases the first commercial projects in the seventies demonstrated a lack of reliability in the culture technique, the difficulty of integrating different components of the system, and have brought back to research many new questions and problems. The rate of development of this new activity and success or failure of many projects will depend on the capacity of the research sector to take charge of these problems through strong cooperation with the producers.

This review deals with the state of the research, its existing input on commercial activity and tries to identify the remaining problems to be solved and the major research efforts in the next few years.

The main steps in a complete production system are: constitution of broodstock in captivity, reproduction, larval rearing, pregrowing and grow-out to commercial size (15-40 g). For each of these phases, research has to answer the same basic questions about feed, water quality control and management, disease control, physiological problems, technology of rearing systems, and harvesting.

### Dominant cultured species

Almost all the different penaeid species of commercial importance have been tried under culture conditions by groups of researchers or producers worldwide (Wickins, 1976). There is no clear relationship between natural growth rates in the wild and growth performance in culture. Some species which are dominant in a fishery just disappear or do not grow when in ponds, while others of minor importance have good survival and rapid growth.

Until recently, shrimp farming was completely dependent

on the presence of native species for wild postlarvae or wild-caught gravid females but the possibility of constituting broodstock in captivity now allows the rearing of species far from their natural area of distribution.

Culture conditions are different for each species in terms of water salinity (10-40 ppt) and temperature tolerance (18-33°C), soil substrate conditions, tolerance to high density, and protein level requirement in the feeds. The final commercial size varies from 10 to 45 g according to species and rearing techniques. The present dominant cultured species are numerous and reflect mostly the presence of native species (Japan, Korea, Southeast Asia, Central and South America). Shrimp culture is now appearing in countries with no local species (France, Hawaii, Tahiti, Caribbean Islands) and some exotic species are replacing local species because of better economic prospects and growth performance (USA, Spain, Italy, Brazil, New Caledonia). This recent trend will increase and in the future, it is possible that only three or four species will be cultured.

For temperate waters, the best species are *Penaeus japonicus* (Shigueno, 1975), *P. orientalis* and *P. setiferus* which are mainly cultured in Japan, Korea and USA, respectively. *P. japonicus* is also reared under extensive conditions in Brazil, France, Spain and Italy where it has been introduced. This species has received much attention from different groups of researchers and most of the data on penaeids under culture conditions have come from its study. For the tropical zone, the dominant species are different in the Southeast Asian countries (ASEAN, 1978) and the Americas (Rosenberry, 1983, 1984). The giant Indo-Pacific tiger prawn, *P. monodon* (Liao, 1981), *P. indicus*, *P. merguensis* and some species of *Metapenaeus* (*M. monoceros*, *M. ensis*) are the dominant cultured species in India, Taiwan, the Philippines, Indonesia, Thailand and Malaysia. *P. vannamei* and *P. stylirostris* are the two cultured species in Ecuador and Panama (Pretto, 1983). *P. semisulcatus* is tolerant to high salinity and reared in the Middle East countries (Farmer, 1979).

Three species now form the bulk of world production: *P. monodon*, *P. vannamei* and *P. japonicus*. Other species like *P. schmitti* in South America or some Australian species which could tolerate low temperature conditions should be tested.

According to the environmental conditions, rearing techniques, production economics, and market, it is then possible to select the best species. In some cases two could be chosen, one for winter time and the other for summer, since optimum growth is strictly correlated with temperature.

In the next few years, it seems necessary to define for each species the optimum culture conditions according to the rearing phase and to test new species to increase the geographical range of culture. For some species with wide distribution, the characteristics of different strains must be investigated to select the best one. Recent results obtained by US researchers on intraspecific or even interspecific hybridization (Lawrence et al., in press) could also produce interesting hybrids for growth potential or disease resistance. It could also be useful to apply to shrimps the polyploidy techniques already used experimentally in fish culture.

### Seeding the rearing systems

Commercial shrimp farms rely on the availability of seeds and the research contribution has been of major importance in developing techniques for mass production of postlarvae first from wild-caught gravid females and more recently from wild-caught adults (Lumare, 1979; Liao and Chen, 1983) induced to mature and mate in captivity all year round. The last achievement has been the controlled constitution of broodstock in captivity through successive generations (Aquacop, 1975, 1979, 1983; Santiago, 1977; Primavera, 1978; Beard and Wickins, 1980; Lumare, 1981) which has extended the possibility of shrimp culture to countries where native species are lacking. Unfortunately, these breakthroughs in techniques have not yet solved the general problem of lack of seed in many countries as the transfer of such technology to the commercial production sector has just begun.

Wild-caught postlarvae are intensively utilized when present in the surrounding waters but there are many constraints such as seasonal availability, large yearly variations in quantity and price, and complaints from fishermen who fear a depletion in the natural recruitment of their fisheries.

Following the work of Dr. Fujinaga (Hudinaga, 1935; Hudinaga and Kittaka, 1967) who was the first to reproduce the species *P. japonicus* from wild females, a large research effort has been developed to identify the fishing grounds where gravid animals can be caught. This sourcing technique developed in Japan has allowed the establishment of many commercial projects in Central and South America and also in Southeast Asia. The constraints are also: seasonal catching, insufficient quantities and large variations in price. For example, during certain periods of the year, gravid females caught in Malaysia are sold for some hundred dollars apiece on the Taiwan market.

To overcome this problem, researchers have developed techniques to control maturation and subsequent spawning from adult size animals caught in the wild and maintained in tanks. The first routine records of such results on a commercial scale are recent (Panama, Ecuador, Mexico). They are obtained by a careful control of rearing conditions. Temperature and photoperiod (Laubier-Bonichon and Laubier, 1976) must be in the range of natural maturation requirements of the species, salinity around 33 ppt and food must be of high quality composed mainly of a variety of fresh food (squid, mollusks, marine worms, etc.). Under these conditions, some species mature and spawn but for others the technique of unilateral eyestalk ablation (Chamberlain and Lawrence, 1981) must be employed to release the action of the gonad-inhibiting hormone. For all species, this last technique dramatically increases the spawning rate. In optimum conditions, the maturation process is very rapid and one female is able to spawn three to four times in one intermoult period, sometimes every three days without reduction in the number and quality of spawned eggs. Variations in light intensity and different pheromones are involved in male behavior and initiate the swimming, chasing and copulation act. For closed thelycum species, sperm deposition is achieved naturally in captivity with a high rate of success for newly molted females and the quantity of sperm is sufficient for the dif-

ferent spawnings. For open thelycum species, copulation takes place in the last hours before spawning and must be renewed with each spawning. As the rate of success is often erratic for some species like *P. vannamei*, artificial spermatophore transfer (Persyn, 1977; Aquacop, 1983) can be practised. Some large commercial shrimp hatcheries in Ecuador and Panama are producing *P. vannamei* and *P. stylirostris* on a routine basis using these techniques. The constitution of broodstock in complete captivity through successive generations is routinely achieved in Tahiti, New Caledonia, France, Brazil, and Italy for the most important species including *P. monodon*, *P. vannamei*, *P. stylirostris*, *P. indicus*, *P. merguensis* and *P. japonicus*. The selection of broodstock can be undertaken when harvesting a pond by sorting the fast-growing animals which are then cultured at low density to ensure maximum growth. Another method is to use particular ponds to fully control the animals from postlarvae to reproductive size. For *P. vannamei*, broodstock can even be produced in intensive systems giving surprisingly high quality spawners.

If the techniques to control reproduction of different penaeid species in captivity are sufficiently known to be transferred to commercial scale, a lot of improvements remain. Research must now be focused on defining the optimum environmental parameters for maturation of each species, developing a maturation feed to replace fresh food, and determining the best rearing conditions to obtain healthy broodstock. It should lead in the future towards complete seed control including the possibility to develop if necessary virus-free broodstock.

#### Larval rearing: Postlarval mass production in hatcheries

To solve the major limiting factor of insufficient availability of postlarvae, mass production in hatcheries has received much attention from researchers and the techniques are now well known although results are not always satisfactory. Three main methods are used (Mock and Neal, 1974). The Japanese method (Hudnaga and Kittaka, 1967) is characterized by low density of around 10 postlarvae (PL)/ $\ell$ , large tanks up to 200 m<sup>3</sup>, a need for numerous wild-caught gravid females, direct water fertilization by inorganic nutrients to promote algal bloom and production of 20- to 30-day-old postlarvae. This method is well adapted to temperate conditions when it is necessary to produce the seed in a short period of time. But in tropical conditions, these large-volume tanks are difficult to control and results are dependent on variations of water quality and light. If disease occurs, a curative treatment is almost impossible with such large volumes. In contrast, the Galveston method (Cook and Murphy, 1969; Mock, 1974; Aquacop, 1983; Fox, 1983; McVey, 1983) is characterized by high density (100 PL/ $\ell$ ), small tanks between 1 to 10 m<sup>3</sup>, few gravid females, phytoplankton or *Artemia* production (Fox, 1983; Liao et al., 1983) in separate culture systems and production of 1- to 5-day-old postlarvae. It allows accurate control of rearing for water quality, food quantity and quality, and diseases by preventive and curative treatments. The intermediate method (Villaluz et al.,

1972) is a combination of the first two with mean density (30 PL/ $\ell$ ), medium-size tanks (30 to 50 m<sup>3</sup>), use of fertilization in the tanks to bloom an algal inoculum cultured separately.

These three methods differ mainly in degree of control and, when practised by experienced hands, give good results. However, it must be mentioned that many existing hatcheries suffer from a lack of reliability in results due to site conditions, inadequate control of algal quality and lack of knowledge of the necessary sanitary procedures like regular dry-out to eliminate the resistant pathogenic bacterial strain problem which is always the most limiting factor in a hatchery operating all year round in tropical conditions. All these results have led in recently established hatcheries to the physical separation of the different steps of the system in rooms which have their independent water pipes, nets, and which can be closed and dried regularly. At the commercial level, the result has been the development of large-capacity production hatcheries (10-20 million PL/month) in Japan, Ecuador, Panama as well as small-scale hatcheries in Taiwan, Thailand and the Philippines. The present problem is not to be able to produce postlarvae, but to optimize the techniques.

To reach the necessary reliability and decrease product costs, research priorities must be focused on:

- characterization of algal quality according to culture techniques;
- replacement of algae and *Artemia* by inert feeds (micro-particles, microcapsules);
- optimization and automation of the procedures; recirculation systems (Wickins, 1983);
- development of strict sanitary procedures like those routinely used for pig husbandry; and
- cryopreservation of sperm, eggs or nauplii to be able to run the hatcheries by sequential period.

#### Pregrowing in nursery systems

Young postlarvae especially PL<sub>5</sub> reared in hatcheries are very sensitive to water conditions and predators. High mortality can be observed in the first days when direct stocking is practised in ponds where these two parameters are not controlled. Also, it seems better to have a pregrowing phase (Pretto, 1983) in nursery systems which are developed for receiving postlarvae with water conditions similar to the hatchery and to avoid predators by filter devices. This method allows the accurate counting of animals which will be later reared in grow-out ponds and determination of the right feeding rates. Two methods are used or under development.

Pregrowing for 30 to 60 days in earth ponds of hundreds to thousands of square meters at a density of 50-200 animals/m<sup>2</sup> is routinely used in semi-intensive production farms (Ecuador, Taiwan). Food is provided by the natural productivity with or without organic or inorganic fertilization and by supplemental compounded feed. Water renewal is done by pumping with a daily exchange rate between 10 and 40%. In these conditions, survival is high (around 80%) and the postlarvae reach a mean weight of 0.5 to 2 g according to the species and site conditions. The problems encountered are mainly benthic (blue-green and green) algal and uni-

cellular algal control, variations in natural productivity and soil conditions, feed quality, harvesting and transfer to grow-out ponds.

Pregrowing in intensive tanks of ten to hundreds of cubic meters at high density (more than 1,000/m<sup>2</sup>) can be achieved with large water renewal (400%) or low renewal (5%) combined with strong aeration. Food is provided in the form of a high quality pellet and, in the case of low water renewal, by manipulation of the induced bacterial floc. It gives juveniles with an average of 0.1 g size which are very easy to harvest and transfer to the grow-out ponds. These procedures look promising and are being developed on the pilot scale.

The pregrowing phase appears necessary for an optimum management of the semi-intensive or intensive system as a proper transfer of juveniles can be done without losses. Knowing the exact biomass, an accurate feeding plan can be determined for the grow-out phase which is the most food-consuming. It might also be interesting to increase the yield of traditional extensive ponds by a better control of the seedling.

Research needs in earth pond systems include pond design for easy control and harvesting, benthic algal control to avoid the trapping of postlarvae, quantification of the role of natural productivity according to soil preparation, fertilization and water management, and harvesting. For intensive systems, better feeds are needed and recirculating systems should be developed. For both, efficient counting systems will be of great use.

### Grow-out systems

The grow-out of shrimps (Shigueno, 1975; Liao, 1981; Liao and Chao, 1983; Pretto, 1983; Lawrence et al., 1983) to commercial size in four to five months is the most important phase from an economic point of view because it includes the major costs of labour and feeding. Three different approaches exist: extensive, semi-intensive and intensive.

The extensive method is practised in large earth ponds or lagunas where the density is less than 1 shrimp/m<sup>2</sup> and gives yields of 50 to several hundred kg/ha. It relies on water exchange by tidal action and feeding through the natural productivity of the ponds which can be enhanced by organic or inorganic fertilization. The major constraints are the variations and availability of water, predator control, inability to drain and dry the ponds, low dissolved oxygen content due to limited water control, and accumulation of organics on the pond bottom. Extensive culture is developed where large areas are available which need only a small input of energy.

Semi-intensive culture is practised in earth ponds of different sizes ranging from thousands of square meters to 50 ha. The smaller ones can be built with cement walls. The densities are 5-15 animals/m<sup>2</sup> and the yields are 1-6 ton/ha/yr. Water renewal is done by large volume sea water pumping systems and in some cases by both fresh and sea water to control water salinity for optimum growth (e.g. *P. monodon* in Taiwan). The rate of exchange is between 5 and 15% according to density and feeding practices but it is necessary for good management to be able to renew 50% of the water in one pond in case of eutrophication or collapse of phytoplankton blooms. Predators are controlled by filtering

devices and by regular bottom drying after each harvest.

Fertilization is done before stocking to promote phytoplankton growth. Daily feeding is by compounded feeds with or without supplementary trash fish according to the estimated shrimp biomass in the pond. Feed conversion rates range from 1.2 to more than 3 according to density, natural pond productivity and feed quality. Right now, this is the most common production technique. It demands accurate control of the water to keep the right level of phytoplankton which maintains water quality and adequate light intensity. If the rate of exchange is too high, the water becomes clear and promotes the growth of blue-green and green benthic algae. With strong photosynthesis and wind action, these benthic algae come to the surface and pile up in corners leading to large reduced organic deposits. If the water renewal is too low, phytoplankton density can increase dramatically with a subsequent rapid collapse which will completely deplete oxygen levels in the early morning hours. Control of phytoplankton balance is thus of primary importance and some aeration devices like aerators or paddlewheels are used in case of emergency during critical periods. A large water exchange must be used from time to time to accelerate and synchronize the molting cycle of the animals. Feed is distributed by hand or by blowers and the feeding schedule varies from one to five times a day with some farmers not feeding one or two days a week. The large variations encountered in final mean weight of the shrimps and in total yield are often due to feed quality. Regular samplings done by cast net or small trawl generally every two weeks are necessary to adjust the quantity of feed. Each farmer has his own feeding curve expressed in percent of estimated biomass decreasing from 10% for the juvenile stage to 2 to 4% before harvest.

All the intensive systems (Shigueno, 1975; ERL, 1978; McVey, 1980) derive from research results. Density is high at around 100 animals/m<sup>2</sup> or more and the yields are between 1 and 4 kg/m<sup>2</sup>/crop for tanks of small capacity. The feed must be of high quality to sustain good growth under such conditions. Two approaches have been used or are being developed. The first one needs a huge renewal of water to maintain the optimum level of dissolved oxygen and to discharge rapidly metabolic products like ammonia. The second is based on low renewal of water with strong aeration to maintain organic particles in suspension. These particles colonized by nitrifying bacteria act as a built-in biological filter in the water mass. The Japanese method developed by Dr. Shigueno (Shigueno, 1975) utilizes outdoor circular tanks (1,000 to 2,000 m<sup>2</sup>) with a double bottom covered with a sand layer to fit the burrowing need of *P. japonicus*. The water renewal generates a circular motion of the water mass and solid organic waste particles are concentrated in the middle of the tank where they are drained out by the outlet flow. Yields reach 2-4 kg/m<sup>2</sup> but mass diseases can occur and this system is only viable under Japanese market conditions where *P. japonicus* is sold live at a high price. The second method developed by the Coca-Cola and F.H. Prince groups (ERL, 1978) uses flowthrough raceways where water is exchanged several times each day. The tanks are under greenhouse covers for more complete environmental control and the species *P. stylirostris* gives the best results. Production

on the pilot scale reaches 4 kg/m<sup>2</sup>. The third method being developed in Tahiti by Aquacop uses circular tanks with a low water renewal of around 5% and aeration devices to maintain organic particles (uneaten food, feces, etc.) in suspension creating a bacterial floc which changes ammonia to nitrate. A circular motion can be maintained regularly to eliminate part of the solids through a center outlet. Yields of more than 1 kg/m<sup>2</sup> have been obtained for *P. indicus*, *P. monodon* and *P. vannamei*. This last species appears to have the optimum capacities for such a system.

There are no strict limits between these systems which differ mainly in the degree of control of water quality and feeding. The present tendency everywhere is to increase the control capacity to obtain more reliable results with maximum feeding efficiency.

Many applied researches in the following fields are needed to support grow-out techniques:

- improvement of traditional extensive fish ponds in terms of water management and predator control;
- development of shrimp polyculture to utilize the whole range of natural productivity;
- aspects of organic and inorganic fertilization to manage benthic and plankton productivity which remain essential for good growth;
- control of benthic algae;
- improvement in water management (continuous or sequential) by pumping or aeration devices;
- developing low-cost commercial feeds using local products and byproducts;
- feed management: feeding frequency, distribution techniques, adjustment of feeding rate according to pond conditions; and
- modelling of the systems for optimum management purposes.

#### Artificial diets

Fresh food remains of major importance either for larvae with the use of unicellular algae and *Artemia* or for grow-out with the large input of natural productivity and the utilization of trash fish or mollusks.

A major contribution of research has been the development of water-stable pellets of different shapes and sizes (worm-like or crumbles) by using finely ground ingredients and different kinds of binders (gluten, alginate, etc.) prepared by cooking-extrusion, dry or wet pelletizing. Most of these pellets stay physically stable for hours but the leaching of some water-soluble components like vitamin C can be very rapid, preventing sufficient intake to cover shrimp requirements. As already noted, there is a strong need to develop appropriate microcapsules or microparticles to replace algae and *Artemia* for larval stages. Some commercial products have already appeared but are not easily adaptable to commercial operations. The secondary problem of water pollution which causes bacterial disease is not adequately controlled in most existing hatcheries.

Advances in feed formulation have been important in recent years and many different commercial products are available on the market. They have been developed more by trial and error than through a scientific approach. Some of them

give promising growth results in tanks equal to those obtained when feeding fresh food (squid, mussel, etc.). However, the growth is still less than that obtained in ponds where natural productivity is high, indicating the absence of some growth factors. This is mainly due to insufficient knowledge about the basic nutritional requirements for each species in each of the rearing phases (larvae, juveniles, adults). Most of the existing basic data are derived from the various works on *P. japonicus* (Deshimaru and Shigueno, 1975; Kanazawa, 1983) and have to be extended to other species. For proteins, 10 amino acids are essential (Colvin, 1983; Deshimaru, 1983) but the quantitative requirements have to be determined as the optimum total level varies with each species. The nutritional value of free amino acids or peptides are for example inferior to that of intact protein-bound amino acids. The way to develop feed by simulating the amino acid profile of the best natural food has not always been satisfactory as the combination of protein sources appears to play a role even if the resulting amino acid profile is similar. There is also a requirement in the feed for sterols (Teshima, 1983) and some fatty acids of the linoleic and linolenic series as their *de novo* synthesis is non-existent in crustaceans (Castell, 1983). The exact role of phospholipids in the promotion of growth is still obscure. The level of total lipid must not exceed 8% and must be provided mainly by fish oils with high levels of polyunsaturated fatty acids. Insufficient data exist about the quantitative requirements for each of the vitamins and minerals (Conklin, 1983). Most of the time, mineral and vitamin premixes are systematically added to the feed. Many improvements are needed particularly to maintain water-soluble components like vitamin C in the feed. The results of recent studies show an important role of unknown growth factors identified in a protein part of squid meal, for example. Incorporation of these growth factors at a low level in a feed leads to dramatic increase in growth.

Much progress has been achieved in the last few years by researchers and food producers in developing different formulated feeds which are sufficient to sustain present activity. Still many improvements can be achieved in the future and research priorities must be focused on:

- determination of quantitative basic nutritional requirements for each species in each phase;
- reducing leaching of water-soluble products by incorporation in a protected form;
- determination of specific growth factors;
- development of adequate feeds for larvae and broodstock;
- development of low-cost feeds from locally available ingredients (least-cost formulation) for semi-intensive culture to supplement natural productivity;
- replacement of costly animal protein by plant protein;
- partial hydrolysis or precooking of complex carbohydrates to improve digestibility; and
- standardization of nutritional tests.

#### Disease problems

With increasing density and production level, diseases (Sindermann, 1970; Couch, 1978) have rapidly appeared. Records of fungal infections (*Lagenidium* and *Sirolopidium*)

(Bland et al., 1976), bacterial attacks (*Vibrio* and *Aeromonas*) and even viruses (*Baculovirus*) are frequent in hatcheries (Lightner, 1983). Most of these problems are due to insufficient control of the rearing systems and absence of sanitary procedures as in terrestrial husbandry (disinfection, regular dry-out, separate equipment for each tank, separate rooms for maturation, spawning, hatching and larval rearing). The combination of minor errors generally leads to a weakness of the larvae which become more sensitive to disease. Anti-fungal products like Treflan or malachite green and antibiotics used at low levels in the tanks can achieve consistent results. However, after six to eight weeks of production, it seems necessary to have a dry-out to eliminate bacterial strains which have become increasingly resistant and pathogenic. Special care must be focused on potential toxicity or subtoxicity of some components of the system by biological tests on nauplii which are very sensitive to the pollutants.

In the grow-out phase, fungus (*Fusarium*) (Shigueno, 1975), parasitic protozoa (Microsporidia), various bacterial attacks, and diseases often due to nutritional, environmental or toxic problems (ascorbic acid deficiency, cramped tail, muscle necrosis, toxic blue-green algae, black gill disease) are recorded (Lightner et al., 1977; Lightner, 1983). An infectious hypodermal and hematopoietic necrosis (IHHN) due to a virus has been recently discovered in the juvenile stages of *P. stylirostris* leading to high mortalities. It could explain the poor survival of this species in Central and South America but its appearance could also be related to stress under culture conditions.

It now seems important to distinguish between true pathogens which have an infectious character and ubiquitous ones which are opportunistic and become dangerous only when the dynamic balance between host and pathogen is disrupted by culture conditions. The accurate characterization of bacterial strains involved in shrimp culture, mainly in hatcheries is needed.

### Basic research

If the preceding applied researches will have a significant impact on commercial production in the short term, they need to be sustained by more fundamental researches in the field of shrimp physiology (Waterman, 1960), basic knowledge about feeding and digestion (Gibson, 1983), growth phenomena, hormonal control of ecdysis, endocrine control of vitellogenesis, characterization of sex pheromones involved in the mating behaviour, influence of sublethal culture parameters on growth performance (low dissolved oxygen, excess of ammonia and nitrites, etc.), effect of feeding on quality product (geosmin for example), and cryopreservation of sperm and eggs. In genetics, the characterization of different species and populations must be analysed by enzymatic electrophoresis and polyploidy techniques must be developed.

### Conclusion

Many research and development projects have emerged in different parts of the world creating a new industry with bright prospects. The demand for shrimp is continuously

growing while catches from traditional fisheries are near their maximum sustainable yields. Estimates indicate that production will have to increase by 55,000 ton/yr starting from 1990 to satisfy the three main markets of Japan, USA, and Europe (Vondruska, 1984).

Considerable progress has been attained in the last years. During the meeting on shrimp farming in the Americas held in Galveston in 1977, three research priorities were identified: completing the life cycle, nutritional requirements, and developing economical commercial feeds. In 1984, many of these goals have been achieved and have begun to have major impact on commercial activity.

The ability to rear broodstock of the most important species allows independence of local species and has considerably enlarged the potential geographic zone for shrimp culture. It is thus possible to choose the best species according to environmental and socio-economic conditions and to start trials on genetic selection.

Increased reliability in seed production with a decrease in production costs and the transfer of larval rearing technology to many places of the world is solving the most immediate limiting factor of insufficient seed quantities.

The different grow-out techniques will continue to improve. The debate between extensive versus intensive is in fact a question of land availability and production costs which vary considerably with each country. Extensive culture uses more land and water, requires less feed with reliance on natural productivity but is more sensitive to environmental conditions, predators and competitors, and needs more labour. On the contrary, the intensive system demands less land and water, requires a well-balanced costly feed but is less sensitive to variations in external parameters. It also has better control of predators and potential diseases and needs less labour for routine work and harvesting as most of the work can be mechanized. The choice between the two systems is essentially an economic one.

The pre-growing and grow-out techniques are evolving rapidly in the direction of better control of water management, predators and feeding. Research has increasingly defined the limits of the major environmental parameters and has developed in collaboration with the feed producers different formulations that are regularly tested and improved. Feed development has been more by trial and error than by scientific approach but present results are sufficient to demonstrate the technical and economical feasibility of culture under different conditions.

Looking at the major constraints that remain, it is easier to focus on the research effort. For the short term, there is a need to optimize the different phases of the culture system to gain consistency in results and to decrease production costs. This effort must be developed mainly in broodstock maintenance, mass production of postlarvae in hatcheries, efficient commercial feed for larvae, juveniles and adults, and improvements in extensive and semi-intensive techniques. Long-term research must be developed in hormonal control of reproduction, genetics, cryopreservation of sperm and eggs, basic nutritional requirements in vitamins and vitamin-like growth factors, diseases and physiology to have a better understanding of individual internal mechanisms and

to gain better control of culture.

Shrimp culture techniques are far from their optimum at a time when commercial operations are already profitable under different socio-economic conditions. We can also look forward to major improvements which will lead to increased productivity with a parallel decrease in costs which in turn will broaden the market.

It is important to analyse the reasons not only for success but also for failure. Technology can succeed only if applied under the right conditions. Many failures have been due to introduction of technology inadequate according to site constraints and logistic availability.

The management of production units is also essential. Too often investors have focused their action on biological and technological problems, forgetting the importance of routine decisions and procedures in any business.

Shrimp culture activity is just emerging from its infancy. The success of the broiler industry was achieved only after more than 20 years of intensive scientific and commercial effort, and the shrimp industry will undoubtedly follow the same way.

The rate of development will depend on how closely researchers will work with producers to identify the constraints and to integrate available techniques according to the socio-economic conditions of each country.

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