Proceedings of the First International Conference on the Culture of Penaeid Prawns/Shrimps

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Proceedings of the First International Conference on the Culture of Penaeid Prawns/Shrimps

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Foreword

Penaeid research at the Aquaculture Department of the Southeast Asian Fisheries Development Center is as old as the Department itself, covering close to a decade of experimental studies, field trials, training courses, and extension and information work. The Department has major research stations located in Panay Island, the center of penaeid R & D in the Philippines. Northern Panay boasts of some two dozen hatcheries and nurseries, around 20,000 hectares of brackishwater farms and one processing plant, in ever increasing numbers.

Moreover, the tradition and practice of aquaculture has spanned the centuries in the Philippines, among other Asian countries.

It was within this framework that the Department sponsored the First International Conference on the Culture of Penaeid Prawns/Shrimps from 4 *to 7* December 1984 in Iloilo City with the co-sponsorship of the Government of Japan and the American Soybean Association.

The following pages record the efforts of some 300 research workers from 36 countries who have attempted to update information about the culture of penaeid prawns and shrimps, share insights, and propose solutions to gaps in knowledge. This effort complements work that brings to bear the suitable application of observations resulting from scientific inquiry to advance human development.

We wish to thank our co-sponsors for funding support that enabled the Department to host this important conference as well as publish the proceedings.

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Introduction

Among various crustaceans, the marine prawns and shrimps of the family Penaeidae constitute the dominant aquaculture group at present. Although culture contributes only 3 to 5% of current total world production of 1.75 million metric tons of prawns and shrimps, this is expected to increase given full or close to full exploitation of wild stocks, rising fuel costs of trawlers, and coastal pollution.

Most of the early information on penaeids was related to fisheries statistics and research. Only a handful of the papers presented during the 1967 FAO World Conference on the Biology and Culture of Shrimps and Prawns in Mexico City dealt with culture. With the growing interest in aquaculture, a workshop on shrimp farming in the Western Hemisphere was convened in 1975.

Since then, enormous strides have been made on both research and industry levels in captive maturation and seed production, feed development, and grow-out, particularly for the seven commercially cultured species — *Penaeus monodon*, *P. indicus, P. merguiensis, P. japonicus* and *P. orientalis* in Asia, and *P. vannamei* and *P. stylirostris* in Latin America. Thus, there was a need to consolidate recent achievements and identify new bottlenecks in penaeid culture. Moreover, past symposia and meetings have either covered a wide range of aquaculture commodities or addressed specific aspects, e.g. hatchery or diseases or specific regions, e.g. Southeast Asia. An international forum transcending the limits of geography and cutting across disciplines while focusing sharply on penaeid culture was clearly in order.

The Conference

In December 1984, the First International Conference on the Culture of Penaeid Prawns/Shrimps (FICCPPS) brought together more than 300 researchers and culturists from all over the world to assess the state-of-the-art of penaeid culture, exchange information on latest developments, and chart research directions to the solution of remaining problems. To attain these objectives, the Conference was organized into seven sessions on General Aspects and Country Papers; Biology, Ecology and Physiology; Broodstock Development and Gonadal Maturation; Larval and Postlarval Rearing; Grow-out; Nutrition and Feed Development; and Economics, Marketing and Processing. Each session was introduced by one to three invited review or special papers by pioneers and authorities in their respective fields. Contributed oral and poster presentations were also classified according to session topics.

The Papers

To start off, Alain Michel of Aquacop gives a comprehensive review of the impact of penaeid culture research on commercial activity. With the need for more applied as well as fundamental research, the rate of industry development will depend on how closely researchers will work with producers and farmers. Pinij Kungvankij describes the status of shrimp culture in Asia: hatchery, pond culture, production and investment. Gilberto Escobar does the same for the various regions in America -- North, Central and South America, and the Caribbean -- in terms of species, facilities and status. Prospects for shrimp culture in each region should be improved by such favorable factors as available technology and support services, cheap land and labor, and negatively affected by hurricanes, political instability and economic crises.

Hiroshi Motoh recommends measures to conserve nursery grounds of *P. monodon,* the most important culture species in many Asian countries, and to increase production. Yutaka Uno proposes the application of shrimp ranching, a technique that combines both capture and culture, to the shallow coastal waters of Southeast Asia. He correlates releases of postlarval *P. japonicus* in Hamana-ko Lagoon by the Shizuoka Prefectura! Government since 1978 with increased and stabilized fisheries production.

Seed supply is a major bottleneck in prawn and shrimp culture and many hatcheries are plagued by inadequate and erratic supply of spawners. The state-of-the-art for most penaeid species is the production of larvae and postlarvae from wild spawners or wild females matured in captivity. In her review of maturation in closed thelycum penaeids, J.H. Primavera stresses the need to improve reproductive performance of captive pond broodstock, to develop alternatives to eyestalk ablation, and to define the environmental and nutritional requirements for maturation and other phases of reproduction. Interestingly, I-Chiu Liao observes that the most suitable species for grow-out, *P. monodon,* is relatively difficult to rear, hatchery-wise. Instead of antibiotics, Liao advocates natural selection in the hatchery so that surviving postlarvae are assured of good growth in subsequent culture periods. In contrast, Donald Lightner emphasizes the need to improve chemotherapy for many penaeid diseases, in addition to prevention and control; to identify and catalog diseases in the major culture areas; and to standardize diagnostic procedures.

Already, microcapsules for penaeid larvae are making the jump from experimental tanks to field-testing in private hatcheries. Akio Kanazawa points to the need to study the nutritional requirements of larvae to hasten the development of artificial diets for partial or total replacement of natural foods. For grow-out, information on the nutrition of other penaeid species is fragmentary, in contrast to the well-studied *P. japonicus.* Kunihiko Shigueno predicts a complete shift from natural food to compounded feeds for kuruma shrimp culture in Japan in the next few years. He expresses reservations about the economic viability of the intensive or "Shigueno" system he developed before the increases in power costs brought about by the oil crisis and agrees with Yutaka Hirasawa and Florentino Apud that the extensive and semi-intensive systems will be dominant in the future. To optimize pond use and increase productivity, Hirasawa recommends stocking of different sizes to allow staggered harvesting, and movement of stock from small, high-density compartments to larger grow-out ponds.

In the Americas, production cost is lower in countries with a long growing season such as Ecuador. If market prices for shrimp decrease, Wade Griffin predicts a poor return on investment for U.S. farmers compared to Ecuadorian investors.

The sixty-five contributed and oral presentations proved as excellent and as stimulating as the reviews. Invited review papers on penaeid biology and maturation in open thelycum penaeids could not be available due to unforeseen events.

To expedite publication, a decision was made at the outset to exclude the full text of contributed papers from the *Proceedings.* Moreover, manuscripts were edited only to improve grammar and scientific clarity while retaining the colorful nuances of non-native users of the English language.

We hope that this volume will serve as a useful and informative reference on the present state prawn and shrimp culture for aquaculturists, researchers, students, entrepreneurs and policy-makers.

Acknowledgements

In our capacity as Conference organizers, we wish to acknowledge the wholehearted cooperation and sustained enthusiasm of the various FICCPPS committees and subcommittees. We would like to thank all those who helped in the preparation of the *Proceedings.* Special mention goes to Ma. Cecilia Baticados, Nieves Aquino and Marubeth Ortega for some bibliographical research; Teresita Cansancio, Alma Tribo, Nancy Villanueva and Emerita Jayme for typing the manuscripts; Jojo Legaspi for the figures; and Sid Tendencia for the group photo.

The Editors

PART I

REVIEW PAPERS

Proceedings of the First International Conference on the Culture of Penaeid Prawns/Shrimps, Iloilo City, Philippines, 1984

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. merguiensis* 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. merguiensis* 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 (Hudinaga and Kittaka, 1967) is characterized by low density of around 10 postlarvae (PL)/ℓ, large tanks up to 200 m^3, 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/ℓ), small tanks between 1 to 10 m^3, 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/ℓ), medium-size tanks (30 to 50 m^3), 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 (microparticles, 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_5 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^2 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^2) 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 seeding.

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^2 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^2 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^2 or more and the yields are between 1 and 4 kg/m^2/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^2) 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^2 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/m². 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/m² 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 *Sirolpidium*)

(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. Antifungal 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 pregrowing 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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Overview of Penaeid Shrimp Culture in Asia

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Abstract Marine shrimp farming is a century-old practice in some Asian countries. Past sluggish development of the industry is mainly due to the inadequacy of hatchery technology resulting in inconsistent and insufficient supply of shrimp fry hence offsetting large scale development of the industry. Recent success in hatchery techniques coupled with high market demand have generated world-wide interest in developing shrimp farms in Asia. This paper attempts to make an in-depth review of the various aspects confronting the development and expansion of the shrimp farming industry.

The cultural significance of the various penaeid shrimps cultivated in Asia (*Penaeus monodon*, *P. japonicus*, *P. indicus*, *P. merguiensis* and *P. orientalis*) is critically reviewed in relation to other subtropical species such as *P. stylirostris* and *P. vannamei* successfully cultivated in South America. The major constraints confronting large scale cultivation of *P. monodon* and other commonly important species are discussed and research gaps outlined. Present status of hatchery techniques is discussed and the need for standardization of viable techniques for technology packaging and verification is highlighted to ensure reliable source of seed supply. The various problems in hatchery development, including development of artificial larval feeds, are emphasized. This paper attempts to compare the technological and financial inputs in high technology with traditional farming practices in the region. The grow-out technology in relation to farming intensity and level of investment are outlined with special reference to the socio-economic condition in Asia. The need to develop viable and appropriate shrimp farming technology within the technical and financial capabilities of the rural small shrimp growers is discussed.

Introduction

Marine shrimp farming is a century-old practice in many Asian countries. Until a decade ago, this commodity was still generally considered a secondary crop in traditional fish farming practices. In Thailand, Malaysia, Singapore and India, shrimp fry were accidentally trapped in the salt beds and paddy fields around estuarine areas, whereas in Indonesia and the Philippines, marine shrimps enter milkfish ponds during tidal exchange. Only recently have farmers eventually converted these fields into shrimp farms due to the higher income derived from the shrimp harvest compared to the principal crop.

In traditional shrimp farming, wild shrimp fry either enter during tidal water exchange or are intentionally gathered from the wild and stocked directly in ponds. Production is dependent on the seasonal abundance of wild fry which fluctuates widely from year to year. In addition, water depth in rearing ponds is generally shallow which often leads to extreme fluctuations in water temperature and salinity causing large-scale mortality. Predation by carnivorous fishes gaining entrance to the ponds also accounts for considerable loss of shrimps. Production relies almost entirely on natural pond fertility since fertilizers and feeds are not generally used. Consequently, yields are low in the range of 100-300 kg/ha/year.

Over the years, some improvements in the traditional methods of culturing shrimp have gradually evolved. For instance, stocking density could be increased with the aid of a water pump. Furthermore, increasing water depth in the pond favors shrimp growth since temperature can be maintained and mortality is reduced. Production can also be raised by increasing stocking density in the pond with fry collected from the wild. However, supply of seed from the wild is still inconsistent and insufficient so that large scale development of the industry cannot be realized.

In 1934, Dr. Fujinaga, the world's acknowledged father of shrimp culture, successfully spawned and partially reared larvae of *Penaeus japonicus* in Japan (Hudinaga, 1942). The success in larval rearing and subsequently in the grow-out of shrimp had brought the art to a point where mass culture was possible. In 1963, Mr. Harry Cook of the Galveston Laboratory in Texas, U.S.A. in collaboration with Dr. Fujinaga, successfully spawned and reared the larvae of two American species, *P. setiferus* and *P. aztecus* (Cook and Murphy, 1966). The technique was later adopted in Taiwan, Philippines, Thailand and Malaysia for local species such as *P. monodon, P. merguiensis, P. indicus* and *P. orientalis.*

However, recent developments have shown that, with proper management, yield in traditional ponds can be increased to 500-800 kg/ha/year without supplementary feeding. In the meantime, yields equivalent to 5 ton/ha/year have been obtained in Thailand with supplementary feed (Kungvankij et al., 1976) and 10 ton/ha/year in Taiwan with artificial feed and aeration (Liao, 1977).

The long gestation period in shrimp farming development is partly due to insufficient technical and financial input to demonstrate its commercial viability. Shrimp farming on a commercial scale has been developed into an important food industry through long years of trial and error by shrimp

farmers in such countries as Japan, Taiwan, Indonesia, Thailand, India, Malaysia and Philippines. However, it is new in other Asian countries such as China, Pakistan, Bangladesh, Sri Lanka and many countries in the Indo-Pacific region. High market demand and export price, growing opportunities in shrimp farming, and generation of employment and foreign exchange earnings have encouraged many countries rich in aquatic resources in the region to place high priority on the development of the shrimp culture industry.

Species cultured

The shrimp species cultured in Asian countries belong to the genera *Penaeus* and *Metapenaeus* of the family Penaeidae. Among the dozen species of these genera, *Penaeus monodon, P. japonicus, P. merguiensis, P. indicus, P. orientalis* and *Metapenaeus ensis* are the important ones.

Penaeus japonicus and *P. orientalis*

Aquafarming of *P. japonicus* is well established in Japan and Taiwan. Spawners are readily obtained in large numbers from the wild. It is hardy and can withstand handling. Survival rate for long distance transport of live adult shrimp is high. However, it cannot tolerate low salinity and high temperature and requires sandy bottom for grow-out ponds as well as high protein (about 60%) feed for best growth. The other temperate species, *P. orientalis,* is cultured in China and Korea. It has a single pronounced spawning season during spring. Since both shrimps are temperate species, the period of hatchery operation is relatively limited.

Penaeus monodon

Known as the tiger or jumbo shrimp, *P. monodon* is the most common or well-known species in Southeast Asian countries. It is the fastest growing of all shrimps tested for culture. In ponds, fry of 3 cm have been grown to a size of 75-100 g in 5 months at the stocking density of 5,000/ha. Forster and Beard (1974) were able to grow *P. monodon* to 25 g in 16 weeks in a tank stocked at 15/m^2. Kungvankij et al. (1976) grew it to 42 g in 210 days in earthen ponds. Liao (1977) grew it to 35 g in three months in a tank stocked at 15/m^2. It is euryhaline and grows well at a salinity range of 15-30 ppt. It is hardy and not readily stressed by handling. Presently, the major source of fry for stocking still comes from the wild but the supply is sparse. Although several hatcheries have been established notably in the Philippines Taiwan and Thailand, fry production is not steady due to dependence on spawners which are difficult to obtain in sufficient numbers from the wild. *P. monodon* females are more difficult to mature in captivity than those of other penaeid species, although excellent progress on this aspect is being achieved. Reliable techniques for maturation are also being developed.

Penaeus indicus and *P. merguiensis*

Generally, the characteristics of these species are the same. Based on actual field surveys, there are many fish farmers who cannot distinguish the two species from each other. However, there are some indications of behavioral differences between these two species. *P. indicus* prefers sandy substratum and is difficult to harvest by draining the pond, while *P. merguiensis*, found most frequently in ponds with muddy bottom, moves out of the pond readily when water is drained. Gravid females of these species are easily obtained in large quantities from the wild and can mature in captivity. Larval rearing techniques are well developed. However, larvae of these species are found to be weaker than other species and juveniles and adults cannot stand rough handling. Large quantities of fry can be obtained from natural grounds and growth rate is relatively high, reaching 12-15 g within the first three months of culture. With the present technology, great difficulty has been encountered after three months of culture in rearing this shrimp without incurring heavy mortality.

Metapenaeus ensis

This species is very tolerant to low salinity ranging from 5 to 30 ppt and high temperature of 25 to 45°C. Wild fry are abundant, have short growing periods and survival in ponds is usually high. This shrimp usually does not grow to a large size and has a low market price compared to other species. However, studies on the culture of this species are limited. Production usually comes from a trapping pond or as a by-product species in other shrimp farms.

Penaeus vannamei and *P. stylirostris*

There are two neo-tropical species which have been successfully cultivated in America. In the U.S.A., yields obtained within a culture period of 144 days were 1,320-2,180 kg/ha/crop and 1,722 kg/ha/crop in intensive culture and 747 kg/ha/crop and 776 kg/ha/crop in extensive culture of *P. vannamei* and *P. stylirostris,* respectively (Chamberlain et al., 1981). These species show a fairly fast growing rate in ponds, particularly in countries like Panama and Ecuador. Many farmers and researchers want to adopt their culture in the Southeast Asian region as a substitute for *P. indicus* or *P. merguiensis* because of heavy mortality normally encountered for these two species after a culture period of three months. The possibility of transplantation of these animals should be carefully considered as a new environment may not be suitable to allow continuous propagation of such species. Introduction of new pathogenic organisms may also occur and could affect endemic species.

Present status

Hatchery design

Basically, there are two hatchery systems: the large-tank hatchery which was originally developed in Japan and is still popularly used in many countries in the Southeast Asian region (China, Taiwan, Thailand, Philippines, Indonesia, etc.) and the small-tank hatchery that originated from Galveston, Texas, U.S.A. and has been applied in the Philippines and, to some extent, Malaysia and Thailand.

Big-tank hatchery. The big-tank hatchery system was established in Japan by Kittaka in 1964. This was based on the idea of utilizing naturally occurring diatoms in the rearing

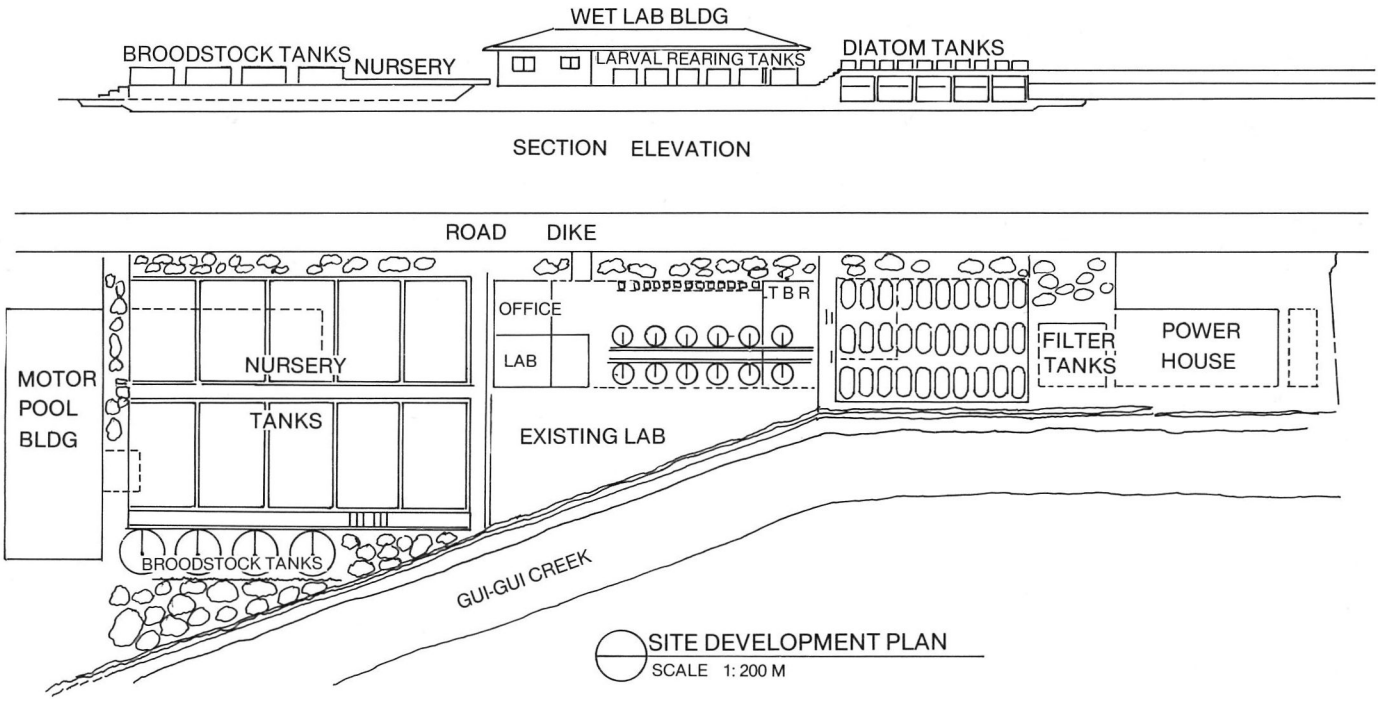

Fig. 1A. Lay-out of medium scale hatchery.

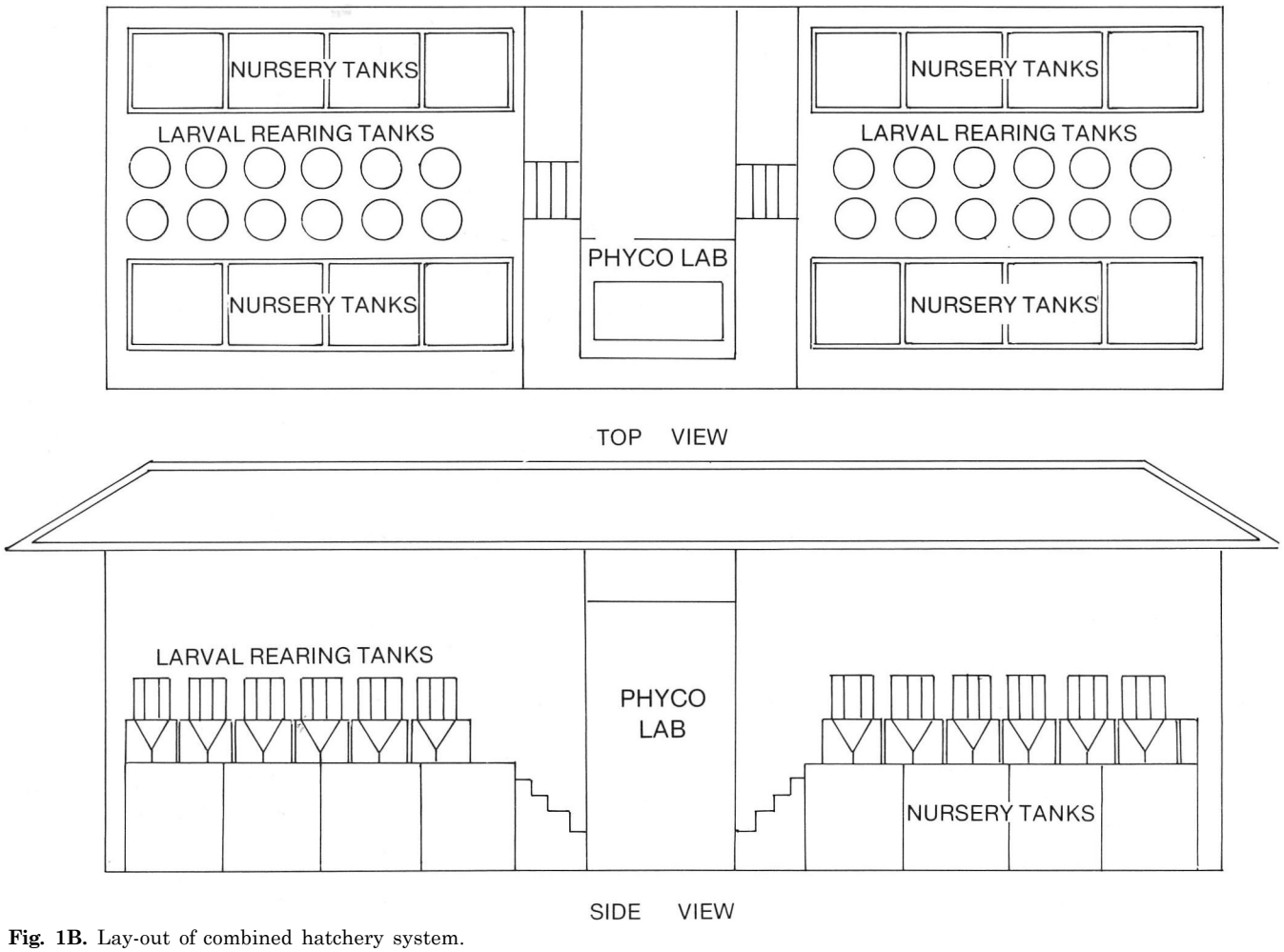

Fig. 1B. Lay-out of combined hatchery system.

water as food for the larvae. To ensure the growth of diatoms, water in the larval rearing tanks is enriched with fertilizer daily. The concrete tanks used are either rectangular or square with a capacity ranging from 40 tons to 2,000 tons, located outdoor or indoor. The depth of the tanks ranges from 1.5 to 2 m. For indoor tanks, transparent roofing is provided to allow sunlight penetration. In this system, spawning, larval rearing and nursery operation are done in the same tank. Technical grade fertilizers are applied directly to the tanks after removal of spawners and hatching of eggs. This operation minimizes the manpower and technical input such as provision for an algal culture room and algal specialist.

Small-tank hatchery. This system was developed in the National Marine Fisheries Service in Galveston, Texas, U.S.A. in late 1960. It utilizes separate algal or diatom cultures for controlled feeding of larvae. Due to inconsistent supply of spawners, the design of the hatchery is much smaller in size than the Japanese system. Spawning tanks are separated from larval rearing tanks and both are usually made of plastic or fiberglass. The sizes of larval rearing tanks range from 1000 to 2000 ℓ and the spawning tanks from 100 to 250 ℓ. The stocking density per tank is high (200-300 nauplii/ℓ) so that larvae can be reared only up to P_1-P_5. Thus, an earthen pond or concrete nursery tank is necessary for further rearing of juvenile size before stocking in grow-out ponds.

Combined hatchery system. Both hatchery systems mentioned above have their advantages and disadvantages in terms of environmental requirements, availability of spawners, etc. (see Table 1). In Japan and China, for instance, where the commonly cultured species are *P. japonicus* and *P. orientalis,* respectively, there are no problems in the availability of spawners and water supply. The capacity of a hatchery tank can be as big as 2,000 m^3. On the other hand, in some Southeast Asian countries, the supply of *P. monodon* spawners is limited. In addition, farmers prefer bigger-sized larvae for stocking in grow-out ponds. Therefore, a hatchery design for this species has been developed with the combined advantages of both systems to meet the requirements of farmers and maximize tank utilization (Kungvankij, 1982). This system makes use of spawning tanks with capacities of 1,000-2,000 ℓ, larval rearing tanks with capacities of 1,000-3,000 ℓ and nursery tanks with capacities of 30-100 tons capable of rearing the larvae up to P_{30} (Fig. 1).

Table 1. Comparison between big- and small-tank hatchery systems.

1. Galveston system
   - 1.1 Advantages
     - i) Low initial investment.
     - ii) Only small number of spawners required for one operation.
     - iii) Larvae from nauplius (N) to postlarva 1 (P_1) could be reared at high density.
     - iv) Easy to control diseases.
   - 1.2 Disadvantages
     - i) Not able to raise larvae up to P_{22} at the same density.
     - ii) Nursery ponds required.
     - iii) More manpower required (in the case of mass production).
     - iv) High cost of maintenance.
2. Japanese system
   - 2.1 Advantages
     - i) Larvae can be raised up to P_{22} in the same tank.
     - ii) Nursery tanks or ponds not required.
     - iii) Less manpower used for operation.
     - iv) Low cost of maintenance.
   - 2.2 Disadvantages
     - i) High cost of initial investment.
     - ii) Difficult to control diseases.
     - iii) Large number of spawners required for one operation.

Hatchery operation

Spawners. Spawners are collected by professional fishermen from coastal waters. Although spawning occurs throughout the year, there are distinct periods when majority of the shrimps spawn. There are two pronounced spawning seasons for *P. monodon* in Southeast Asian waters, December to March and June to September. For *P. merguiensis* and *P. indicus,* it is from June to September and for *P. japonicus,* April to August.

In Japan, hatchery operators can easily procure spawners from fish markets because shrimps are sold live to consumers who prefer live over dead ones. In contrast, hatchery operators in some Southeast Asian countries must deal directly with fishermen to secure live spawners. In most cases, they provide the fishermen with necessary facilities such as aerators, tanks, etc. and teach them proper handling techniques to ensure getting quality spawners.

Hatchery management

Big-tank hatchery. Once the spawners arrive in the hatchery, they are kept in holding tanks and then placed in the hatchery tank just before sunset. The volume of rearing water for spawners in the spawning tank varies from species to species. The normal practice for *P. japonicus* is one spawner/2 m^3; *P. monodon*, one spawner/5 m^3; *P. indicus* or *P. merguiensis*, one spawner/m^3. An initial water level of 100 cm (half of total depth) is generally maintained. Spawning usually occurs the night of transfer from holding to larval rearing tank. Spawners are then removed in the early morning of the following day. Often, the number of eggs or nauplii is few, and the spawners may be maintained in the tank for one more night. Soon after hatching, 3 ppm KNO_3 and 0.3 ppm Na_2HPO_4 are added to fertilize the rearing water. The amount of fertilizers applied thereafter depends on the density of the plankton present in the rearing water. Shrimp larvae begin to feed on plankton when they reach the protozoea stage. During this stage, about 10-20 cm of fresh filtered water is added daily depending upon the density of plankton. If the density of plankton is not enough to feed the larvae, soybean cake, soybean curd, egg yolk, or fertilized eggs of oyster are usually given as supplementary feed. During the mysis stage, rotifer (*Brachionus plicatilis*) or brine shrimp (*Artemia salina*) nauplii are fed. In the early postlarval stage, brine shrimp is usually given as feed. Once the postlarvae reach the sixth day (P_6), they are fed with minced mussel,

clam meat or formulated larval feeds with a corresponding decrease in ration quantity of brine shrimp nauplii until they reach P_9. Beyond this stage, the larvae are fed solely with minced mussel, clam meat or artificial diets 3 to 4 times daily. To ensure sufficient amount of algae in the rearing tank, an improvement of this system makes use of pure cultures of diatom before application of fertilizer.

Small-tank hatchery. In this system, the algae are cultured separately and fed to the larvae at a pre-determined quantity. *Skeletonema costatum* and *Tetraselmis* sp. are produced generally in 300-ℓ to 1-ton tanks at a density of $3.5\text{-}5 \times 10^6$ cells/ml or at $3.3\text{-}4 \times 10^5$ cells/ml (Mock and Murphy, 1974) in algal culture rooms.

The spawners are placed individually in spawning tanks. Separately spawned egg batches are selected and distributed to larval rearing tanks or discarded as required. Individual spawning also facilitates the removal of dead spawners and unfertilized eggs after hatching of nauplii and the transfer of nauplii to larval rearing tanks. In the larval rearing tanks, algal cells are added daily during the protozoea stage while newly-hatched *Artemia* are given during the mysis and early postlarval stages.

Combined system. In the combined system, spawners are placed individually in spawning tanks. The spawner is removed from the tank the morning after spawning. Prior to cleaning, the eggs are either collected and washed or 2/3 of the water is drained from the spawning tank through filter nets and then replenished with new water, thus allowing the eggs to hatch in the same tank. The number of hatched nauplii is estimated, then nauplii are transferred to a bigger tank (20-100 tons) if the count after hatching averages more than 0.5 million (20-30 nauplii/ℓ). In this tank, the larvae are reared until P_{25}. On the other hand, if the number of nauplii is less than the minimum requirement for big tanks, stocking is carried out in small larval rearing tanks at the rate of 100-200 larvae/ℓ. The larvae are reared either to P_2 or P_6 after which they are transferred to the big tank and reared to P_{25} (Fig. 1A, B).

Both pure algal culture and direct fertilization of rearing water are used in this system. This practice is typical in Taiwan, Thailand and the Philippines.

Pond culture system

Although shrimp farming has been developed for more than a century in Southeast Asian countries, most shrimp farmers still follow the traditional method of extensive farming. Such traditional practice is characterized by low production of about 100-300 kg/ha/year, irregular pond size and shape, and relatively low technical and financial input. Due to a high market demand, high export price and low acquisition cost of land, these traditional farms are still commercially profitable despite low production.

Shrimp yield in ponds can be increased by applying modern farming techniques such as intensification of culture operations through regularization of pond sizes, increasing stocking density, employment of aeration, application of formulated feed, etc. This will mean a considerable increase in financial and high technology inputs which most small farmers in developing countries may not be able to afford.

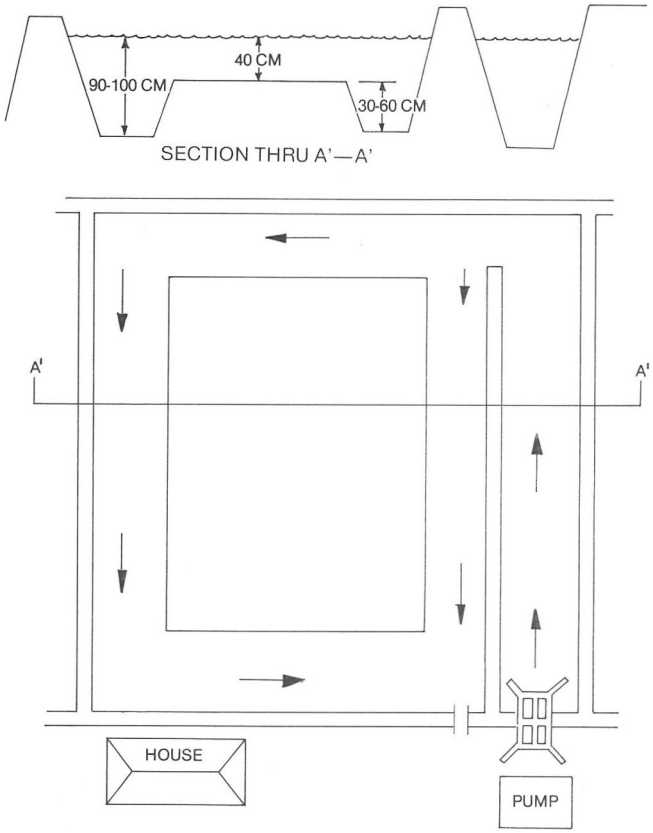

Fig. 2. Typical extensive pond in Thailand.

Traditional or extensive shrimp farming. This type of farming system is characterized by irregular shapes and sizes of ponds which range from 3 to 20 ha. Usually, each pond has a peripheral ditch 10-20 m wide and 30-60 cm deep. In Thailand, the middle portion of the pond is slightly elevated to about 40 cm (Fig. 2) while the pond bottom is entirely flat in the Philippines.

Extensive farming has been considered the simplest culture approach. Seedstock normally comes from the wild and supply is seasonally dependent. Shrimp fry found in these farms either accidentally gain entrance during water exchange or are intentionally stocked by the farmer with fry collected from the wild. Extensive farming employs very low stocking density, in the range of about 3,000 to 5,000 fry/ha. In this grow-out scheme, supplementary feed is not given and water management is by tidal fluctuations. Typical examples of traditional shrimp farming are found in Thailand, Indonesia, Philippines and Malaysia.

In Thailand, Indonesia and Malaysia, shrimps occur in ponds by mere opening of the pond gates during high tide. The natural stocks of shrimp seeds are brought in by the incoming water. The gates are then closed at low tide. Trapped fry are allowed to grow inside the pond for two months before harvest. In contrast, shrimp farmers in the Philippines do not rely on natural shrimp seed that come in with the tide water but stock their ponds with fry collected from the wild usually in polyculture with milkfish. The average stocking density ranges between 2,000 to 5,000 fry/ha. In both culture approaches, yield per unit area is very low.

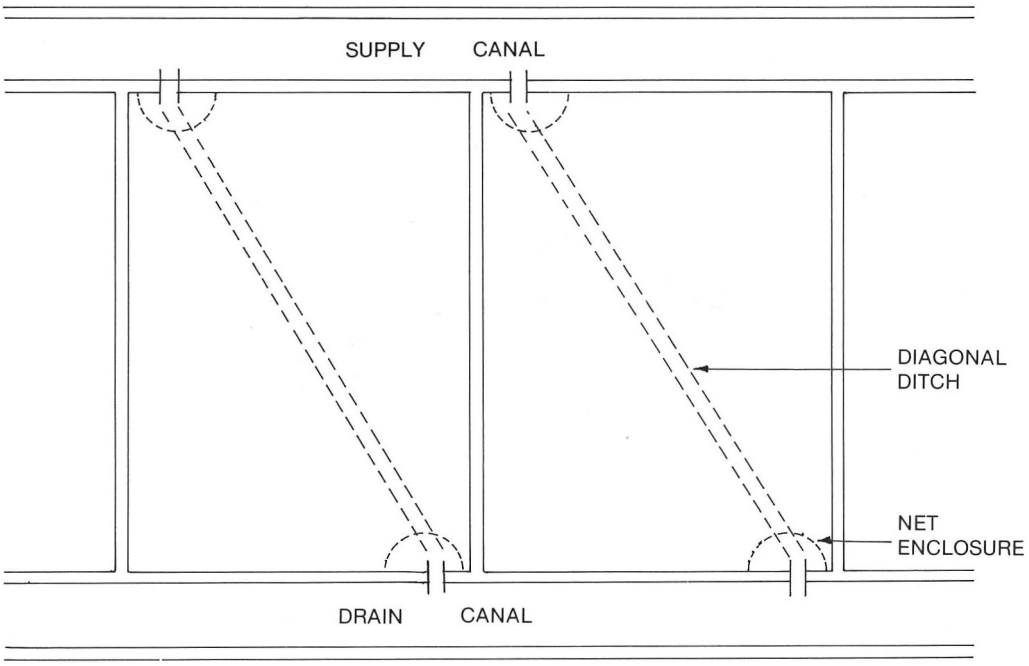

Fig. 3. Typical semi-intensive pond.

During the past decade, improvement and innovations in the extensive shrimp culture method have appreciably increased production. Among these improved techniques are application of lime prior to stocking to condition the soil, use of pesticides to control or eradicate pests and predators, application of organic or inorganic fertilizers to enhance natural food production, increased pond water depth, and increased stocking density either through pumping water daily or direct stocking. These innovations generate higher and more consistent yields. The extensive culture approach, despite many drawbacks, is still the most profitable enterprise for subsistence fish farmers with very low capital.

Improved traditional or semi-intensive system. In this farming method, the improvement over the traditional method is the systematic lay-out of ponds. Ponds are generally rectangular in shape with size of about 1-3 ha and depth of 0.8-1.2 m. Each pond has separate inlet and outlet gates to facilitate water exchange, pond preparation and harvesting. A diagonal ditch, 5-10 m wide and 0.3-0.5 m deep extending from inlet to outlet is also constructed to facilitate draining of water and collection of shrimp during harvest (Fig. 3). This also serves as hiding place for shrimp during daytime. This method involves higher stocking rates, use of supplementary feed, and a regular water management scheme. Current practices vary from country to country and within each country, the normal practice of stocking "seeds" in the semi-intensive system varies from 28,000 to 50,000 fry/ha. Feed, either formulated or fresh, are given daily to the stock as supplemental feed in addition to the existing natural food produced through application of fertilizers. This system also requires the use of a water pump to maintain good water quality.

While this approach would substantially increase yield per cropping, the use of supplemental feeds entails additional cost that generally accounts for the biggest share in operational expenditure. Hence, this deters most subsistence farmers from actually venturing into such level of farming operation.

The Amakusa type or pen culture in Japan can be classified under this level of culture. It is an artificial enclosure constructed along shallow bays and intertidal areas for holding and raising shrimps. It consists of a rectangular or square vertical wall of concrete, constructed to a height of 1 m for holding water during low tide and a wooden frame with nylon netting set on top of the concrete wall to prevent escape of shrimp and facilitate water exchange during high tide. This culture method takes advantage of a large body of water that is constantly renewed through tidal fluctuations and by water current (Fig. 4). The dimensions of the enclosure range from 2,000 to 10,000 m^2 with a depth of 1.0-1.5 m. Stocking rate is between 20 and 30/m^2. Average production is about 300-400 g/m^2 or about 3-4 ton/ha/year.

Intensive culture. This culture operation is the most sophisticated system and requires very high financial and technical inputs. Rearing facilities are either earthen ponds or concrete tanks. The distinct features of this system include the use of hatchery-produced seed, high stocking density, use of formulated diets, application of aeration to increase dissolved oxygen level in ponds, and an intensive water management scheme.

Sizes of pond or tank vary from 500 to 5,000 m^2 as found in Japan, Taiwan, Philippines and Thailand. Dikes may be of pure earthen material, earth coated with plastic sheets or concrete. Most designs include separate inlet and outlet gates or small water inlets for flowthrough purposes. Drain-out system is provided in the form of a centrally located drain pipe, a drain gate (sluice or monk type) or a combination of both (Fig. 5).

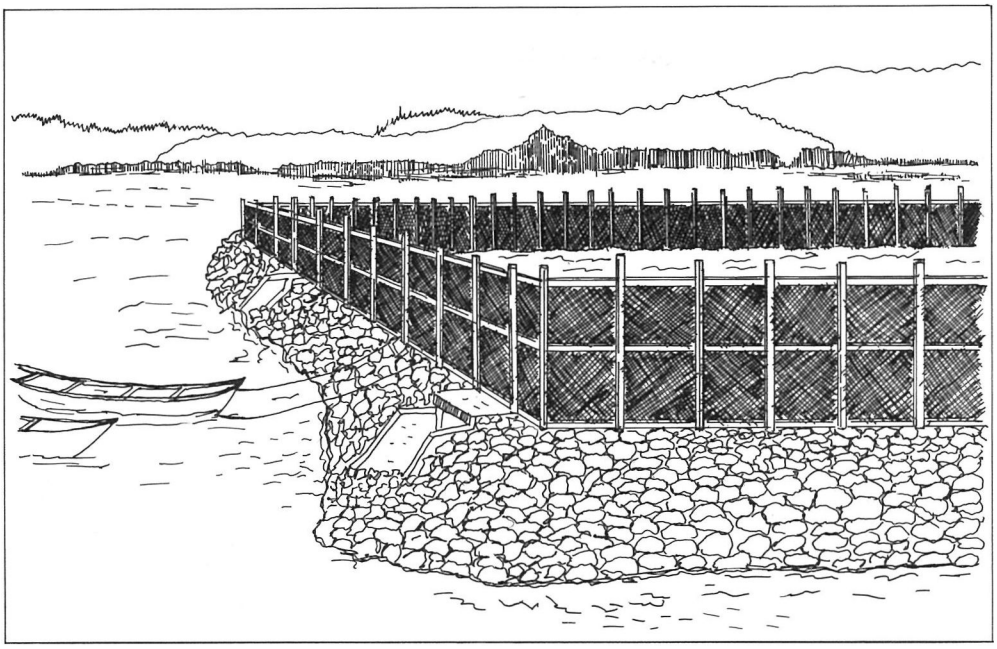

Fig. 4. Amakusa type shrimp farm in Japan.

An excellent intensive culture method for kuruma shrimp called the "Shigueno type" has been developed in Japan. Culture facilities consist of circular concrete tanks with capacities ranging from 1,000 to 2,000 tons and an average height of 2 m. Tank bottom is provided with a sand substrate and water circulation is effected by a flowthrough system (Fig. 6). Shrimp are fed daily with a high protein formulated diet. Stocking density ranges from 200 to 250/m^2 and average production ranges from 1.5 to 3 ton/crop in a 1,000-ton tank and about 10-20 ton/ha/year in earthen ponds with concrete dikes.

Aquaculture production of shrimps in Asia

Various hatchery and nursery techniques have been developed over the decade and are being adopted by both private and government hatcheries. However, hatchery seed production of tiger shrimp is still inconsistent and erratic. Meanwhile, 80% of shrimp farms in Asia still operate on the traditional or extensive method which relies on wild fry or fry collected from trapping ponds.

Over 1.5 billion postlarvae of *P. japonicus* and *P. monodon* are produced annually in Taiwan and Japan. The farmer in these countries uses entirely hatchery-bred postlarvae for stocking the pond. In Japan, only 50% of postlarvae produced are used for grow-out ponds while the rest are stocked in open waters.

Among Southeast Asian countries, Philippines, Indonesia and Thailand are the main producers of *P. monodon* postlarvae. The Philippines leads in seed production of tiger shrimp with 300 million per annum, while Thailand and Indonesia produce only about 100 million each per annum. However, there is need for a larger amount of fry to support the growing needs of shrimp farmers. The recent development of shrimp farming techniques and the consequently upgraded traditional shrimp farming in the region have created the need for more fry.

At least 0.12 million tons of crustaceans were produced through aquafarming in 1983 (Table 2). This represents only 1.2% of total world aquaculture production of about 10 million tons (Table 3). Crustacean production has increased by 73% from 1980 to 1983 (Table 3).

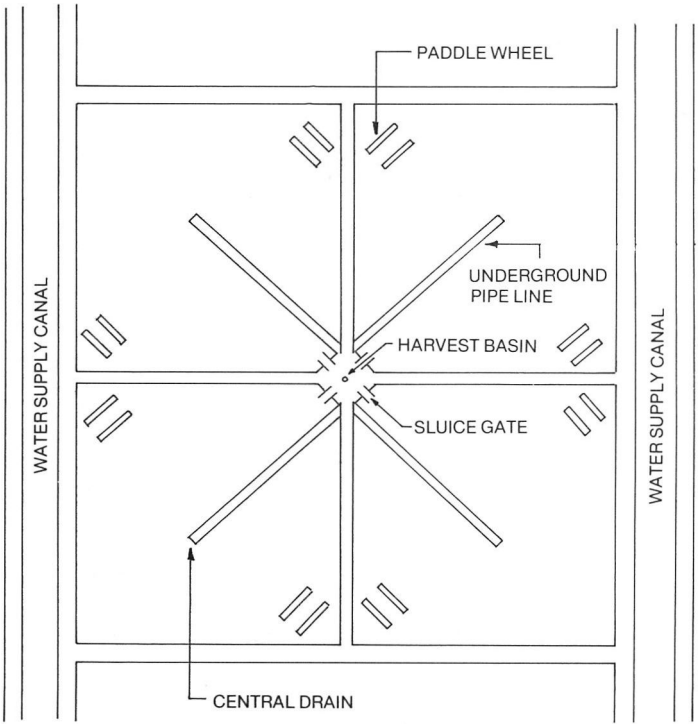

Fig. 5. Intensive pond (earthen with concrete dikes; after Liu and Mancebo, 1982).

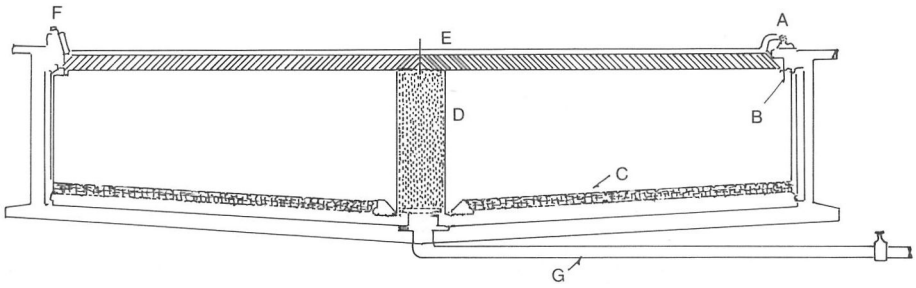

Fig. 6. Shigueno-type intensive culture tank: A, Gate valve of spray-pipe; B, Aeration bubbling-tube; C, Sand bed; D. Cylindrical screen; E, Spray pipe; F, Gate valve of supply pipe; and G, Drain pipe.

Over 61.1% (Fig. 7) of total crustacean production through aquaculture is produced in Asia (Table 4). Indonesia caps the world's top 10 shrimp producers. Six Asian countries, namely Indonesia, India, Thailand, Taiwan, Philippines and Japan contribute at least 60% of world production of crustaceans.

About 123,000 tons of crustaceans were produced from aquafarming in 1983. Shrimps are the main crustaceans cultured. Almost 62% of total world crustacean production is produced by nine Asian countries. The main species of shrimp cultured in Asia are *P. monodon*, *P. merguiensis*, and *P. indicus* in the warm waters of Southeast Asia, India and Taiwan and *P. japonicus* and *P. orientalis* in the cold waters of Japan, China and Korea.

Investment in shrimp aquaculture in Asia

Earlier investments in the shrimp industry were confined to the development of small-scale shrimp farms mostly using the fish farmers' personal resources with little or no external financial support. Since shrimp farming is considered a lucrative industry, investment by the private sector has increased considerably in recent years as evidenced by the number of new farms established under various levels of operation. In the last few years, many large-scale multi-million shrimp farms have been developed especially in China, Thailand, Philippines and Malaysia.

On the other hand, investment from the public sector has also increased due to the growing confidence in many countries in shrimp farming as a source of foreign exchange earnings, and as an important component for rural development. However, public investments either through government input or through external aid focus more on small-scale shrimp culture by upgrading traditional shrimp farming practices.

Despite worldwide interest in the shrimp farming industry, large-scale investments in shrimp culture projects are still relatively limited. Investors are hesitant to venture in large-scale shrimp culture projects mainly because relatively few of these projects have proven to be financially successful in the long-term. Some of the major constraints in attracting private ventures in shrimp culture particularly in countries where there are no traditional shrimp culture practices are the lack of: 1) technicians and scientific personnel with hands-on practical experience in shrimp farming and farm management; 2) relevant technical and economic information on pilot farms; and 3) supply and distribution services of seeds, feeds, fertilizers, etc. The major consideration for private investment is economic viability and the internal rate of return while public venture may place emphasis on social benefits instead of profitability alone.

The non-availability of insurance for aquaculture farms may reflect the instability of the industry. High risk and unstable technology have made it extremely difficult to propose bankable projects which can be accepted by insurance companies. Although insurance schemes are now available in Japan for some technologically advanced, large-scale fish-farms, this is not a common practice in most countries in Asia.

The main financial input in aquafarming is the initial capital needed for the procurement and development of shrimp aquafarming facilities as well as operational costs for feeds, fertilizers and seed which usually amounts to more than 70% of total operational cost.

Successful shrimp culture ventures are dependent on numerous technical, biological and economic factors. Apart from management skill, proper choice of culture sites and suitable technical personnel with hands-on practical experience in shrimp farming practices, are perhaps the most important considerations to ensure success and adequate financial inputs. Experience in most developing countries in Asia seems to demonstrate that at the family level, low

Table 2. World aquaculture production in 1983.

Region	Crustacean production	%	Total aquaculture production	%
Africa	26	0.02	43,865	0.43
Asia and Pacific	75,644	61.29	8,412,131	82.38
Europe and Near East	162	0.13	1,221,511	11.96
Latin America	20,188	16.35	220,505	2.16
North America	27,425	22.27	312,691	3.06
Total	123,445MT		10,210,730MT	

Table 3. World production of aquaculture commodities.

	1975	%	1980	%	1983	%
Finfish	3,980,492	(65.23)	3,233,326	(37.13)	4,447,946	(43.56)
Mollusk	1,051,341	(17.23)	3,196,308	(36.71)	3,245,530	(31.79)
Crustacean	15,663	(0.25)	71,245	(0.82)	123,445	(1.21)
Seaweed	1,054,793	(17.29)	2,206,484	(25.34)	2,393,782	(23.44)
Total	6,102,289MT		8,707,363MT		10,210,703MT	

capital aquafarms are economically feasible instead of large-scale, capital intensive shrimp farms. However, through sufficient farm management and technical inputs, remarkable success with optimum economic production has been attained in large-scale shrimp farms in many countries in Asia.

Constraints to shrimp culture development in Asia

Spawners

Inadequate supply of wild spawners remains one of the major constraints in the development of the shrimp farming industry notably that of farming the tiger shrimp *P. monodon).* To ensure consistent supply of spawners of this species, many hatcheries in Southeast Asian countries have been developing techniques for maturing *P. monodon* in captivity but so far results are not consistent. Thus, techniques for gonadal maturation of captured and pond-reared adult tiger shrimp need to be improved.

Larval feeds

Natural food still remains the major feed in shrimp larval rearing operations. One of the key factors ensuring success in shrimp hatchery production is the timely supply of the needed food organisms in sufficient quantity. Majority of the hatcheries usually have algal cultures and zooplankton areas to maintain pure stocks of the needed live food such as *Chaetoceros*, *Skeletonema*, *Tetraselmis*, *Chlorella* and *Brachionus.* Algal stocks can be easily maintained in standard culture media whereas pure rotifer stock must be sustained through year-round culture. Very often, contamination by undesirable species occurs as well as failure in diatom bloom especially during the rainy months resulting in lack of food supply for the larvae. Maintenance is not only costly but also requires a specialist for this purpose. On the other hand, in the big-tank hatchery system which utilizes natural diatoms, the major problem encountered is the overbloom of diatoms, of which some such as *Nitzschia* sp. are undesirable species which cannot be eaten by the larvae and may normally attach to their appendages. This makes molting impossible and high mortality occurs particularly in outdoor hatcheries. Failure in diatom bloom may also occur especially during the rainy season leading to lack of food in the larval rearing tanks.

Both private and government sectors have attempted to develop pelleted artificial feeds or microencapsulated diets for larval rearing. It will be advantageous to the shrimp hatchery industry if artificial larval feeds become reliable. Nevertheless, supplemental live food is still needed.

Development of compound feeds

Shrimps are usually fed with minced trash fish or mussel and fine rice bran. However, not all portions of the given feeds are consumed. Sometimes, the given feeds may be in excess resulting in pollution of the pond water. This leads to lower feed conversion efficiency and low productivity. For intensive culture, the use of formulated diets is essential especially when the supply of fresh feeds is limited or very costly. Despite the limited studies on the nutritional requirements of shrimps, several formulated diets have already

Table 4. Asia and Pacific countries with crustacean production through aquaculture.

	Production (MT)	%	Main species
Indonesia	21,797	28.8	*Penaeus monodon*, *P. merguiensis*, *P. indicus*
India	20,700	27.4	*P. monodon*, *P. indicus*
Thailand	14,931	19.7	*P. monodon*, *P. merguiensis*
Taiwan	1,431	15.1	*P. monodon*, *P. japonicus*, *P. orientalis*
Philippines	3,920*	5.2	*P. monodon*, *P. indicus*
Japan	2,500	3.3	*P. japonicus*
Malaysia	245	0.3	*P. monodon*, *P. merguiensis*
Korea	50	0.06	*P. japonicus*, *P. orientalis*
Singapore	39	0.05	*P. monodon*, *P. merguiensis*
Mauritius	23	0.03	
Total	75,644		

*The Philippine Shrimp Farming Industry: Risk and opportunities for private investors. Submitted to the Philippine Government by the International Finance Corporation, 1984.

Fig. 7. 1983 world crustacean production (in %), by region.

been developed and commercially produced in some countries. Some of these feeds appear to have better conversion efficiency compared to fresh feeds. However, the prices may be high and supply is insufficient. Since the formulations for these diets are considered trade secrets, manufacturers generally limit production in order to increase market demand especially if the diet shows good feed conversion efficiency. As a result of these conditions, feed cost has hampered the development of intensive shrimp culture.

To offset these problems, more research must be done on the nutritional requirements of shrimp as well as their physiology and biology in order to improve existing formulated diets and develop new ones. Suitable cheap feedstuff must be found and incorporated into the diets. Testing of these diets must be done not only on an experimental scale but also on small commercial scale to ascertain conversion efficiency. Once found to be efficient, production techniques must be standardized, packaged and made freely available to any interested small- or large-scale manufacturing company for commercial production. This will minimize monopoly of feed supply and thus lower the cost and increased feed availability to shrimp farmers thereby paving the way to intensive shrimp farming.

Diseases

Disease is a serious problem both in hatcheries and rearing ponds. The most serious disease-causing organisms in the larval stages are *Zoothamnium,* fungi (*Lagenidium*) and bacteria (*Vibrio*) which may contaminate the intake water, or may result from a collapse of *Artemia* population in the pond. General signs of infection include increased opaqueness of abdominal muscle, expansion of chromatophores (usually appearing reddish in color), and occasionally a dorsal flexure of the third abdominal segment.

It is very difficult and expensive to treat infected larvae. Prevention is always better than cure. The best remedy is to prevent the onset of fungal and bacterial infection. This can be done by separating the spawning tank from the rearing tank and using clean or purified rearing water.

In rearing ponds, black gill disease caused by *Fusarium* spp. also occurs when the bottom of the rearing pond is in bad condition. Body cramps has also been noted in pond-reared *P. monodon* and *P. japonicus* when these were caught in daytime under a hot sun. High mortalities usually follow. Intensive culture using high stocking densities should be avoided until an effective treatment for this disease is found.

Technology packaging

Although various techniques in shrimp farming have been developed as a result of more than 50 years of research studies, these techniques have yet to be refined, standardized, packaged and tested in different environmental conditions so that appropriate technology can be disseminated to shrimp farmers. The techniques that have been established

in one country may not be applicable to other countries. Hence, shrimp farming techniques are not disclosed and will remain untold until such time that aquaculturists and researchers are confident that research results can be packaged into a standard technology.

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Overview of Penaeid Culture in the Americas

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Abstract The paper discusses the reasons behind the farming success of Ecuador, as well as the limitations associated with farming throughout the rest of the Americas. Emphasis is given to specific farming practices, management techniques, and physical design characteristics. Through improved techniques the farmer is approaching the point where he can reliably manage his crop size and harvest time as dictated by market trends and postlarval supply.

Until recently, pond production has been characterized by relatively small-scale operations often experimental in origin. Due to the farming success in one country, production output has risen from 4,800 tons in 1978 to 23,390 tons in 1983. As evidenced by this dramatic rise in production, Ecuador is in a period of expansion and increasing technical awareness, the combined results of which have led it to become the production leader in pond-grown shrimp.

The economic pull towards Ecuador is now slowly giving way to shrimp development in other parts of the Americas. Owing to the technical gains brought about by government programs, universities and private industries, shrimp farming has become a potential activity in many areas previously thought inadequate. Production methods have progressed from the traditional extensive method to sophisticated closed system raceways. All but the latter method are exemplified by the techniques used throughout Ecuador.

Presently, Ecuador has in production 50,000 ha of ponds. Of these, 30,000 ha are farmed using the extensive method characterized by low cost and low output. The successful approach referred to as the semi-extensive method occupies approximately 15,000 ha. This style of farming, while requiring increased cost, leads to a proportionately higher production output. The third approach is the semi-intensive method under which an estimated 5,000 ha are in production. Increasingly higher production rates are being achieved through improvements in physical pond design, pond maintenance and preparation, feeding and fertilization regimes, technical management, and control.

Introduction

There are four major shrimp farming areas in the Americas: 1) North America — U.S.A. (Hawaii, Texas, North and South Carolina) and Mexico; 2) Caribbean — Antigua, Bahamas, Cuba, Dominica, Dominican Republic, Grenada, Guadalupe, Jamaica, Martinique, Puerto Rico and U.S. Virgin Islands; 3) Central America — Belize, Costa Rica, Guatemala, Honduras and Panama; and 4) South America — Brazil, Ecuador and Peru.

Shrimp culture in Latin America

Latin America (Central and South America) has recently become the world leader in shrimp farming. Among the several countries presently involved, Ecuador and Panama have developed the techniques now used in extensive marine shrimp culture. The viability of natural resources all year round, low wages, inexpensive coastal areas suited for farming, cheap fuel, adequate climate, and plenty of wild postlarvae from the estuaries have all contributed to the expansion

Table 1. Status of shrimp and prawn production in North America.

Country	Species	Facilities	Status	Prospects
U.S.A.				
Hawaii	Marine shrimp (*Penaeus vannamei*)	Farms (200 ha) Raceways	In production	Limited due to cost of land and available area High technology
	Intensive marine shrimp	Hatcheries		
	Freshwater shrimp (*Macrobrachium*)			
Texas	Marine shrimp (*P. vannamei*)	Farms (100-200 ha)	In production	Limited due to cost of land and labor Limited season
Florida and the Carolinas	Marine shrimp Freshwater shrimp (*Macrobrachium*)	Small area	In production	Very limited
Mexico	*P. vannamei*	Very small area	Projected and under construction	Great potential Need to change laws

of farming in these countries. What were accidental observations early in the sixties have grown to a multi-million dollar industry.

The introduction of technology and management has improved the yield, reliability and profitability of the farms into sophisticated operations which involve careful planning

Table 2. Status of shrimp and prawn production in Central America.

Country	Species	Facilities	Status	Prospects
Belize		Very small	Projected or under construction	With potential
Costa Rica	Marine shrimp	Farms (130 ha)	Not very good, closed in 1982	Uncertain Some interest due to government stability
	Freshwater shrimp (*Macrobrachium*)	Farms (80 ha)	Original investor gone	
Guatemala	Marine shrimp (*P. vannamei*)	Farms' (260 ha)	In production	Small potential
	Freshwater shrimp	Farms (40 ha) Hatchery		
Honduras	Marine shrimp	Farm (100 ha)	In production Hatchery closed in 1981	
	Freshwater shrimp	Farms (50 ha)		
Panama	Marine shrimp (*P. vannamei* and *P. stylirostris*)	Farms (2,000-3,000 ha) 2 hatcheries	In production since 1978	Suitable areas limited to 5,000 ha Limited supply of postlarvae

Table 3. Status of shrimp and prawn production in the Caribbean Islands.

Country	Species	Facilities	Status	Prospects
Antigua		Farm (about 10 ha)	Under construction	Uncertain, dependent on imported postlarvae
Bahamas	Marine shrimp		Limited production (one crop harvested)	Imported postlarvae
	Freshwater shrimp			Limitation due to winter influence
Cuba	*P. schmitti*	Farm (8-20 ha)	Top priority, Ministry of Fisheries	Uncertain
Dominica	Freshwater shrimp	Farm (small) for demonstration		Limited
Dominican Republic	Marine shrimp	Farm (50 ha)	Under construction	No marine shrimp hatcheries
	Freshwater shrimp	3 hatcheries	In production	
Grenada	Freshwater shrimp	For demonstration	Under construction	Limited
Guadalupe	Freshwater shrimp	Ponds (11 ha) since 1978	More ponds projected	
	Marine shrimp	3 hatcheries (with very small production)		
Jamaica	Freshwater shrimp	Farm (10 ha) Hatchery	In production	Small
Martinique	Freshwater shrimp	Farm (100 ha) Hatchery	In production since 1976	For local consumption
Puerto Rico	Freshwater shrimp	Farm (10-50 ha)	One project, another closed	
U.S. Virgin islands	Marine shrimp (*P. vannamei*)	Hatchery	Fry production for Bahamas	

Table 4. Status of shrimp and prawn production in South America.

Country	Species	Facilities	Status	Prospects
Brazil	*P. japonicus* *P. vannamei* *P. schmitti*	Farms (1,000-2,500 ha) 10-20 companies	In production Problems with fry supply, salinity and rain	Large potential Difficulties: Access, financing, fish meal packing plants and government are near South
Ecuador				
Machala Bahia Guayas Esmeraldas	*P. vannamei* and other marine shrimp	Very large involvement Farms (=50,000 ha) 4 hatcheries, several in planning stage	In production since 1970 20-40% yearly increase in production since 1978 Exported 50,000 lb tails in 1983	Areas available for expansion 70,000 ha Limited availability of postlarvae led to decreased production in 1984
Peru				
Northern Peru	*P. vannamei*	Farms (2,000-3,000 ha) Limited to border with Ecuador	Production from wild fry	Potential 6,000 ha No hatcheries

Table 5. Factors affecting the growth of the shrimp industry in the Americas.

Area	Favorable factors	Constraints
North America		
U.S.A.	1. U.S. market 2. Technology and technicians available 3. Excellent support services — roads, transportation, telephone, electricity, equipment, parts, services	1. Short growing season 2. High cost of land, labor and energy 3. Limited areas available 4. Hurricane threats 5. Cultured species are exotic, hence the need for hatcheries
Mexico	1. Market proximity 2. Extensive areas available with year-round growing season 3. Availability of native species for culture 4. Relatively stable government	1. Laws limit export of shrimp to cooperatives 2. Difficulties in obtaining resident visa 3. Economic crisis which devaluates foreign investments by paying export dollars in pesos 4. Complicated country to deal with
Central America	1. Availability of wild fry 2. Cheap land 3. Cheap labor 4. Closer than South America to U.S.A. and Europe 5. Existing shrimp trawling industry and processing plants, with knowhow in packing and marketing	1. Political instability 2. Past failures make financing more difficult 3. Limited areas 4. Limited skill and knowhow 5. Limited support services 6. Some countries are complicated to work in
Caribbean	1. Sometimes with local shrimp market (tourists) 2. Proximity to U.S. market 3. Air transportation available 4. Nice area to live in	1. Exotic species 2. Hurricane-prone areas 3. Limited available land 4. No processing plants 5. Limited facilities 6. Unstable governments in some cases
South America		
Brazil	1. Large country with all types of land and climates 2. Existing processing plants and post-harvest facilities 3. Cheap electric energy 4. Interest in promoting exports 5. Shrimp farming already initiated 6. Pleasant country to live in	1. Native species not suitable for farming 2. Suitable areas far from main cities 3. Unstable climate 4. Limited support in Northern area 5. Lack of knowhow 6. No fish meal
Ecuador	1. Successful experience which facilitates promotion 2. Some wild postlarvae available 3. Existing processing plants 4. Some experienced people 5. Year-round good weather with no hurricane threat 6. Good clay soil 7. Limited rain	1. Inadequate postlarvae cannot meet demand 2. Available land limited and costly (US$1,000-2,000/ha) 3. Overcharging of shrimp farmers 4. Too much government control 5. Poorly trained manpower out of school and universities 6. Difficult areas to live in

and execution of the several phases of production. From simple farming the process has grown to include hatcheries, nurseries, grow-out, feeding, fertilizing, harvesting, processing and exporting. The coordination of all phases has to be accomplished for the successful production of shrimp.

The outstanding quality of farmed shrimp is slowly being recognized in the most demanding markets. It is principally achieved due to freshness in processing, considerably less handling compared to common boat operations, and constant year-round supply. Farming is becoming a serious threat to boat operators who will be forced to reduce the number of boats to improve their catch per boat, and to stay in step with the rising cost of energy and the lowering of prices for shrimp.

The involvement of different countries can be individually observed in Tables 1-4 which summarize some of the information.

Ecuador

Ecuador has three major production areas:

1. Machala (south) — Where shrimp farming originated; has maintained its tradition of extensive, low-yield production.

2. Bahia (north in Manabi Province) — Second area where shrimp farming developed very rapidly with the introduction of some technology and farm rationalization.

3. Guayas (central near Guayaquil) — Largest of all three areas and also has largest potential. Mixed results when technology was copied from other two areas. Better results from large farms where advanced technology in design, construction and management has been applied with very good results.

The reasons for the successful farming experience in Ecuador may be traced to ecology, agriculture, politics and economics. Ecology has been the most important factor, providing postlarvae of the species *Penaeus vannamei* and *P. stylirostris* year-round, salinity between 6 and 33 ppt, temperature between 23 and 32°C, and sufficient land with high clay content and pH of 8.

Ecuador is a country of agricultural workers forced out of agriculture due to land reform implementation and political prices for its products. It was easy to convert the equipment and workers from agriculture to a similar activity — aquaculture — with limited skill required.

Politically, poor government management of the oil resources produced inflation and an economic crisis which practically stopped commerce, housing construction and industry, on top of the semi-paralyzed agricultural activities. People who wanted to work and produce legally had no other choice but to start a shrimp farm taking advantage of a non-labor intensive operation, with some financing available.

Last but not the least factor was profitability due to good shrimp prices and good revenues in dollars which was the kind of money everybody wanted.

Future of shrimp in the Americas

There will be individual problems in each country (Table 5) but, on the whole, shrimp culture will grow very fast due to the following factors:

1. Development of hatcheries and technology
2. Strong dollar-oriented activity and belief in its profitability
3. Non-labor intensive
4. Techniques which can be easily copied
5. Availability of coastal land in areas not suitable for agriculture.

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Biology and Ecology of *Penaeus monodon*

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Abstract The giant tiger prawn, *Penaeus monodon*, the largest and most commercially important species among penaeids reaching 270 mm in body length or 260 g in weight, is suitable for culture in ponds and offers high market prices. This species occurs mainly in Southeast Asian waters, though it is quite widely distributed from 30°E to 155°E longitude and 35°N to 35°S latitude. Mating and spawning generally take place at night. The maximum number of eggs spawned at a time is more than 800,000. The life history is classified into six phases: embryo, larva, juvenile, adolescent, Subadult, and adult. The biological minimum size is 37 mm carapace length for males and 47 mm CL for females. The food consists mainly of small crustacea, mollusks and annelids. The adult is a predator of slow-moving benthic macroinvertebrates, or opportunistic in feeding behavior. This prawn is relatively eurythermal and euryhaline, growing rapidly to a large size. The life span may be one and a half to two years, and the female may live for a longer period than the male. In general, the female is larger than the male.

Introduction

The giant tiger prawn, *Penaeus monodon* Fabricius, is one of the largest penaeid prawns in the world, reaching some 270 mm in body length, and is of commercial importance in markets.

Recently in Southeast Asian countries, enthusiasm for natural and artificial propagation of both fry and adult giant tiger prawn has been growing rapidly among government and private agriculturists due to strong demand with higher prices in the national and international markets. On the other hand, their habitats such as shore areas and mangrove waters are under destruction in several areas. Therefore, it is important to understand the principal characteristics of the species.

The world crustacean catches in recent years have been about 1.6 million tons. Shrimps and prawns comprise about 1 million tons, of which almost 75% appear to be penaeids.

Identity

Penaeus (Penaeus) monodon Fabricius, 1798

Synonyms

Penaeus carinata Dana, 1852
P. tahitensis Heller, 1862
P. semisulcatus exsulcatus Hilgendorf, 1879
P. coerulus Stebbing, 1905
P. monodon var. *manillensis* Villalluz and Arriola, 1938
P. bubulos Kubo, 1949
P. monodon monodon Burkenroad, 1959

FAO names

Giant tiger prawn (English)
Crevette géante tigrée (French)
Camarón tigre gigante (Spanish)

Description

The rostrum, extending beyond the tip of the antennular peduncle, has 6 to 8 (mostly 7) dorsal and 2 to 4 (mostly 3) ventral teeth, and is sigmoidal in shape. The adrostral carina reaches almost to the epigastric spine. The carina reaches to the posterior edge of the carapace. The gastro-orbital carina occupies the posterior one-third to one-half distance between the post-orbital margin of the carapace and the hepatic spine. The hepatic carina is predominant and the anterior half is horizontal. The antennular flagellum is sub-equal to, or slightly longer than the peduncle. The 5th pereopod has no exopod. The abdomen is carinated dorsally from the anterior one-third of the 4th to 6th somites. The 4th and 5th somites each has a small lateral cicatrice, and the 6th, 3 lateral cicatrices. The telson is unarmed (Fig. 1).

Color in life is as follows: Carapace and abdomen are transversely banded with red and white. The antennae are greyish brown. Pereopods and pleopods are brown and fringing setae red. Upon entering shallow brackish waters or when kept in ponds, the color changes to dark brown and often to blackish.

Distribution

The giant tiger prawn is widely distributed throughout the greater part of the Indo-West Pacific region: South Africa, Tanzania, Kenya, Somalia, Madagascar, Saudi Arabia, Oman, Pakistan, India, Bangladesh, Sri Lanka, Indonesia, Thailand, Malaysia, Singapore, Philippines, Hongkong, Taiwan, Korea, Japan, Australia, and Papua New Guinea (Fig. 2). In

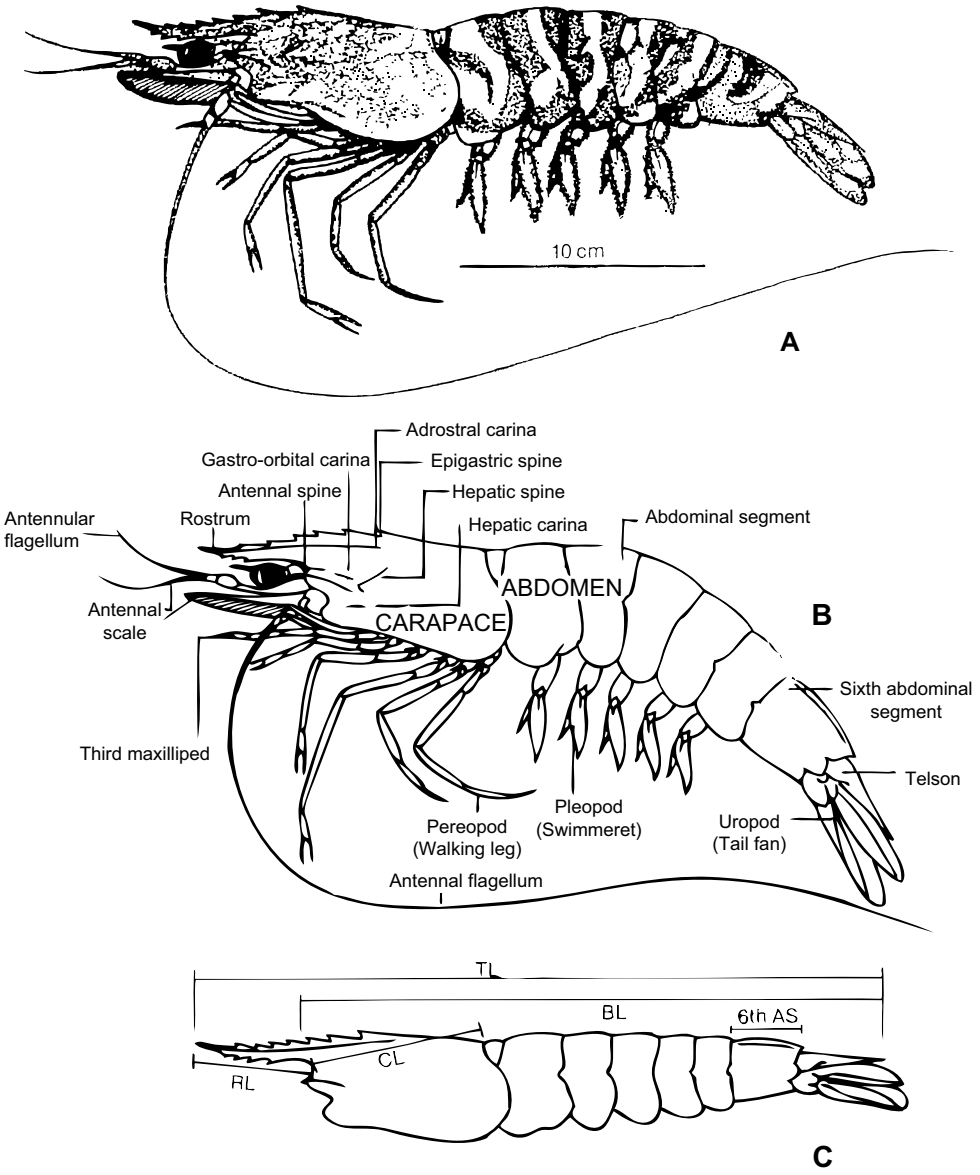

Fig. 1. A: Adult female of *Penaeus monodon;* B: External anatomy of *P. monodon; C:* Methods of measurement of *P. monodon* (RL, rostrum length; CL, carapace length; TL, total length; BL, body length; 6th AS, length of 6th abdominal segment).

general, *P. monodon* is distributed from 30°E to 155°E longitude and from 35°N to 35°S latitude. However, the main fishing grounds are mostly located in tropical countries, particularly in Indonesia, Malaysia and the Philippines.

The fry, juveniles and adolescents inhabit surface waters such as shore areas and mangrove estuaries, while most of the adults inhabit waters down to about 160 m.

Bionomics and life history

Reproduction

Sexuality. *Penaeus monodon* is heterosexual. The sexes can be distinguished by external characters (genital organs): petasma and a pair of appendix masculina in male and thelycum in female (Fig. 3). The petasma is situated between the 1st pleopods and the appendix masculina on the exopods of the 2nd pleopods, while the thelycum is between the 4th and 5th pereopods.

A pair of genital openings in the male is situated on the coxae of the 5th pereopods (walking legs) and in the female on the coxae of the 3rd pereopods.

Females attain a relatively larger size than males.

Morphological development

Embryo (Fig. 4). Viable eggs of *P. monodon* are spherical, yellowish green in color and somewhat translucent, ranging from 0.27 to 0.31 mm with an average of 0.29 mm in dia-

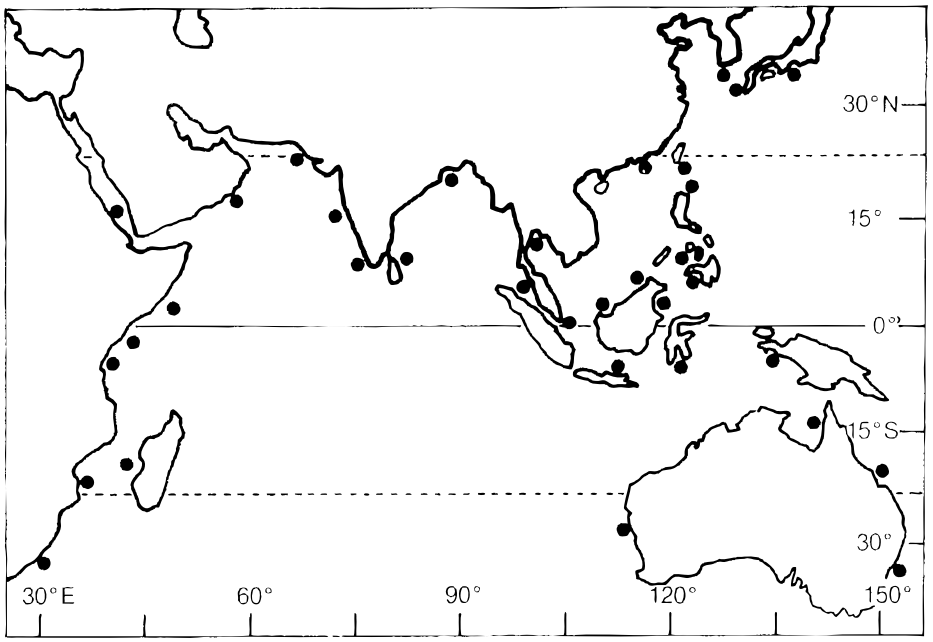

Fig. 2. Geographic distribution of *Penaeus monodon.*

meter. In still water, the eggs sink slowly to the bottom. The 2-celled, 4-celled, morula and embryonic nauplius stages develop approximately 0.5, 1, 1.8 and 11 hours, respectively, after spawning. Before hatching, the embryonic nauplius is observed to move intermittently inside the egg.

Larva (Figs. 5, 6). The larval stage of *P. monodon* consists of 6 nauplius, 3 protozoea, 3 mysis, and 3 or 4 megalopa substages, and the time required for each stage are about 1.5 days, 5 days, 4 to 5 days, and 6 to 15 days, respectively. Swimming is by antennal propulsion in the nauplius, antennal and thoracic propulsion in the protozoea, thoracic propulsion in the mysis, and abdominal propulsion in the megalopa. Occurring offshore, they are planktonic in behavior. The protozoea and mysis are collectively called zoea. Furthermore, the megalopa as well as earlier juvenile stages are called postlarvae traditionally or fry for commercial purposes. The body of the megalopa is transparent with a dark brown streak from the tip of the antennular flagellum to the tip of the telson. The 6th abdominal segment is relatively longer than the carapace length. The carapace length of the megalopa varies between 1.2 and 2.2 mm. *P. monodon* enters nursery grounds during the last substage of the megalopa.

Juvenile (Fig. 6). During the earlier juvenile stage, the body is partly transparent with a dark brown streak on the ventral side similar to the megalopa. For convenience, they are traditionally called postlarvae or fry in the earlier stage and fingerlings in later stages.

They differ from the megalopa as follows: relatively shorter 6th abdominal segment compared to the carapace length, greater body size, completion of rostral spines and gill system, and benthic behavior. The ratio of the length of the 6th abdominal segment to the carapace length is still greater (about 0.65) than that in the adolescent (about 0.58).

In the middle stage reaching about 2.7 mm in carapace length (CL), the body becomes blackish in color and the rostrum has 6 dorsal and 2 ventral spines. When it reaches about 3.7 mm CL, the body becomes more blackish and bulky and the rostrum has 7 dorsal and 3 ventral spines which is the same in adults. The carapace length varies from 2.2 to 11.0 mm. They crawl using pereopods and swim using pleopods; the former become the main locomotive organ and the latter may be regarded as supplementary and used for rapid movement, both functioning through to the adult stage in the same manner. Juveniles inhabit brackish water areas as nursery grounds.

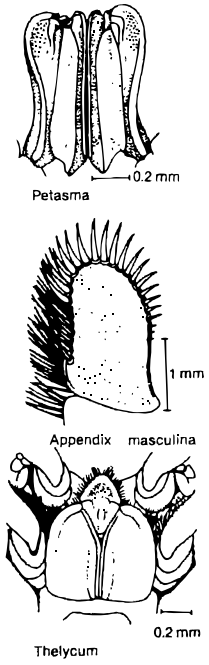

Fig. 3. Genital organ of *Penaeus monodon.*

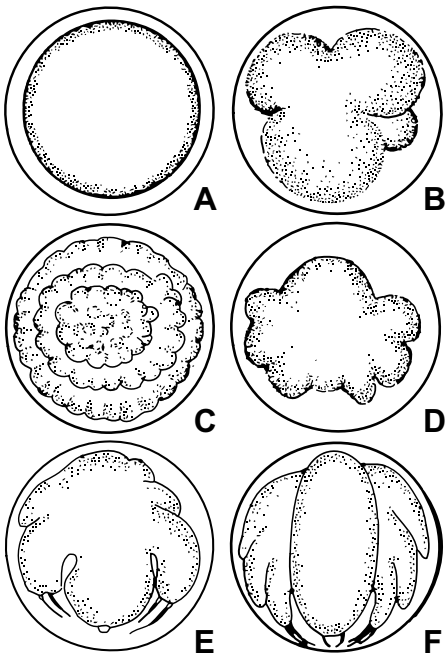

Fig. 4. Eggs of *Penaeus monodon* at various embryonic developmental stages. A: newly spawned egg; B: 4-cell stage (about 1 hr after spawning); C: morula stage (about 1.8 hr after spawning); D: early embryonic nauplius; E: late embryonic nauplius; F: embryonic nauplius immediately before hatching.

Adolescent. The body proportion is almost the same as that in the adult or slightly greater with the ratio of the length of about 0.58. The sexes can now be identified, beginning at 11 mm CL. The carapace length of the adolescent varies between 11 to 34 mm. The minimum size of males possessing a jointed petasma is about 30 mm CL, and the minimum size of females possessing adult-like thelycum is about 37 mm CL.

Subadult. This stage begins at the onset of sexual maturity i.e., minimum-sized males possessing spermatozoa in terminal ampoules, and minimum-sized females possessing spermatozoa inside the thelycum through copulation.

A sex size disparity occurs at almost 30 mm CL, and hereafter the size of females becomes greater than males. They migrate from nursery to spawning grounds. During this stage, first copulation takes place between males with minimum CL of 37 mm and females of 47 mm in the estuarine or inner littoral areas before migrating to deeper water.

Adult. This stage is characterized by the completion of sexual maturity. Males possess spermatozoa in the paired terminal ampoules, and in fact there are no sexual differences from Subadult males apart from size increment and different habitat. Females start to spawn mostly offshore, whereas some spawn in shallow water. A second and other copulations may occur in majority of individuals. Their major habitat is the offshore area at depths of about 160 m.

The maximum size of males recorded is 71 mm CL, whereas the maximum recorded length of females is 81 mm CL, reaching 270 mm in body length or 260 g in weight. Carapace length varies between 37 and 71 mm in males and 47 and 81 mm in females.

The life history phases of *P. monodon* are summarized in Table 1, and the diagram of its life history is shown in Fig. 7. As mentioned earlier, the nursery ground of the giant tiger prawn is in the estuaries which include wide brackish water rivers (mostly upstream and middle portion), mangrove swamps and interior portions of enclosed bays. These areas are exposed to wide fluctuations of physico-chemical conditions, such as water temperature and salinity, so that juveniles and adolescents should have high tolerance to those conditions for their survival. Within those nursery

Table 1. Life history phases of the giant tiger prawn, *Penaeus monodon*.

Phase	Begins at	Duration	Carapace length (mm) Male	Female	Mode of life	Habitat
Embryo	Fertilization	12 hours	0.29[a]		Planktonic	Outer littoral area
Larvae	Hatching	20 days	0.5-2.2		Planktonic	Outer/inner littoral area
Juvenile	Completion of gill system	15 days	2.2-11.0		Benthic	Estuarine area
Adolescent	Stability of body proportion, development of outer genitalia	4 months	11-30[b]	11-37[c]	Benthic	Estuarine area
Subadult	Commencement of sexual maturity, first copulation	4 months	30-37[d]	37-47[e]	Benthic	Inner/outer littoral area
Adult	Completion of sexual maturity	10 months	37-71[f]	47-81[f]	Benthic	Outer littoral area

[a]Egg diameter, [b]Minimum size with jointed petasma, [c]Minimum size with adult-like thelycum, [d]Minimum size with spermatozoa in terminal ampoules, [e]Minimum size with spermatozoa in thelycum. [f]Maximum size ever found

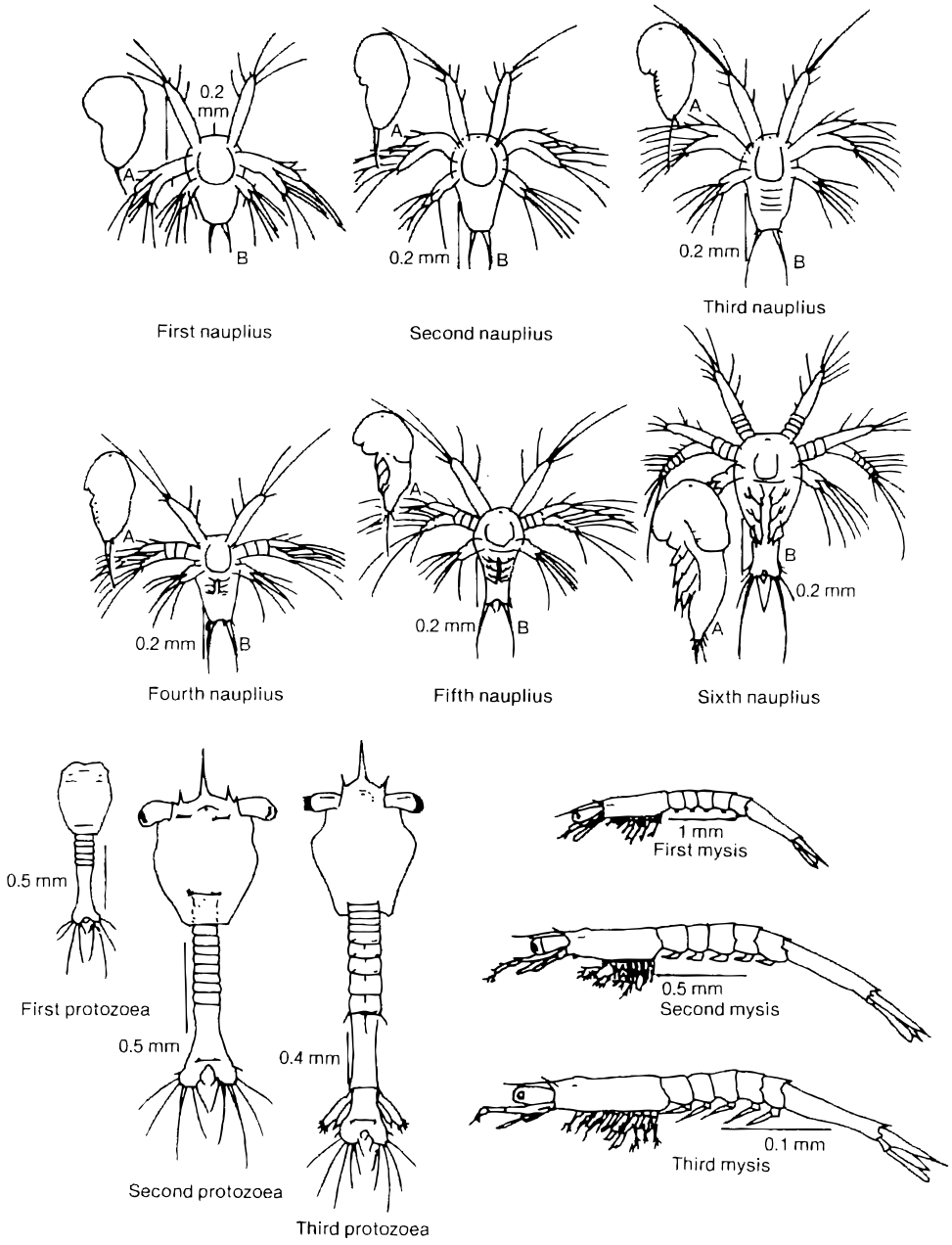

Fig. 5. Larval stages of *Penaeus monodon*. A, lateral view; B, ventral view.

grounds, however, the pressure of predators, particularly big finfishes, is generally not strong unlike in the open sea, and more nutrients are available. The mean monthly temperatures fluctuate between 26.3 and 31.2°C, and salinities between 20.0 and 28.9 ppt; both are extremely and suddenly decreased to about 20°C and 4 ppt, respectively, after a heavy rain.

Longevity

Based on data from pond-rearing experiments and size composition of wild specimens, the longevity of *P. monodon* is arbitrarily estimated to be about one and a half years for males and about two years for females. The higher female to male ratio of 1.5 in offshore waters compared to 1.0 in the nursery areas may be a result of the greater longevity of the female. However, more studies on this aspect are highly needed.

Mating*

Mating generally takes place at night, following molting of the female. The courtship and mating behavior may be observed in three distinct phases (Primavera, 1979):

Phase 1: Female above-male below in parallel swimming (Fig. 8A). From a moving or stationary position on the tank

*Descriptions and figures are all cited from Primavera (1979).

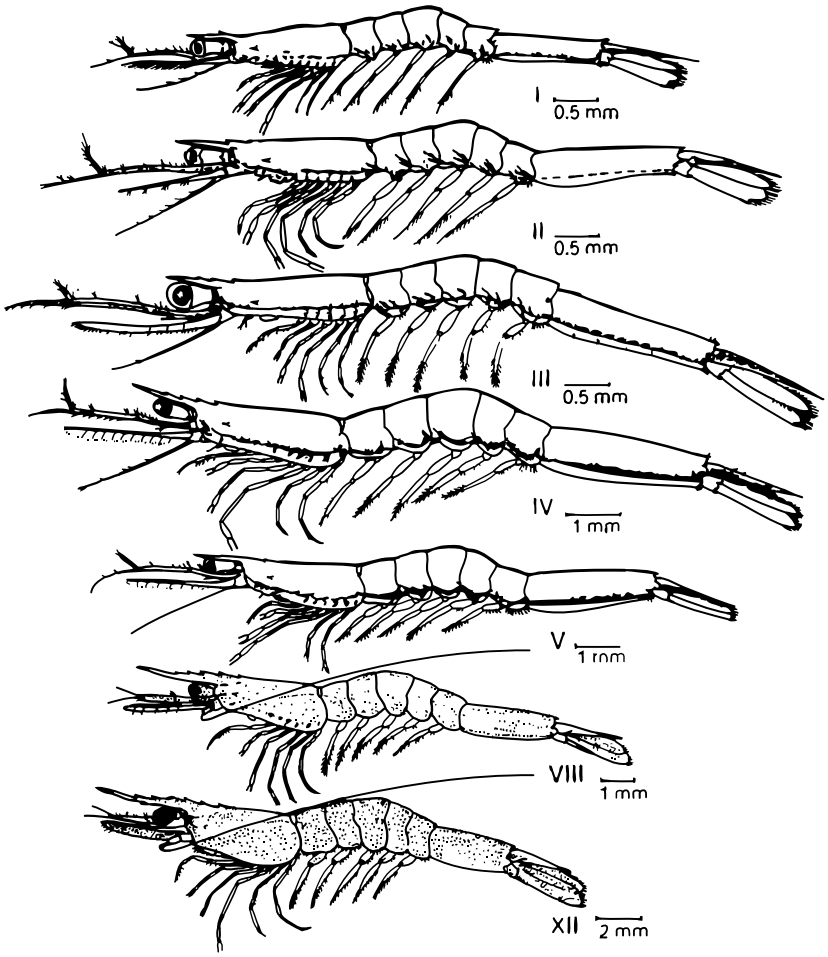

Fig. 6. Morphological development of megalopa (I-III) and juvenile (IV-XII) of *Penaeus monodon*.

bottom, the female swims upwards to a height of 20-40 cm. It moves in a slightly curved line over a distance of 50-80 cm, then changes course, either completely reversing direction or turning at a right angle. These swimming movements are interspersed with rests on the bottom lasting from seconds to a few minutes. While either swimming or resting, the female is approached by one to as many as three males after some kind of initial attraction, the males trailing behind the female as it swims. Eventually the male, or one particular male, in case of many initially attracted to the female, catches up with the female and positions its body directly below the latter. The pereopods of the female hold on to the carapace of the male and help to keep it in position while swimming continues; even later, the pereopods of both partners actively help to maintain the desired positions in the succeeding phases. This phase is the longest and can last up to 2 hours if the male is dislodged from its position below the female by another male or if lengthy rests on the tank bottom intersperse with the swimming activities. It may be as quick as 20 minutes if the male immediately attains the position described in phase 2 below.

Phase 2: Male turns ventral side up and attaches to female (Fig. 8B). Swimming in tandem with the female, the male turns abruptly to a ventral side up position, attempting to align the thoraco-abdominal junction with the posterior thorax of the female. Once the ventral-to-ventral position is achieved, it is difficult for other males to displace the first male and copulation is certain. If unsuccessful, the male immediately returns to the former upright position, still trying to swim parallel to the female, following the latter's every change in direction.

Phase 3a: Male turns perpendicular to female (Fig. 8C). Once the male succeeds in attaching ventrally to the female, it turns perpendicular to the latter, rotating at the point of the posterior end of the thorax. At this junction, the pair may either maintain their position in the water or slowly settle to the bottom.

Phase 3b: Male arches body around female and flicks head and tail (Fig. 8D). Immediately after assuming a position perpendicular to the female, the male curves its body in a U-shape around the thorax of the female and flicks both head and tail simultaneously, as in a squeezing action, up to three times in quick succession. Soon after, the male separates from the female and moves or swims away. The female may also move away.

Progress from ventral attachment (phase 2) to head- and tail-flicking (phase 3b) is very quick, lasting a few seconds. The whole process from the initial upward swimming move-

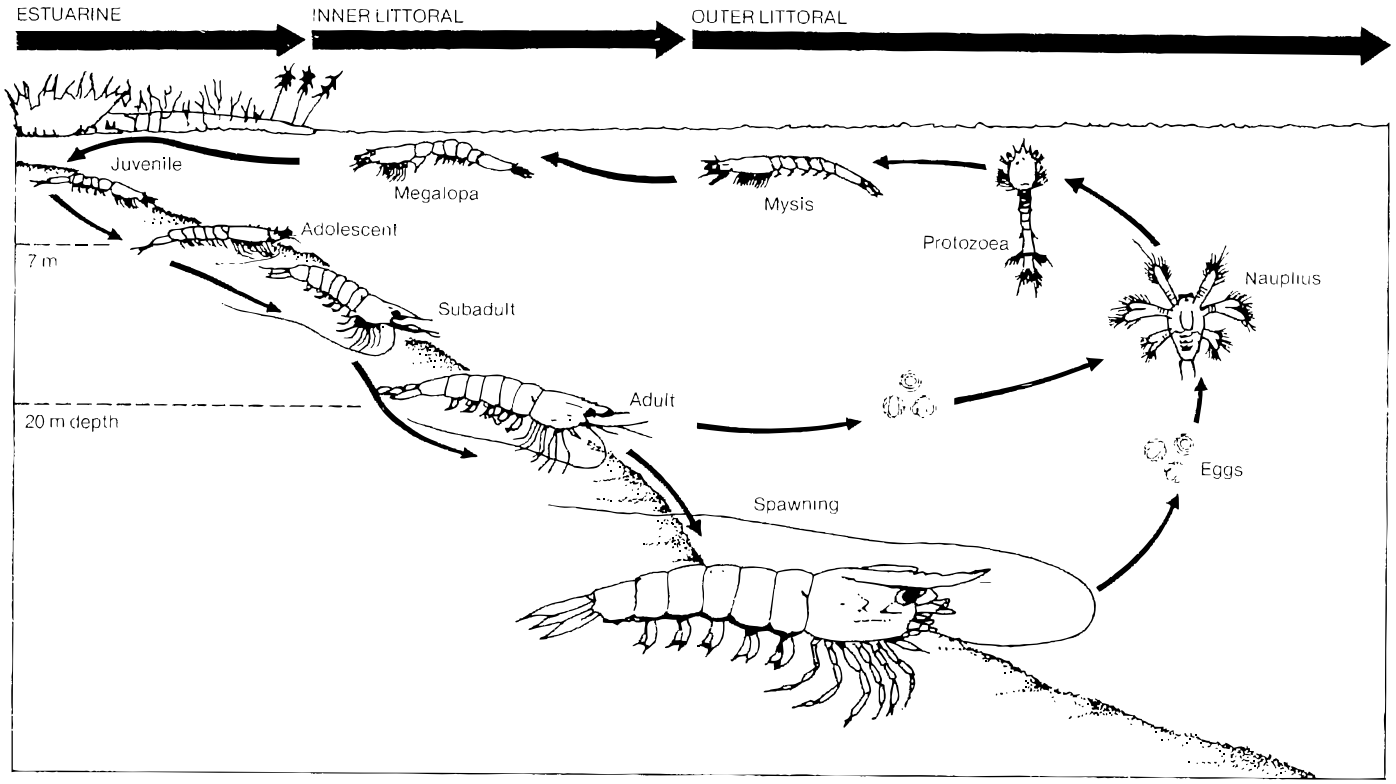

Fig. 7. Diagrammatic representation of the life history of *Penaeus monodon*.

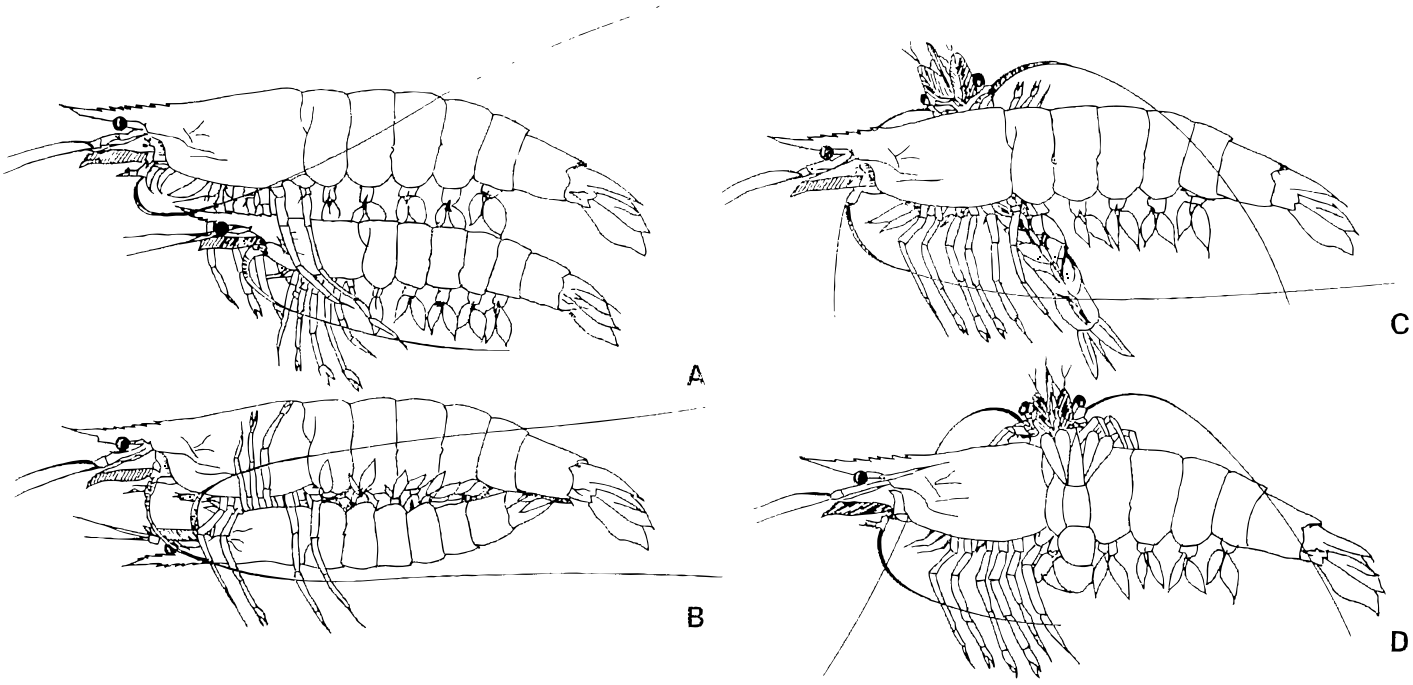

Fig. 8. Courtship and mating behavior of *Penaeus monodon*. A: Female above-male below in parallel swimming (phase 1); B: Male turns ventral side up and attaches to female (phase 2); C: Male turns perpendicular to female (phase 3a); D: Male curves body around female and flicks head and tail simultaneously (phase 3b) (Primavera, 1979).

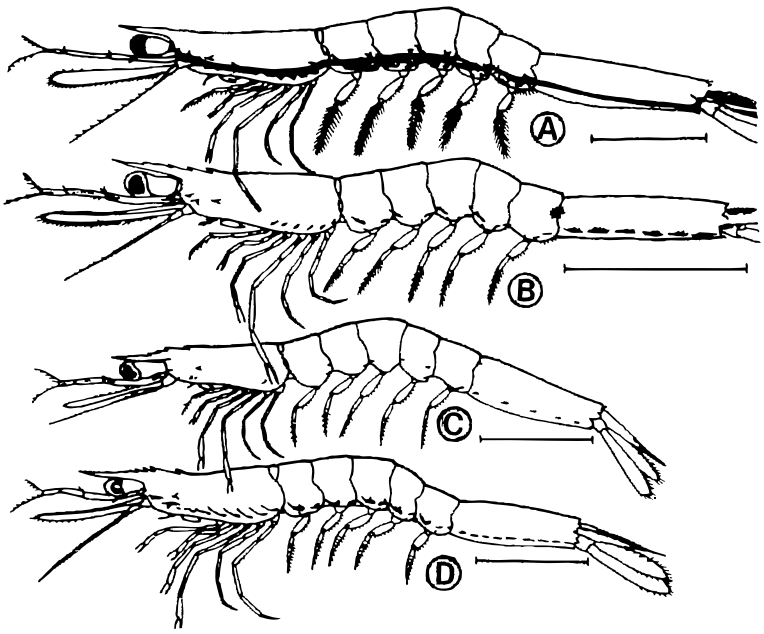

Fig. 9. Lateral view of *Penaeus* postlarvae showing chromatophore patterns. A: *P. monodon*; B: *P. semisulcatus*; C: *P. merguiensis* group; D: *P. japonicus* group. Scales represent 2 mm.

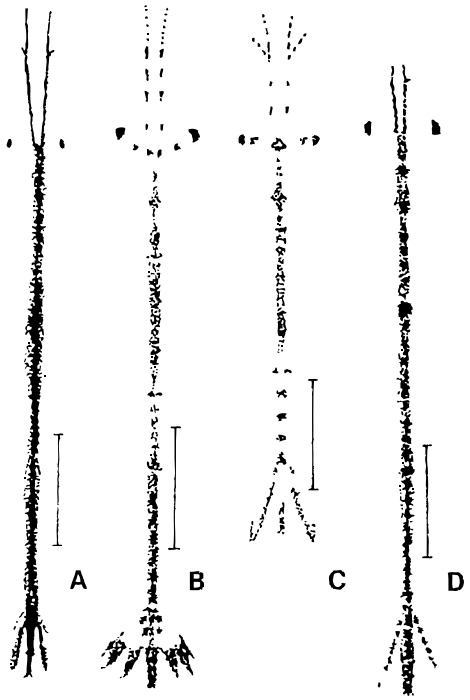

Fig. 10. Dorsal view of *Penaeus* postlarvae showing chromatophore patterns for quick identification. A: *P. monodon*; B: *P. semisulcatus*; *C: P. merguiensis* group; D: *P. japonicus* group. Scales represent 2.5 mm.

ments of the female to the separation of the pair may last from half an hour to 3 hours.

Spawning

Spawning generally takes place at night. While resting on the sandy bottom, the spawner suddenly becomes active, swimming in the water for about one minute, and then starts to spawn while swimming very slowly in the upper or middle part of the water. During spawning, the last three pairs of pereopods are held tightly together and flapped with an open and close movement, presumably to help discharge eggs and spermatozoa, while strongly moving the pleopods for swimming. The eggs are extruded from the paired genital pores located at the base of the 3rd pereopods at the same time as spermatozoa from the thelycum located at the base of the 5th pereopods, looking like greenish smoke and whitish smoke, respectively, blowing backward. It is believed that these discharged eggs are fertilized in the water owing to turbulence generated by the forward and backward movements of the pleopods. As a result, the movement of the pleopods seems to aid not only in swimming but also in fertilizing the eggs spawned. The fertilized eggs remain suspended in the water for a few minutes making the water turbid, and then gradually sink to the bottom. The time required for each spawning is approximately 2 minutes.

Fecundity

The carapace of spawners varies from 53.1 to 81.3 mm, and the number of eggs from 248,000 to 811,000. It may be said that the number of eggs spawned increases with carapace length.

Food and feeding habit

The food of *P. monodon* consists mainly of crustacea (small crabs and shrimps) and mollusks, making up 85% of ingested

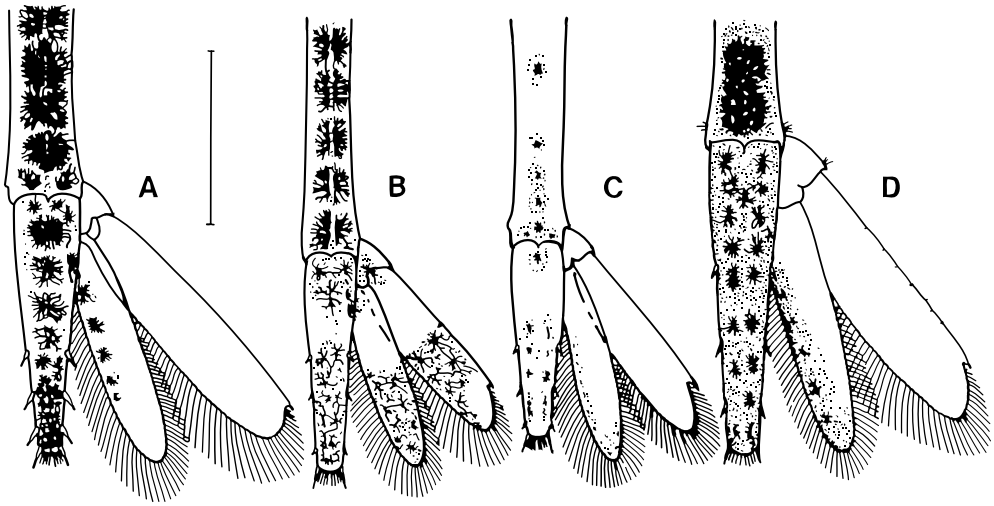

Fig. 11. Dorsal view of the 6th abdominal segment, telson and uropods of *Penaeus* postlarvae showing chromatophore patterns. A: *P. monodon;* B: *P. semisulcatus;* C: *P. merguiensis* group; D: *P. japonicus* group. Scale represents 1 mm.

food. The remaining 15% consists of annelids and others. *P. monodon* is more of a predator of slow-moving benthic macroinvertebrates rather than a scavenger or opportunistic in feeding habit. The feeding habit appears to be associated with the tidal phase (Marte, 1980).

Identification of postlarvae (fry)

It has been observed that fry collectors and concessionaires sometimes mistakenly identify the postlarvae of *P. monodon*. However, identification of the postlarvae can be made based on their morphological characteristics such as shape of the rostrum, number of rostral teeth, relative length of antennular flagella, antennal spine, and presence of dorsal spinules on the 6th abdominal segment. The chromatophore patterns on the 6th abdominal segment and on the telson and uropods are also useful (Figs. 9-11, keys).

Key to the postlarval *Penaeus* appearing at shore waters, based on morphological features

1) Rostrum stout and inferior to tip of eye, spinules on the 6th abdominal segment present[a], antennal spine prominently present, carapace slightly longer than 6th abdominal segment.....*P. japonicus* group

   Rostrum slender and exceeding tip of eye, spinules on the 6th abdominal segment absent, antennal spine absent or minute, carapace slightly or distinctly shorter than 6th abdominal segment.....2
2) Inner (lower) antennular flagellum nearly 1.6 times the outer (upper), exceeding the latter by its distal one segment.....*P. merguiensis* group

   Inner antenullar flagellum 1.6 to 2.0 times the outer, exceeding the latter by its distal two segments ..... *P. semisulcatus*

   Inner antennular flagellum more than 2.0 times the outer, exceeding the latter by its distal three segments ..... *P. monodon*

[a]When the number of rostral teeth is less than four, the spinules are sometimes poorly present or absent. In this case, other criteria are useful.

Key to the postlarval *Penaeus* appearing at shore waters, based on chromatophore patterns

1) Number of chromatophores on the 6th abdominal segment less than seven. Anterolateral chromatophore of the 6th abdominal segment present..... ..... *P. merguiensis* group

   Number of chromatophores on the 6th abdominal segment more than seven. Anterolateral chromatophore of the 6th abdominal segment present or absent.....2
2) Number of chromatophores on the 6th abdominal segment less than 12. Anterolateral chromatophore of the 6th abdominal segment present, chromatophores on the middle portion of telson and inner uropods absent ..... *P. semisulcatus*

   Number of chromatophores on the 6th abdominal segment more than 12. Anterolateral chromatophore of the 6th abdominal segment absent, chromatophores on the middle portion of the telson and inner uropods present.....3
3) Chromatophores on the 6th abdominal segment dense and thickly continuous.....*P. monodon*

   Chromatophores on the 6th abdominal segment discontinuous or confluent.....*P. japonicus* group

Recommendations

For the conservation of the nursery grounds and for increasing production of the giant tiger prawn, the following are recommended:

a) Avoid conversion of nursery grounds (brackish water areas) into fishponds or human settlement areas.
b) Ban spreading of chemicals for killing predators in fishponds and nursery grounds.
c) Introduce postlarval *P. indicus* as well as *P. merguiensis* into prawn ponds in addition to *P. monodon* for their cultivation.
d) Keep statistical data on the population of fry and adults of *P. monodon* and other penaeids in relation to their habitat and growth stages.
e) Artificial fertilization to utilize dead or weak spawners and genetic study to produce more suitable prawns might be necessary in the near future.

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An Ecological Approach to Mariculture of Shrimp: Shrimp Ranching Fisheries

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Abstract Mariculture production in Japan has grown recently to nearly one million tons per year. Mariculture production in the shallow coastal waters of Japan mainly consists of eight species of finfish, six species of shellfish, and three species of algae.

Kuruma shrimp culture techniques are highly developed. Nevertheless, only 1,800 tons of kuruma shrimp can be produced yearly. There is a demand for this species but culture grounds have become limited and there is not enough space to raise shrimp. In 1980, 600 million postlarvae were produced but one-half had to be released to the sea. The released shrimp that survived and grew have formed a new basis for the "Sea Ranching Fisheries" industry. The trial releases of postlarvae have proven that sea ranching of shrimp can be successful.

To strengthen the foundation of sea ranching fisheries, there must be future research on ecological impact, as well as on physico-chemical water parameters. The life cycle, feeding habits, and predators of the shrimp must also be studied. Recent releases in Hamana-ko Lagoon, Shizuoka Prefecture, made by the research group of the Hamana-ko Substation of the Shizuoka Prefectural Fisheries Research Station have demonstrated the possibilities of sea ranching. This report discusses the research studies obtained at Hamana-ko Lagoon and the main problems of the use of this sea ranching method in mangrove swamp areas of Southeast Asia.

Introduction

Recent commercial mariculture production in the shallow coastal waters in Japan has grown to nearly one million tons per year. It is about 8.2% of total production or 940 x 10^4 tons and consists of yellowtail, sea bream, oyster, scallop, "nori" (*Porphyra*), and *Undaria* (Fig. 1; Table 1). There are more varieties of species cultivated as compared to Southeast Asian countries, for example: Philippines—milkfish, Malaysia—blood cockle, and Thailand—blood cockle and mussel. In Japan, the number of species for culture has been increasing. In the commercial mariculture of various species, the basic thing is to establish mass production techniques for seed supply. In hatcheries, techniques are studied and progressively being developed for various species. In 1981, the Japan Sea Farming Association and prefectural governments produced more than 2,400 million seed of finfish and shellfish to stock the open sea as shown in Table 2.

In the case of kuruma shrimp, *Penaeus japonicus,* techniques have been stabilized at a high level with production of about 513 million postlarvae in 1981, of which 60% were released to the sea. The released postlarvae that have survived and grown have formed a new basis for sea ranching fisheries. Many trial releases of postlarvae have proven that sea ranching of shrimp can be successful. To strengthen the foundation of sea ranching fisheries, much ecological knowledge is needed about the distribution, food habits, predation, population dynamics, etc. of the species to be restocked.

In this report, some problems in shrimp ranching fisheries are described based on results of trial releases of *P. japonicus* postlarvae in the Hamana-ko Lagoon, Shizuoka Prefecture, made by the research group of the Hamana-ko Substation, Shizuoka Prefecture Fisheries Research Station.

Fishing area

A brief topography of Hamana-ko Lagoon is shown in Fig. 2. It is one of the largest lagoons on the coast of Honsyu, main island of Japan. The water system is very simple in comparison with many mangrove areas in the Philippines (Motoh, 1981) and the Mexican coastal lagoon complex (Edwards, 1978a). Directly connected with the sea through a narrow neck 200 m wide, the lagoon has a surface area of 6,900 ha and maximum depth of 12 m in the inner part. Tidal range varies from 30 cm in the bottom part to 180 cm near the sea mouth. The water exchange due to tidal current is estimated to be about 42.3 million ton/day.

Subjected to tidal influence, salinity ranges from 18.56 ppt in January to 15.17 ppt in July near the sea mouth of the lagoon and from 16.98 to 14.22 ppt in the center. Water temperature ranges between extremes of 3.8 to 29.2°C in the center, and from 8.8 to 25.8°C near the sea mouth.

The lagoon bottom is silty clay mud in depths of more than 5 m and predominantly sand or muddy sand in shallower areas. These shallower sandy waters support a shrimp fishery of commercial importance. Recently, shrimp fisheries in the lagoon have developed steadily with production reaching 100 tons in 1984 due to restocking of the shrimp postlarvae. Shrimp fishing gear consisting of three types, drift gill net, traditional cover net, and small set net, contributes to the shrimp catches. The fishing grounds for set nets are shown in Fig. 3.

Table 1. Annual mariculture production (in tons) by species in Japan (after Fisheries Agency, Japan, 1984).

Year	Finfish						
	Yellow-tail	Sea-bream	Horse mackerel	Hardtail (*Caranx*)	Fugu	Filefish	Others
1972	77,059	1,380	127		14	39	104
1973	80,439	2,741	378	—	16	40	150
1974	92,946	3,298	619	48	8	25	140
1975	92,407	4,462	920	22	9	8	170
1976	101,786	6,572	704	58	11	2	125
1977	115,098	8,245	743	61	15	10	238
1978	121,956	11,315	809	177	47	3	701
1979	155,053	12,253	1,461	304	73	—	1,178
1980	149,449	14,973	2,272	228	68	3	2,724
1981	150,907	18,243	3,195	158	162	3	2,235
1982	146,486	20,648	3,613	256	503	15	3,484

	Invertebrates						
	Oyster	Scallop	Pearl	Octopus	Japanese prawn	Ascid-ians	Others
1972	217,373	23,049	42	68	454	1,118	36
1973	229,899	39,397	34	56	659	4,675	289
1974	210,583	62,651	30	54	912	5,036	134
1975	201,173	70,313	30	41	936	6,313	114
1976	226,278	64,946	34	42	1,042	8,390	73
1977	212,779	83,213	39	16	1,124	7,463	92
1978	232,069	67,750	37	11	1,184	5,759	207
1979	205,509	43,622	40	22	1,480	5,287	173
1980	261,323	40,403	42	22	1,546	5,746	370
1981	235,241	59,106	46	8	1,666	6,909	481
1982	250,287	76,876	52	4	2,000	7,382	283

	Algae				**Grand total**
	Porphyra	*Undaria*	*Laminaria*	Others	(finfish, invertebrates and algae)
1972	217,906	105,695	3,340		647,905
1973	311,410	113,211	7,681	—	790,974
1974	339,314	153,762	10,201	—	879,761
1975	278,127	101,937	15,759	—	772,741
1976	291,050	126,701	22,096	—	849,909
1977	279,031	125,798	27,260	64	861,389
1978	350,471	102,665	21,890	194	917,244
1979	325,686	103,788	25,291	1,164	992,620
1980	357,672	113,532	38,561	2,904	991,843
1981	340,510	91,273	44,220	5,329	959,680
1982	263,312	118,338	42,978	1,888	938,680

Life history

There are many reports on the life history of penaeid shrimps, e.g., *Penaeus vannamei* (Lopez, 1967; Chavez, 1973), *P. japonicus* (Kurata, 1972), *P. monodon* (Motoh, 1981), *P. setiferus* and *P. aztecus* (Mock, 1966). *P. japonicus* (Kurata, 1972) and *P. monodon* (Motoh, 1981) have six life cycle history phases: embryo, larva, juvenile, adolescent, Subadult and adult. Each stage has its preferred habitats. Penaeids exhibit typical migratory behaviour—postlarvae migrate towards inshore waters on tidal currents and spend juvenile and adolescent phases in brackish waters like lagoon complexes, estuarine areas including mangrove and swamp areas, and interior portions of bays. At the end of the juvenile and adolescent phases, they migrate back downstream to the outside coastal waters.

Penaeus japonicus in Hamana-ko Lagoon also shows a typical life cycle pattern. The postlarvae metamorphose outside the lagoon, then move to the mouth part and enter the lagoon. The abundance of postlarvae (Fig. 4) was determined by plankton net sampling at approximately monthly intervals over a 12-month period in 1955-56. The postlarvae enter the lagoon mostly from July to September. The inshore movement of postlarvae continues during flood tides, noticeably decreases during ebb tides, and stops three hours after the commencement of ebb tide. *P. japonicus* spends juvenile,

adolescent and Subadult phases in the lagoon. There is no evidence of occurrence of mature adults more than 37.5 g in body weight and 180 mm in body length. Migratory routes of the shrimp are shown in Fig. 5.

Growth and recruitment

Trial releases of postlarval *P. japonicus* in Hamana-ko Lagoon have been carried out by the Shizuoka Prefectural Government since 1978. The number of postlarvae released reached a total of 17.6 million over a period of five years. Table 3 shows the postlarvae released at the Shirasu area from August 1981 to November 1984. The method of release consists of three steps: hatchery production, nursery culture and release. Hatchery-produced postlarvae of 14-15 mm body length are cultured in an enclosure with an average area of 6,000 m^2 at a stocking rate of 270 individuals/m^2 fed on artificial diets for 16.8 days. They grow to 29.6 mm body length with 49.7% survival rate. Some 9.7 million postlarvae have been released at the Shirasu area over three years (Table 3).

To obtain growth estimates of the released stocks and naturally recruited populations, continuous sampling at 5-day intervals during the fishing season (April to early December) was done. Specimens were collected from shrimps caught in set nets in offshore Shirasu, Shonai-ko as shown in Fig. 3. The length frequency distribution was analyzed by Cassie's method (1954). Each population could be extracted from these polymodal length frequencies in spite of continuous recruitment and release. Weight (W) in grams was calculated using the formula:

$W = 1.9001 \times 10^{-5} \times L^{2.8927}$ (mm), R = 0.9984 for females

$W = 2.0239 \times 10^{-5} \times L^{2.2748}$ (mm), R = 0.9992 for males

The results are shown in Fig. 6 and Table 4. The potential stocks of 1983 in the lagoon consisted of five populations

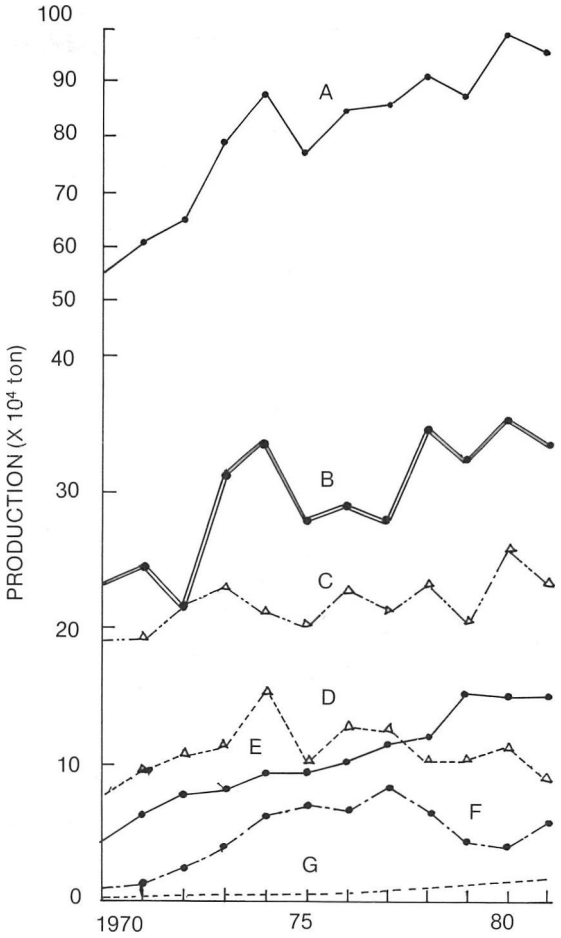

Fig. 1. Annual mariculture production by species. A, total; B, *Porphyra*; C, oyster; D, *Undaria*; E, yellowtail; F, *Pecten*; G, sea bream (Fishery Agency, 1983).

Table 2. Annual seedling production (× 10^3 inviduals) for mariculture in Japan (after JASFA, 1984).

Species	No. of seedlings produced				No. of seedlings released in the sea			
	1978	1979	1980	1981	1978	1979	1980	1981
Fish								
Pagrus major	6,942	11,594	13,457	16,120	5,109	8,600	10,359	12,044
Acanthopagrus schlegelii	443	2,113	2,386	2,867	407	1,267	1,314	1,955
Gadus macrocephalus	1,100	1,834	1,209	2,350	1,100	2,113	1,209	2,350
Limanda yokohamae	1,795	1,601	1,693	1,727	1,215	401	733	815
Paralichtys olivaceus	379	1,051	3,203	3,688	297	898	2,370	1,156
Fugu rubripes	602	1,615	445	454	550	615	442	454
Sebastiscus marmorata	68	325	75	127	48	25	75	57
Seriola quinqueradiata	0.3	105	230	216	—	21	120	63
Lateolaborax japonicus	56	36	325	104	53	31	25	104
Invertebrates								
Penaeus japonicus	448,864	534,634	599,853	513,111	280,075	337,229	297,842	302,138
Metapenaeus ensis	10,960	32,516	29,301	39,144	10,595	25,141	12,483	19,193
Neptunus trituberculatus	10,280	18,070	16,041	18,352	7,870	12,171	11,519	11,212
Patinopecten yessoensis	1,798,315	1,822,143	2,131,713	2,055,439	1,566,655	1,699,127	1,525,333	2,127,447
Anadara broughtonii	1,490	11,932	11,854	6,766	651	2,764	5,187	3,137
Haliotis spp.	10,863	11,724	16,471	18,881	7,205	8,597	10,690	12,485
Meretrix lusoria	390	1,500	2,530	35	395	2,158	10,348	2,860
Babylonia japonica	65	109	177	3,240	50	109	212	2,627

Table 3. Release of postlarval *Penaeus japonicus* (ave. body length 14.1 mm) at Shirasu area, Hamana-ko Lagoon (after data from Hamana-ko Substn., Shizuoka Pref. Fish. Res. Stn.).

Year and group	Nursery culture				Release	
	No. stocked (× 10^3)	Period (days)	Survival rate (%)	Body length (mm)	No. (× 10^3)	Date
1981 RS_1	2,567	14	43.5	33.1	1,374	Aug. 12
RS_2	500	10	32.8	30.9	164	Sep. 9
RS_3	1,742	24	66.7	29.1	1,162	Oct. 31
1982 RS_1	500	16	3.3	28.5	50	Aug. 7
RS_2	500	13	57.1	26.3	285	Oct. 9
RS_3	2,092	18	49.7	26.1	2,150	Nov. 6
1983 RS_1	2,038	14	42.6	30.3	1,652	Aug. 10
RS_2	377	16	42.8	33.0	522	Sep. 24
RS_3	4,388	27	52.6	29.0	3,308	Nov. 2
Total/Ave.	14,704	16.8	49.7	29.6	9,667	—

derived from natural recruitment (groups $82N_4$ and $83N_{1-4}$) and five released populations (groups $82RS_{1-3}$ and $83RS_{1-2}$). The females released in August 1982 (group $82RS_1$) were caught in set nets, attaining 5.4 g average body weight in early October and 20.2 g in mid-December (Table 4). Some appeared to emigrate to the outside sea but those that remained in the lagoon contributed to the next year's catches with average body weight of 27.2 g after overwintering in the lagoon. The groups of $82RS_2$ and $82RS_3$ released in October and November 1982, respectively, were not found in the 1983 catches due to smaller size. All of them overwintered in the lagoon and contributed to the 1983 catches with sizes of 6.6-15.9 g in early April to early June for group $82RS_2$ and 4.1-13.5 g in late April to late June for group RS_3.

Shrimp from the population originating from the fourth recruitment in 1982 (group $82N_4$) attained 3.6 g body weight in mid-October and 11.9 g in mid-December 1982. All of them appeared to winter and were caught with the size group 14.7-21.6 g from early April to late May 1983. Shrimp from the first to third natural recruitments in 1983 (groups N_{1-3})

Table 4. Estimated growth of *Penaeus japonicus* in Hamana-ko Lagoon in 1982-83 based on statistical analysis of samples caught in set nets in Shonai Inlet. N_{1-4}: population from natural recruitment; RS_{1-3}: population from postlarvae released at Shirasu area, Shonai Inlet (after data from Hamana-ko Substn. Shizuoka Pref. Fish. Res. Stn.).

Group	1982		1983		Remarks
	Estimated body weight		Estimated body weight		
	Start	End	Start	End	
Female 1982 $82N_4$	4.6 g late Aug.	27.6 g mid-Dec.			Emigration in 1982
$82RS_1$	5.4 g early Oct.	20.2 g mid-Dec.	27.2 g mid-Apr.	29.6 g late May	
$82N_4$	3.6 g mid-Oct.	11.9 g mid-Dec.	14.7 g early Apr.	21.6 g late May	Emigration to the
$82RS_2$	Released early Oct. (W)		6.6 g early Apr.	15.9 g early Jun.	sea in 1983
$82RS_3$	Released early Nov. (W)		4.1 g late Apr.	13.5 g late Jun.	
1983 $83N_1$			3.6 g late Jun.	14.4 g mid-Aug.	Emigration to the
$83N_2$			5.7 g late Jun.	12.5 g late Aug.	sea in 1983
$83N_3$			5.2 g mid-Aug.	26.3 g mid-Oct.	
$83N_4$			5.4 g early Sep.	25.4 g early Dec.	Wintering in the
$83RS_1$	Released mid-Aug. 1983		6.4 g late Sep.	16.3 g early Dec.	lagoon
$83RS_2$	Released late Sep. 1983		4.9 g late Oct.	9.5 g early Dec.	
$83RS_3$	Released early Nov. 1983				
Male 1982 $82N_3$	4.7 g late Aug.	17.7 g mid-Dec.			Emigration to the
$82RS_1$	5.4 g early Oct.	19.4 g mid-Dec.			sea in 1982
$82N_4$	4.1 mid-Oct.	12.2 g mid-Dec.	11.9 g early Apr.	16.1 g late May	Emigration to the
$82RS_2$	Released early Oct. 1982 (W)		6.8 g early Apr.	13.6 g early Jun.	sea in 1983
$82RS_3$	Released early Nov. 1982 (W)		4.3 g late Apr.	11.8 g late Jun.	
1983 $83N_1$			6.5 g mid-Jun.	10.6 g early Aug.	Emigration to the
$83N_2$			5.7 g late Jun.	11.8 g late Aug.	sea in 1983
$83N_3$			6.1 g mid-Aug.	18.2 g mid-Sep.	
$83N_4$			5.6 g early Sep.	18.9 g early Dec.	
$83RS_1$	Released mid-Aug. 1983		6.1 g late Sep.	13.1 g early Dec.	Wintering
$83RS_2$	Released early Sep. 1983		4.5 g late Oct.	9.5 g early Dec.	
$83RS_3$	Released early Nov. 1983				

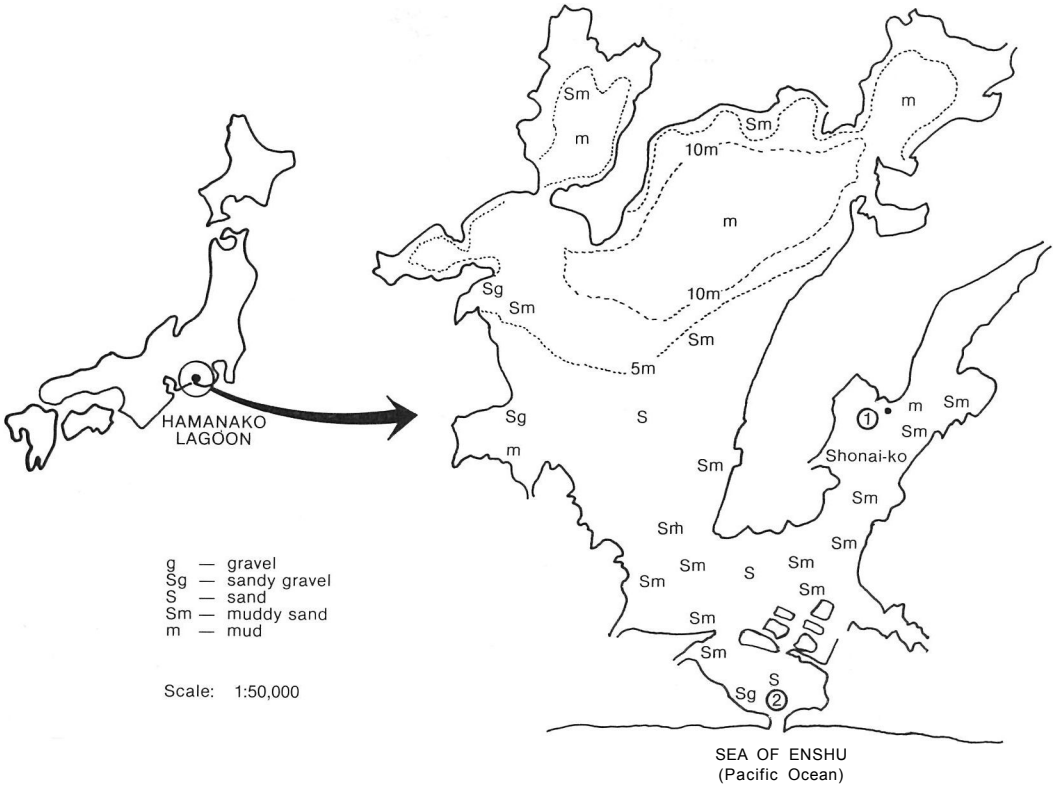

Fig. 2. Topography of Hamana-ko Lagoon showing bottom conditions and depth. 1, site of enclosure for nursery culture; 2, mouth of lagoon (Imakiriguchi).

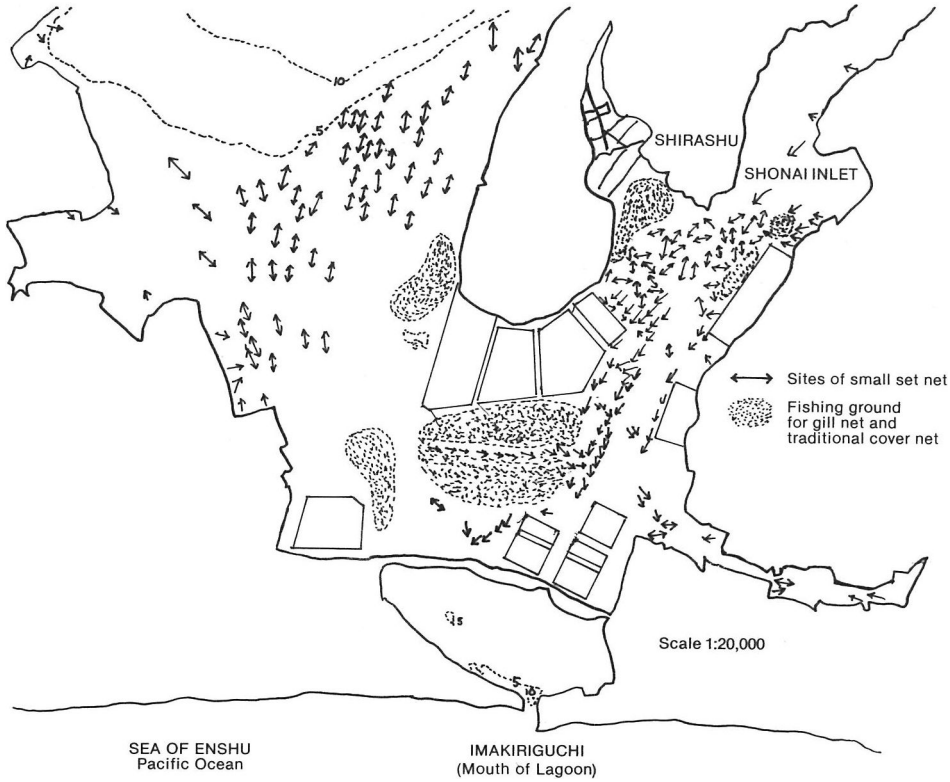

Fig. 3. Fishing grounds of kuruma shrimp, *Penaeus japonicus,* in Hamana-ko Lagoon. Figures denote depth in m.

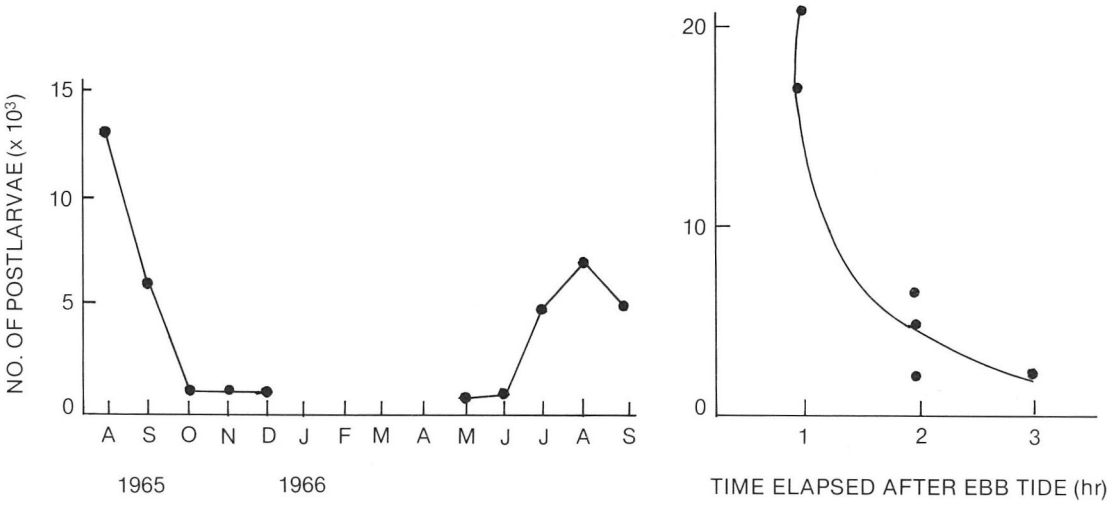

Fig. 4. Variation in number of postlarval *Penaeus japonicus* by month and in relation to ebb tide at the mouth portion of Hamana-ko Lagoon in 1973. (After data from Hamana-ko Substn., Shizuoka Pref. Fish. Res. Stn.)

were caught with the sizes 3.6-14.4 g from late June to mid-August for N_1, 5.7-12.5 g from late June to late August for N_2, and 5.2-26.3 g from mid-August to mid-October for N_3. The remaining shrimp appeared to emigrate to the outside sea. The group $83N_4$ could not be caught in this year due to smaller size. They could contribute to the catches for next year as described in the case of $82N_4$.

Estimated growth in body length based on size distribution data is 0.62 ±0.16 mm/day with a range of 0.41-0.87 mm for females and 0.53 ± 0.17 mm/day with a range of 0.26-0.80 mm for males. Growth rate of 0.87 mm for females and 0.80 mm for males were derived from group $83N_3$ and $83N_2$, respectively, which were caught in summer. Minimum growth rate of 0.41 mm for females and 0.26 mm for males were derived from groups $82RS_1$ and $82RS_2$ caught in spring after overwintering.

There are many reports on growth rates of *Penaeus* spp. — *P. aztecus* (Cook and Lindner, 1970), *P. setiferus* (Williams, 1955), *P. vannamei* (Sato, 1979; Edwards, 1977) and *P. stylirostris* (Menz and Bowers, 1980). Direct comparison of growth rates of *P. japonicus* with those of other species is difficult because of different ways of data presentation. The present results indicate that the sizes of *P. japonicus* that immigrate to the lagoon in summer are greater than those in spring and autumn with differences between males and females.

The catch curve (Ricker, 1975) was obtained according to the variation of catch per unit effort calculated at 5-day intervals throughout the 1983 fishing season and the annual catch for each naturally recruited and released population. Results are shown in Table 5.

A total of 6.98 million postlarval *P. japonicus* (30 mm size) were stocked in the Shirasu area (fishing ground ca. 200 ha) and production was 2.4 times greater than catches in natural waters.

Application of sea ranching to Southeast Asia

The activity of releasing postlarval *P. japonicus* has recently become extensive in Japan, reaching 302 million postlarvae released in 1983. The main sites for releases are inlets and open or semi-open waters. The trial in the Hamana-ko Lagoon is the first successful one. After many studies on the feasibility of stocking open waters with shrimp postlarvae, it has been proven that this system provides three advantages: 1) increased production, 2) stabilized

Table 5. Estimated annual catch for each population of *Penaeus japonicus* in the Shirasu area, Shonai Inlet, Hamana-ko Lagoon. 1983.

Group	Annual catch		Body wt. (g)	Percentage	Remarks
	Number	Wt. (kg)			
Natural population					
$82N_4$	24,048	370.1	15.4	5.15	Wintering
$83N_{1\text{-}4}$	276,192	2,533.5	9.2	35.14	
Total	300,240	2,903.6		40.39	
Released population					
$82RS_{1\text{-}3}$	386,483	4,030.0	10.4	56.05	Wintering
$83RS_{1\text{-}2}$	29,551	256.1	8.7	3.56	
Total	416,083	4,286.1		59.61	
Grand total	716,278	7,189.7	10.9*	100.10	

*Average

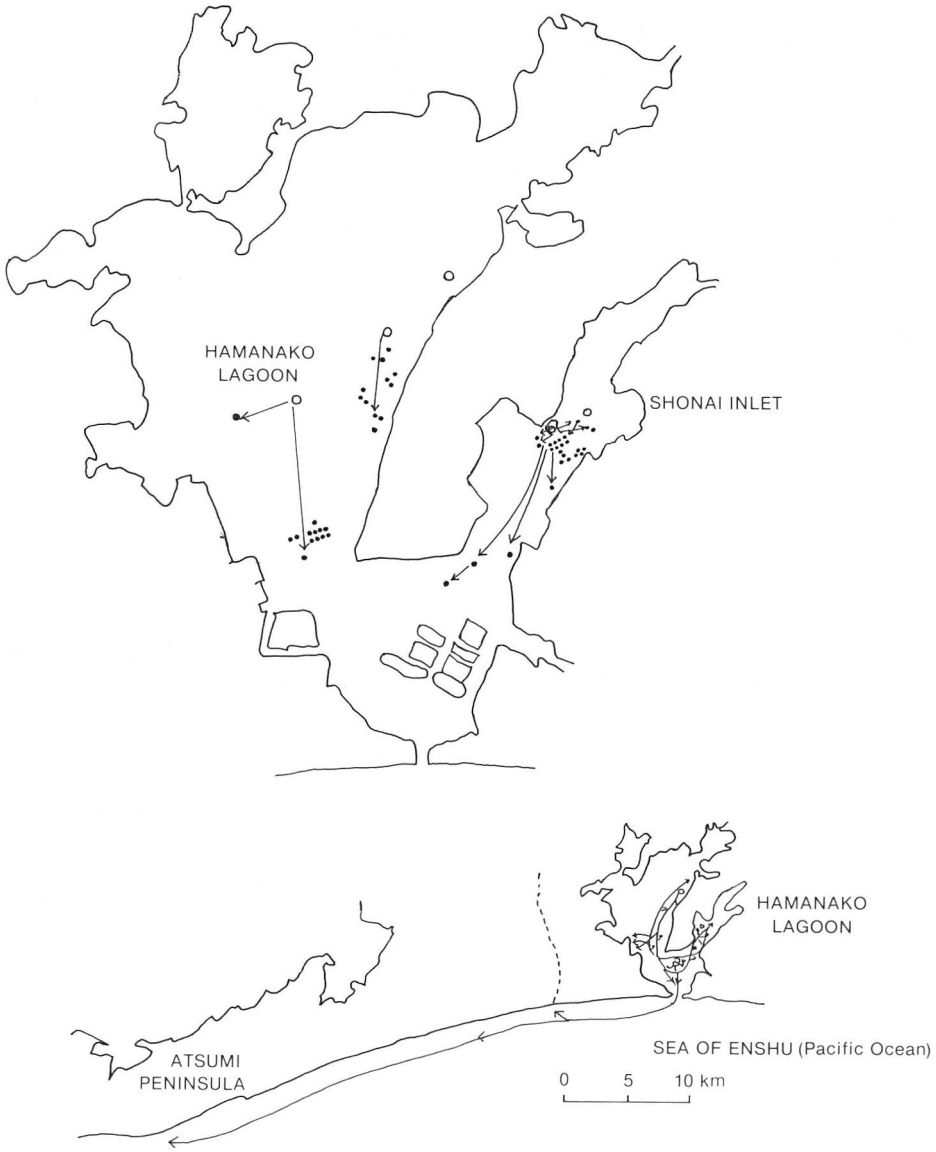

Fig. 5. Migration of kuruma shrimp in Hamana-ko Lagoon and the open sea based on tagging experiments in 1973-74; ● release site: → migration route. (After data from Hamana-ko Substn., Shizuoka Pref. Fish. Res. Stn.)

production through adjustment of the time postlarvae are released, and 3) addition of shrimp not caught to the natural breeding population. In the case of the Hamana-ko trials, it becomes clear that the released postlarvae survived and grew, contributing to fishery catches and forming a new basis for sea ranching fisheries.

The author proposes the application of this sea ranching system to the shallow coastal zones of Southeast Asian countries for the development of large-scale prawn culture. There are very large areas suitable for commercially important penaeid prawn species such as *Penaeus monodon*, *P. merguiensis*, *P. indicus*, *P. brevicornis*, *P. semisulcatus*, *Metapenaeus ensis*, etc. Among all these species, *P. monodon* has been most closely investigated as a suitable species for culture. Pond cultivation of prawns in coastal zones is rapidly developing in the countries of Southeast Asia. In other words, the traditional method of building ponds in mangrove swamps now causes the destruction of mangrove areas and the gradual disappearance of the mangrove ecosystem.

It is well known that mangroves have both a land-building and coast-protecting function (Davis, 1940). These backwater areas are a complex combination of swamps, creeks, rivers and mangrove forests where salt water and fresh water gradually mix. They are an important buffer zone between freshwater and marine environmental conditions.

From the ecological point of view, these mangrove areas are natural nursery ponds for juveniles of many organisms including penaeid prawns (MacNae, 1974). This brackish-water zone has abundant shelter and the decomposition of leaves and other organic matter, and inorganic nutrients carried by river floods provide a rich supply of detritus as food for the benthic community.

In order to preserve the mangrove ecosystem and still make use of this large productive coastal area, a new approach to culture like sea ranching is needed. Penaeid prawns come into mangrove and estuarine areas as juveniles and remain there until they reach Subadult size. Then they emigrate offshore to deeper waters where they mature and reproduce. In the case of *P. monodon*, they remain in the coastal area up to a size of about 30 g in body weight. This means that the mangrove coastal habitat is most suitable for this stage of their life cycle. It is possible to enclose large coastal areas, *P. monodon* and other penaeid species could be kept in such enclosures of several hundred hectares. This type of enclosure could be constructed in the same way as the fish pens in Laguna de Bay (Delmendo and Gedney, 1974). They could be used to enclose shallow water areas along the coast and river estuaries as well as mangrove areas. Harvesting would be done by trapping prawns as they try to emigrate offshore after growing to Subadult size. Trapping methods are well documented for the Pacific coast of Mexico (Edwards, 1978b) and Adriatic coastal lagoons (Ravagnan, 1978). The process of harvesting would be continued and stocking of hatchery-produced fry would be timed through adjustment of release dates to stabilize and increase the potential stock relying on natural fry which enter the enclosed areas. With such a stocking system, some supplementary feeding may be necessary. In this way, coastal areas could be used for prawn production without the need to construct ponds thereby preserving the basic mangrove areas.

In order to develop large-scale prawn culture based on the system of sea ranching, much basic ecological information is needed about population dynamics, life history, and biotic and abiotic parameters of the ecosystem. Furthermore, several engineering and biotechnical points need investigation for the layout of such large-scale enclosures. These include the most suitable enclosure area, optimum water level within the enclosure, construction of a low dike to maintain water level at low tides, and increasing the tidal pool water area within the mangrove swamp to act as nursery pools.

It will be necessary to establish some legal framework such as fishing rights and licenses to promote large-scale aquaculture using mangrove areas while preserving their natural conditions by not building fishponds. As the utilization of mangrove areas for this kind of culture will greatly affect the villager's small-scale fisheries and community life in general, some form of administration is needed to settle conflicts of interest. Moreover, if the use of mangrove areas is limited to just a few individuals, the disparity of income among villagers may increase to the extent of disturbing the peace of communities. In order to prevent such negative results, it is advisable to work out a legal system with fixed rules for the use of mangrove areas that will benefit large sections of coastal communities.

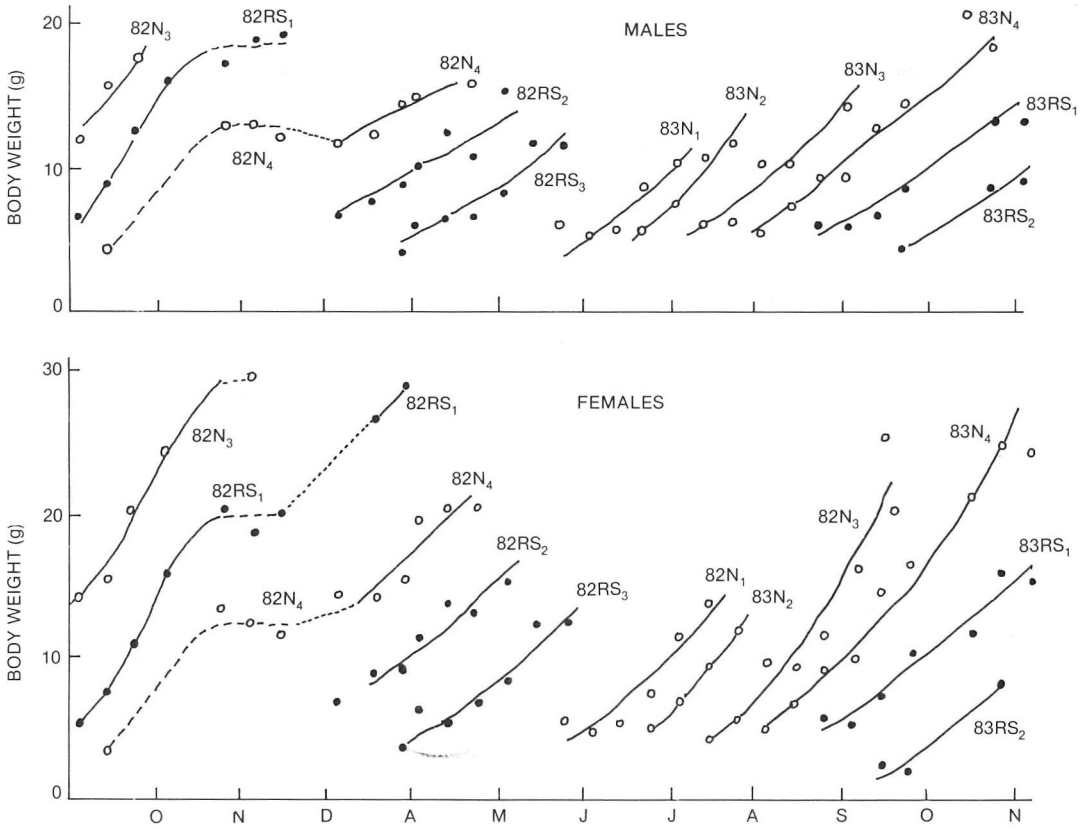

Fig. 6. Estimated growth curves of kuruma shrimp, *Penaeus japonicus,* in Hamana-ko Lagoon based on statistical analysis of samples caught in set nets in offshore Shirasu, Shonai-ko in 1982-83; ○ $N_{1\text{-}4}$ population from natural recruitment; ● $RS_{1\text{-}3}$ population from postlarvae released at Shirasu. (After data from Hamana-ko Substn., Shizuoka Pref. Fish. Res. Stn.)

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A Review of Maturation and Reproduction in Closed Thelycum Penaeids

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Abstract Commercially important penaeids of the closed thelycum group belong to five subgenera of the genus *Penaeus* — *Penaeus, Fenneropenaeus*, *Marsupenaeus* and *Melicertus* that are almost exclusively Indo-West Pacific and *Farfantepenaeus* that is predominantly Western Atlantic. Since the ablation of *Penaeus duorarum* more than a decade ago, the first for any penaeid, around 23 species have been matured in captivity, 17 of them belonging to the closed thelycum subgenera (*P. aztecus*, *P. brasiliensis*, *P. californiensis*, *P. duorarum*, *P. esculentus*, *P. indicus*, *P. japonicus*, *P. kerathurus*, *P. latisulcatus*, *P. merguiensis*, *P. monodon*, *P. notialis*, *P. orientalis*, *P. paulensis*, *P. penicillatus*, *P. plebejus*, and *P. semisulcatus*).

The complete spectrum of controlled reproduction in penaeids covers maturation, spawning, hatching of eggs into viable larvae, and the production of postlarvae to constitute the next batch of broodstock. The full closing of the cycle has been achieved in at least six closed thelycum species whereas gaps, e.g. inability of mature females to spawn or nonhatching of eggs, remain for the others.

Spawners or mature females used in commercial hatcheries and research laboratories are either wild-caught or matured in captivity with human control ranging from nil to a regular closing of the cycle. Wild spawners may be spawned directly after capture and transport or subjected to environmental manipulation, e.g. thermal control to induce or inhibit spawning. Females matured in captivity may come from wild broodstock (adults and subadults caught from estuaries or "sourced" by trawlers from offshore waters) or captive (pond- or tank-reared) broodstock. Introduced or exotic penaeid species must depend on a pond- or tank-reared broodstock whereas indigenous prawns and shrimps may be constituted from wild or captive broodstock.

There are three basic approaches employed singly or in combination to induce ovarian maturation in penaeids — endocrine, dietary or nutritional and environmental. Endocrine manipulation has so far been synonymous with unilateral eyestalk ablation, a technique with far-reaching impact on penaeid aquaculture. Closed thelycum penaeids may be classified into those that require ablation in order to mature and those that do not. To a third group belong species that have been experimentally induced to mature with and without ablation.

Diets for maturation include fresh and frozen animal sources (mussel, clam, oyster, squid, marine worms, shrimps, fish) and formulated pellets given in any combination. The choice of marine worms and mollusks is based on their high levels of arachidonic, eicosapentaenoic and docosahexaenoic acid, the dominant fatty acids found in mature ovaries and testes. Environmental parameters studied in relation to maturation include light (intensity, quality and photoperiod), temperature, salinity and pH.

Although a regular closing of the cycle has been achieved for some, the state-of-the-art for most penaeids is the successful production of larvae and postlarvae from either wild spawners or wild immature/spent females matured/rematured in captivity. The improvement of reproductive performance including larval quality from captive broodstock remains a major area for future research and includes the determination of minimum age and size for maturation. The complete description of the nutritional and environmental requirements for maturation should lead to the development of alternatives to ablation such as photoperiod manipulation or the use of reproductive hormones.

The present focus on characterizing the physicochemical and dietary requirements for maturation should be extended to other phases of reproduction: mating, spawning, fertilization and hatching. Studies on biology (molting, mating, fertilization including the cortical reaction) and biochemistry (maturation stages) provide baseline information for designing maturation tanks and formulating broodstock pellets. Investigations of wild stocks complement laboratory studies in elucidating the interrelationships among molting, mating, maturation and spawning.

Manual spermatophore transfer is being developed to solve the problem of nonmating in closed (and open) thelycum species. This technique will also be useful in future hybridization work, together with *in vitro* fertilization.

Introduction

Seed supply in the culture of penaeids had its beginnings in the tidal entry of wild fry into milkfish ponds as in the Philippines or in the *pokkali* (paddy) fields of Kerala, India (Fig. 1). This progressed to the stocking, first, of wild-caught fry from the coastline or estuaries, and then of hatchery-reared fry. The spawners used in hatcheries are either wild-caught or matured in captivity from wild "broodstock" or immature females. The final stage in this evolution — the regular closing of the cycle with the use of spawners from broodstock reared in ponds or tanks — completely eliminates dependence on the wild.

In penaeids, the thelycum or structure that receives the spermatophores during mating may be of the open type with ridges and protruberances for spermatophore attachment or closed featuring lateral plates that lead into a seminal receptacle where the spermatophores are inserted. Commercially important species of the genus *Penaeus* belong to six subgenera: a single open thelycum subgenus, *Litopenaeus*.

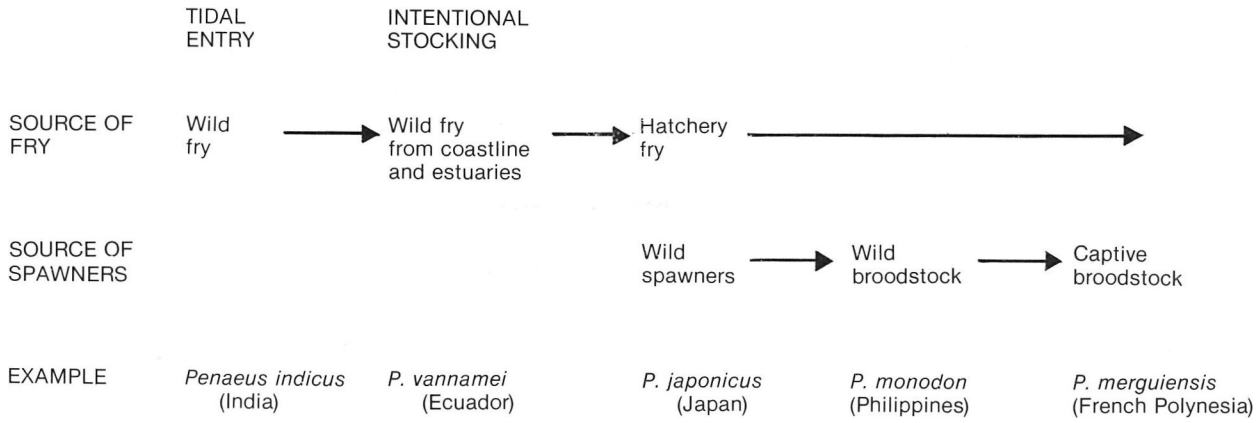

Fig. 1. Evolution of fry supply in pond culture of penaeid prawns and shrimps.

and five closed thelycum subgenera. Among the latter, *Penaeus, Fenneropenaeus, Marsupenaeus* and *Melicertus* are almost exclusively Indo-West Pacific in distribution while *Farfantepenaeus* is predominantly Western Atlantic (Table 1).

Although the first captive spawning of a penaeid (a wild *Penaeus japonicus* spawner) was by Fujinaga in 1934 (Hudinaga, 1942), it was not until 1970 that maturation was first obtained in ablated *P. duorarum* (Caillouet, 1972) and unablated *P. latisulcatus* (Shokita, 1970). Almost 30 years earlier, Panouse (1943, cited by Adiyodi and Adiyodi, 1970) observed precocious maturation and egg deposition in a palaemonid that had undergone ablation. Since 1970, around 23 penaeid species have been matured (and 14 spawned) in captivity, 17 of them belonging to the closed thelycum group (Table 6). Two interesting points are highlighted in Table 1 — the worldwide interest in *P. monodon* as a species for culture based on number of studies, and the introduction of penaeids outside their natural range of distribution, e.g. *P. japonicus* to France and Italy and *P. monodon* to the U.K.

Ovarian maturation

Studies on reproduction have predominantly focused on female maturation. Stages of ovarian maturity described for various closed thelycum species generally fall into five groups — immature, early maturing, late maturing, mature and spent (Tuma, 1967; Rao, 1968; Villaluz et al., 1972; Brown and Patlan, 1974; Gehring, 1974; Duronslet et al., 1975; Aquacop, 1977a).

Ovaries have been classified *in vivo* or dissected using such criteria as size, outline, texture, color and gonadosomatic index (GSI); measuring lipid and fatty acid levels; and under light and electron microscopy describing oocytes (diameter, staining, nuclear appearance, cortical rods, etc.) and follicle cells. Given the need to keep female prawns alive for spawning, most penaeid workers use the *in vivo* classification by looking at the ovaries externally through the dorsal exoskeleton.

There are three basic approaches employed singly or in combination to induce ovarian maturation in penaeids — endocrine, nutritional and environmental.

Endocrine

Reproductive hormones. It was Panouse (1943, cited by Adiyodi and Adiyodi, 1970) who first demonstrated that removal of the eyestalk during sexual quiescence in *Leander serratus* led to ovarian development and egg deposition. In the eyestalk of decapod crustaceans, a gonad-inhibiting hormone (GIH) is produced by the neurosecretory cells of the X-organ and transported to the sinus gland for storage and release (Adiyodi and Adiyodi, 1970). In *Parapeneopsis hardwickii,* the activity of the ovary-(gonad-)inhibiting hormone was highest in the eyestalk of females with inactive and spawned ovaries whereas it was negligible in those at full vitellogenesis (Kulkarni and Nagabhushanam, 1980).

Earlier, the target organs of the GIH were postulated to be the brain and/or thoracic ganglionic mass with the GIH preventing their synthesis of a gonad-stimulating hormone (Adiyodi and Adiyodi, 1970). More recent studies however, suggest the fat body or the ovary (Meusy and Charniaux-Cotton, in press).

The ovaries of the amphipod *Orchestia gamarella* have been demonstrated to produce the vitellogenin-stimulating ovarian hormone (VSOH) which controls the synthesis of vitellogenin (Meusy, 1980). Vitellogenin is a lipoprotein complex found in the hemolymph during reproduction, synthesized outside the ovaries but used by the oocytes to constitute the yolk during secondary vitellogenesis in malacostracans (Meusy, 1980; Meusy and Charniaux-Cotton, in press). During reproductive rest, the GIH inhibits the synthesis of vitellogenin (Meusy and Charniaux-Cotton, in press). Ongoing trials in CNEXO-COB (Centre Oceanologique du Brest) in France are testing the effect of ovarian extract injections on immature *P. japonicus* and *P. vannamei* (C. Cahu, pers. comm.).

In *Parapeneopsis stylifera,* Joshi (1980, cited by Kanazawa, 1982) observed a greater GSI and egg diameter in

females injected with the mammalian hormone progesterone (4.74 and 106.48 µm, respectively) compared to ethanol-injected females (2.46 and 48.59 µm, respectively) and uninjected controls (0.70 and 18.26 µm, respectively).

Eyestalk ablation. Other than the few studies mentioned above, endocrine manipulation has so far been synonymous with unilateral eyestalk ablation, a technique first performed in penaeids on *P. duorarum* (Caillouet, 1972) and with far-reaching impact on crustacean aquaculture.

Penaeids in captivity may be divided into a difficult-to-breed group that requires ablation to mature, e.g. *P. aztecus, P. duorarum, P. monodon*, and *P. orientalis* and those that have matured without ablation, e.g. *P. californiensis*, *P. indicus. P. japonicus,* and *P. merguiensis* (Table 3) among the closed thelycum species. *P. monodon* is classified as a difficult species because the proportion of females that have matured without ablation is so far very low (Santiago, 1977; Primavera et al., 1978; Aquacop, 1979; Emmerson, 1983).

For either easy- or difficult-to-breed species, the effect of ablation is to increase maturation and spawning rates. Unablated controls did not mature or had a lower maturation rate than ablated females of *P. aztecus* (Aquacop, 1975), *P. esculentus* (P.J. Crocos, pers. comm.), *P. monodon* (Aquacop, 1977b; Santiago, 1977; Primavera and Borlongan, 1978; Hillier, 1984) and *P. plebejus* (Kelemec and Smith, 1980). Ablated *P. indicus* produced 10 times the number of spawns, 8 times the number of eggs and 6 times the number of nauplii as unablated controls (Primavera et al., 1982). Ablation also increased the spawning rate up to 8-17 spawns/♀ in one run for *P. kerathurus* (Lumare, 1979) and 4-6 spawns/♀/molt cycle for *P. monodon* and *P. orientalis* (Arnstein and Beard, 1975; Beard and Wickins, 1980; Hillier, 1984) (Table 2). In contrast, unablated females have a rate of 0.38 spawns/♀/month for *P. japonicus* (Laubier-Bonichon and Laubier, 1979), 0.38 spawns/9/month and 1 spawn/♀/molt cycle for *P. merguiensis* (Beard et al., 1977; Crocos and Kerr,

Table 1. List of closed thelycum subgenera and species of the genus *Penaeus* matured in captivity including distribution.

Distribution[a]	Subgenus	Species	Country[c]	References
Indo-West Pacific	*Penaeus*	*esculentus*	Australia	P. Crocos, pers. comm.
		monodon	French Polynesia, India, Indonesia, Kenya, Philippines, South Africa, Taiwan, Thailand, U.K.	Liao, 1973; Alikunhi et al., 1975; Arnstein and Beard, 1975; Aquacop, 1977a, b, 1979, 1980, 1983; Muthu and Laxminarayana, 1977, 1984; Santiago, 1977; Haider, 1978; Primavera, 1978, 1982, 1983; Primavera and Borlongan, 1978; Primavera and Gabasa, 1981; Primavera et al., 1979; Vicente et al., 1979; Beard and Wickins, 1980; Pudadera and Primavera, 1981; Pudadera et al., 1980a, b; Ruangpanit et al., 1981, 1984; Emmerson, 1983; Poernomo and Hamami, 1983; Hillier, 1984; Lin and Ting, 1984; Millamena et al., 1984
		semisulcatus	French Polynesia, Israel	Aquacop, 1975; Browdy and Samocha, 1985, in press
Indo-West Pacific	*Fenneropenaeus*	*indicus*	French Polynesia, India, Philippines, South Africa	MSU-IFRD, 1975; Muthu and Laxminarayana, 1977; Muthu et al., 1984, Emmerson, 1980; Emmerson et al., 1983; Primavera et al., 1982; Aquacop, 1983a
		merguiensis	French Polynesia, Indonesia, U.K.	Alikunhi et al., 1975; Aquacop, 1975, 1983; Nurjana and Won, 1976; Beard et al., 1977
		orientalis[b]	China, U.K.	Arnstein and Beard, 1975: Liang et al., 1983
		penicillatus	Taiwan	Liao, 1973
Indo-West Pacific	*Marsupenaeus*	*japonicus*	France, French Polynesia, Italy, Japan	Aquacop, 1975: Caubere et al., 1979; Laubier-Bonichon and Laubier, 1979; Lumare, 1981; Kanazawa, 1982; Yano 1984
Indo-West Pacific	*Melicertus*	*latisulcatus*	Japan	Shokita, 1970
		plebejus	Australia	Kelemec and Smith. 1980. 1983
Eastern Atlantic and Mediterranean Sea		*kerathurus*	Italy, Spain	Lumare, 1979
Western Atlantic	*Farfantepenaeus*	*aztecus*	French Polynesia. U.S.A.	Aquacop, 1975; Duronslet et al., 1975
		brasiliensis	Brazil	Martino, 1981; Barros et al., 1982
		duorarum	U.S.	Idyll, 1971; Caillouet, 1972
		paulensis	Brazil	Martino, 1981; Marchiori and Boff, 1983
Eastern and Western Atlantic		*notialis*	Cuba	Ramos and Gonzales, 1983
Eastern Pacific		*californiensis*	Honduras, U.S.A.	Broom. 1972; Moore et al., 1974

[a]Holthuis, 1980
[b]*P. chinensis* is the accurate but less familiar name (Holthuis, 1980)
[c]Where maturation work was done in alphabetical order

1983 and a maximum of 3 spawns/♀/2 months for *P. indicus* (Primavera et al., 1982).

Consequently, the interval between consecutive spawnings is reduced to only 3 to 15 days in ablated females compared to a minimum of 10 days up to 2.7 months in unablated controls and females in the wild (Table 2). This gap of 1-2 months (Fig. 2) probably represents the length of time for eggs to fully mature during a reproductive season (Rao, 1968). By reducing it to as short as three days with rapid maturation and overstimulation of spawning, ablation may lead to insufficient reserves in the hepatopancreas (Aquacop, 1977b; Lumare, 1979; Beard and Wickins, 1980). A decline in fecundity, hatch rate and egg viability has been observed with successive spawns in a single intermolt or with successive molt cycles in *P. monodon* (Beard and Wickins, 1980) and *P. indicus* (Primavera et al., 1982) and an increase in the proportion of partially developed ovaries and partial spawnings in successive spawnings of *P. kerathurus* (Lumare, 1979).

Given this reproductive decline, *P. monodon* broodstock are replaced 6-8 weeks after ablation (Simon, 1982; Primavera, 1983). Emmerson (1980) obtained viable spawns from ablated *P. indicus* for up to 7 months and from unablated females for one year. Ablated females gave lower fecundity and hatch rates compared to nonablated females due to a greater number of poor spawns which may be traced to a rapidity of egg development. However, spawning frequency of ablated females (2.24 spawns/molt cycle of 19.1 days) was not much higher than for unablated *P. indicus* (1.98 spawns/molt cycle of 20.1 days). Therefore, the lower hatch rates may be due to inherently poor egg quality in ablated females and not the rapidness of ovarian development.

In addition to the exhaustion of female reserves, this decline in reproductive performance could also be attributed to a decrease in quantity if not quality of sperm (Beard and Wickins, 1980) considering that sperm from a single mating will need to fertilize up to six spawns within a single molt cycle (Fig. 2). However, Emmerson (1980) concluded that decreased hatchability of successive spawns within a molt cycle from ablated *P. indicus* females was not due to insufficient sperm but a decline in egg quality because the two spermatophores deposited during a single mating could fertilize up to three successive spawns.

Many commercial hatcheries that use broodstock for part or all of their spawner requirements prefer to do eyestalk ablation even for penaeid species demonstrated to mature unablated in captivity. Ablation leads to predictable peaks of maturation and spawning which facilitates the setting up of production schedules, in contrast to scattered spawns from unablated females. For production purposes, this predictability in availability and number of nauplii compensates for the trend towards decreased fecundity and hatch rates with successive spawns from ablated broodstock.

The various techniques used to ablate penaeids may be classified into two. The first method results in the total removal of the eye and the partial/total removal of the eyestalk by cutting with scissors; cautery using clamps or soldering iron or electrocautery; tying with a string; or manual pinching (Caillouet, 1972; Arnstein and Beard, 1975; Duronslet et al., 1975; Aquacop, 1977a). The second method partially destroys the eyestalk but retains the outer (corneal) layer of the eye. It is performed by first incising the eye, pressing the contents outwards then crushing the eyestalk (Primavera, 1978). The important thing is to prevent excessive loss of fluids and infection either by cauterizing the open wound and applying antibiotics as in the first method or by means of the remaining corneal layer that contains the bleeding and also forms a scar in the second method.

The term "ablation" meaning removal of a part especially by cutting strictly applies to the first method, so with "extirpation" meaning the rooting out or complete destruction.

Table 2. Effect of ablation on maturation and spawning in closed thelycum penaeids.

Species	Spawning rate		Interval between spawnings	
	Unablated	Ablated	Unablated	Ablated
P. japonicus	0.37 sp./♀/mo[a]		2.7 mo[a]	
P. merguiensis	0.38 sp./♀/mo[b] 1 sp./♀/molt cycle[c]		2.6 mo[b]	
P. indicus	3 sp./♀/2 mo (max.)[d] 1.98 sp./♀/molt cycle[e]	7 sp./♀/2 mo (max.)[d] 2.24 sp./♀/molt cycle[e]	2 mo[l] 10.2 days[e]	
P. kerathurus		8 sp./♀[f]		
P. paulensis		17 sp./♀[g]		5 days[d,e,f,h,j,m,n,o,p,q,r]
P. monodon		1 sp./♀/mo[h] 1-6 sp./molt cycle[i,j,q]		
P. orientalis		4 sp./molt cycle[k]		
P. latisulcatus			30-40 days[m]	
P. semisulcatus	1.13 sp./♀[s] 2-4 sp./♀/molt cycle (max.)[s,t]	4.46 sp./♀[s] 4-6 sp./♀/molt cycle (max.)[s,t]		

[a]Laubier-Bonichon and Laubier, 1979; [b]Beard et al., 1977; [c]Crocos and Kerr, 1983; [d]Primavera et al., 1982; [e]Emmerson, 1980; [f]Lumare, 1979; [g]Marchiori and Boff, 1983; [h]Aquacop, 1977a; [i]Beard and Wickins, 1980; [j]Hillier, 1984; [k]Arnstein and Beard, 1975; [l]Rao, 1968; [m]Penn, 1980; [n]Nurjana and Won, 1976; [o]Primavera and Borlongan, 1978; [p]Primavera et al., 1979; [q]Aquacop, 1980; [r]Poernomo and Hamami, 1983; [s]Browdy and Samocha, in press; [t]Browdy and Samocha, 1985.

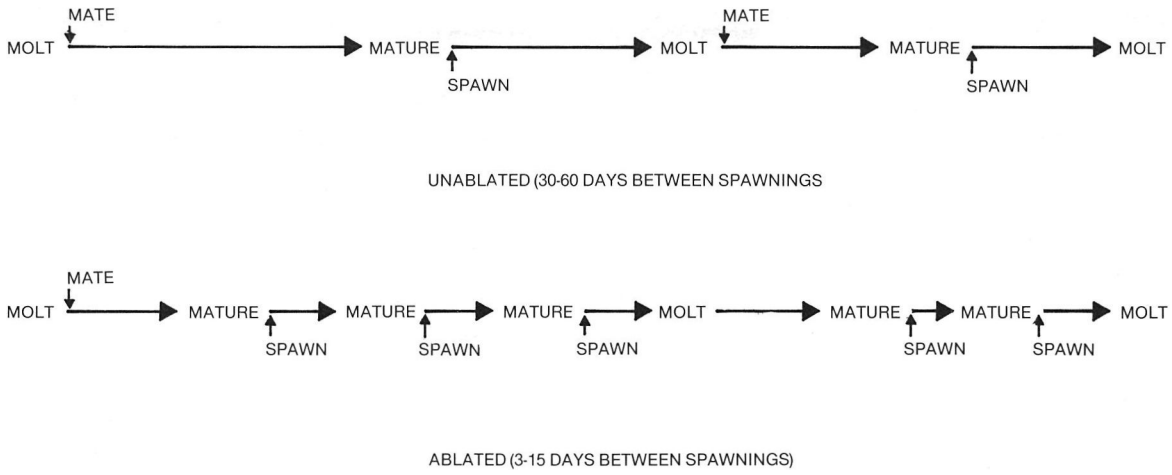

Fig. 2. Frequency of maturation and spawning in unablated and ablated closed thelycum penaeids.

"Enucleation" or the removal from a sac or capsule more appropriately describes the second method, although ablation has become the generally accepted term for most penaeid workers. Other terms used are the French *ablatíon* and *épédonculatíon* and the Spanish *ablacíon* and *oculotomía.*

At present, the standard procedure is unilateral ablation of either left or right eyestalk. Arnstein and Beard (1975) and Santiago (1977) observed that ablation of a single eyestalk was sufficient to induce maturation in *P. orientalis* and *P. monodon,* respectively, contrary to the findings of Alikunhi et al. (1975). In addition to the high mortality rates experienced in these species, bilateral ablation also leads to a loss of balance, swimming in spiral motion near the water surface, and other abnormal behavior in *P. duorarum* (Caillouet, 1972) and *P. merguiensis* (Alikunhi et al., 1975) and to lack of copulation in *P. paulensis* (Marchiori and Boff, 1983).

The latency period from ablation to the onset of maturation and subsequent spawning ranges from three days up to two months depending on the age and source of broodstock, stage of the molt cycle, and other factors at the time of ablation. Wild Subadult *P. monodon* caught in mangroves took 40 days to mature and 69 days to spawn after ablation (Hillier, 1984) compared to a minimum of only three days for wild adults from offshore waters (Primavera and Borlongan, 1978; Simon, 1982). Similarly, wild *P. monodon* from offshore Indian Ocean took only 4-5 days to spawn after ablation in contrast to 20-30 days for females from brackishwater Songkhla Lake (Ruangpanit et al., 1984). Lumare (1979) observed a longer latency period for captive *P. kerathurus* compared to wild stock.

Correlating events in the reproductive cycle with the molt cycle in *P. indicus* and *P. merguiensis,* respectively, Emmerson (1980) and Crocos and Kerr (1983) conclude that ovarian maturation proceeds through the intermolt and early premolt followed by spawning during the intermolt or premolt and that mating occurs immediately after ecdysis when the females have undeveloped ovaries. Ideally, ablation should be undertaken during the intermolt for maturation to follow in less than a week. Ablation during the premolt leads to molting with a subsequently longer latency period of 2-4 weeks before maturation in *P. monodon* (Aquacop, 1979; Primavera et al., 1979). On the other hand, ablation during the postmolt leads to mortality because of added stress on the female and excessive loss of hemolymph (Aquacop, 1977a).

Mortality associated with ablation may be immediate or of a long-term nature. Ablation did not affect survival of *P. monodon* (Aquacop, 1977a; Vicente et al., 1979) and *P. plebejus* (Kelemec and Smith, 1980) whereas initial mortality due to ablation was observed in *P. kerathurus* (Lumare, 1979) and *P. monodon* (Primavera et al., 1978). Survival rates of 0, 38 and 49% for bilaterally ablated, unilaterally ablated and unablated *P. monodon,* respectively, were obtained after 196 days (Santiago, 1977). Higher survival of unablated females was also observed in *P. duorarum* (Caillouet, 1972) and *P. indicus* (Primavera et al., 1982). Other causes of broodstock mortality could be nutritional deficiency, stress due to molting, spawning, handling, etc. *P. monodon* males generally show a higher survival rate due to the absence of ablation, spawning and handling stress (Primavera et al., 1979; Pudadera et al., 1980b).

Environmental

The life cycle of most penaeids consists of an estuarine phase with the shoreward movement of postlarvae and a marine phase with the offshore migration of adolescents and subadults. The postlarvae grow into juveniles in mangroves, rivers and other brackishwater nurseries. Ovarian development may start in the estuaries but it is only after returning to the sea that full maturation and spawning take place. Attendant to this return migration are changes in physicochemical factors that may provide the stimuli for the lowering of GIH levels. Among the parameters so far studied, temperature and light appear to play a role in maturation. Tables 3 and 4 give details on various physicochemical parameters in maturation tanks.

Light. The deeper offshore waters where adult penaeids breed is characterized by reduced light intensity and greater

Table 3. Physicochemical parameters, stocking, feeding and water management in maturation tanks for closed thelycum penaeids.

Species	Ablation[a]	Broodstock source	Age	Stocking density (no/m²)	Sex ratio (♀:♂)	Daily water exchange rate	Water management	Temp. (°C)	Salinity (ppt)	pH	Light intensity & quality	Photoperiod (hr light)	Food	Reference
Penaeus aztecus	+	captive	9 mo	16-24	1:1	200-300%	flow-through	25-29	34.5	8.2	10-40%	natural	art. diet & bonito	Aquacop, 1975
P. brasiliensis	–	wild		2	1:1		flow-through	23.5-27	34-35	7.6-8.1	reduced		fresh mussel	Barros et al., 1982
P. californiensis	–	wild		6			water spray	22-28	35	8-8.3	20%	natural	commercial flake, shark & art. food	Moore et al., 1974
P. duorarum	+	wild & captive							30-35				commercial trout food & squid	Caillouet, 1972
P. esculentus	±	wild						26				14.5 hr		P. Crocos, pers. comm.
P. indicus	+	pond & wild					recirculating	24.5-30.2	26.8-38.6			natural	fresh clam, live mysids	Muthu & Laxminarayana, 1977
	±	wild		2.5/ton	1.5:1	30%/2 days	replacement	19.0-29.1	20-35	7.1-8.6	70 μW cm^{-2} (covers)	natural	prawn & dry pellet	Emmerson, 1980
	±	pond	3 mo	35	1:1	200-400%	flow-through	26-31.8	26.4-31.9	7.8-8.1	reduced	natural	brown mussel & pellet	Primavera et al., 1982
	–	pond		16-24	1:1	200-300%	flow-through	25.5-30	34	8.2	10%, 100 lux	natural	squid, mussel, troca & pellet	Aquacop, 1983a
	–	wild		2.5/ton	1.5:1		recirculating	24.1-26.6		7.8-8.1	45-50 μW cm^{-2} blue (480 nm) green (510 nm)	natural, artificial	prawn & dry pellet	Emmerson et al., 1983
	+	pond		1-1.6/ton	1:1		recirculating			8.2-7.2; 8.2	500-3,600 lux; natural light		clam	Muthu et al., 1984
	+	pond	3 mo	21/ton	1.3:1	100%/5 days	replacement	24.9-29.4	32	6.5-8.6	dark cover	natural	squid, mussel & marine worms	A. Openiano, pers. comm.
P. japonicus	+	captive	11 mo	16-24	1:1	200-300%	flow-through	25-29	34.5	8.2	10-40%	natural	art. diet & bonito	Aquacop, 1975
	–	captive	1 & 2 yr	7	1:1		recirculating	24-26		8.1-8.3	500-1,500 lux	14.75-16 hr	mussel	Laubier-Bonichon & Laubier, 1979
	–	captive	7 & 18 mo		1:1		recirculating	24-28	30.5-36	7.5-8.5	4,000 lux	8→16 hr		Caubere et al., 1979
	+	pond		20	1:1		recirculating	18-26	34-38	7.6-8.4			mussel, crab & fish	Lumare, 1981
	+	wild & captive						15-25			black cover	8→16 hr	clam	Kanazawa, 1982
	–	wild spent		12/1.5 ton	0.7:1	0.3 ton/hr	flow-through	25±1	32-34		1,000-3,000 lux	15 hr	pellet, clam & krill	Yano, 1984
P. kerathurus	+	wild & captive		10-15	1:1	1/3 daily	recirculating	24-26	35-37	7.7-8.1			mussel	Lumare, 1979
P. merguiensis	–	pond	4-5 mo	16-24		200-300%	flow-through	25.5-30	34	8.2	10%, 100 lux	natural	squid, mussel, troca & pellet	Aquacop, 1975, 1983a

[a]+ with eyestalk ablation; — without eyestalk ablation

Table 3. (continued).

Species	Ablation	Broodstock source	Age	Stocking density (no/m²)	Sex ratio (♀:♂)	Daily water exchange rate	Water management	Temp. (°C)	Salinity (ppt)	pH	Light intensity & quality	Photoperiod (hr light)	Food	Reference
P. merguiensis	—	pond			1:1			27.8-30.6	24-31				mysid, pellet & shrimp	Alikunhi et al., 1975
	—	wild		1.5	1.6:1	60%	replacement	26-30	30-34				mysid	Nurjana & Won, 1976
		pond	6-7 mo	5-15	1-2:1	50%/wk	recirculating	25-31	30-36	7.5-8.5			mussel & shrimp	Beard et al., 1979
P. monodon	+	pond			1:1		recirculating	27.8-30.6	24-31				mysid, shrimp & art. pellet	Alikunhi et al., 1975
	+	pond	9-12 mo	5	1:1	200-300%	flow-through	25.5-30	34	8.2	10%, 100 lux	natural	squid, mussel troca & pellet	Aquacop, 1977a, b 1979, 1980 1983a
		pond	15 mo	0.8	1:1			22.5-33.2	33 ± 1.6		± outdoor pens			Santiago, 1977
	+	pond	5 mo	4	1:1	30%/3 days	replacement	23.8-26.2	30-34	7.8-8.1		natural	salted mussel	Primavera, 1978
		pond	1-2 yr	5-6	1-2:1	30%/3 days	replacement				±	natural	salted mussel	Primavera et al., 1978
	+	pond		6	2:1	200-400%	flow-through	24-34	27.6-30.2		60%	natural	pellet, mussel, squid	Primavera et al., 1979
	+	wild		4-5	2:1	200-400%	flow-through	28.6-33.6		7.0-8.2	40-60%	natural	brown mussel & pellet	Pudadera et al., 1980a
	+	wild		5	1-4:1, 1:0	200-400%	flow-through	25-30.5	15.4-34.8	7.2-8.1	60%	natural	brown mussel & pellet	Pudadera et al., 1980b
	+	pond		6	1:1	200-400%	flow-through	21.3-33.6	28-36	7.9-8.1	1,210-3,500 lux; blue, red, natural	natural	mussel & pellet	Pudadera & Primavera, 1981
	+	wild & pond		7.5/ton	3.3:1			26-28.5	32.3-34.1			natural	mussel, pellet & fish	Vicente et al., 1979
	+	captive		1.6	1:12	15%/week	recirculating	28±2	30±2		40-70 lux	19 hr	mussel & shrimp	Beard & Wickins, 1980
	+	wild		13/ton	1:1			26-28	30-31	7.8-8.0		natural	squid, cockle & prep. feed	Ruangpanit et al., 1981
	+	wild		4	1:1	100-200%	flow-through	28-31	30-31			natural	green mussel & cow liver	Ruangpanit et al., 1984
	+	pond & wild	5-8 mo	7	1:1	100-250%	flow-through	26.5-30.5	28-32		fluorescent light	14 hr	squid & clams	Simon, 1982
	+	pond		2.7	1:1	20-50%/2-3 days	replacement	26-28	25-30			natural	squid, cockle & prep. feed	Poernomo & Hamami, 1983
		wild		2.2/ton	1:1	30%/2 days	replacement	27±2.2	30±3		± 70 μW cm^{-2} (reduced)		pellet, prawn	Emmerson, 1983
	+	wild		2.3	3:1			26-31			green	natural (12 hr)		Hillier, 1984
P. notialis	+	wild			1:0			24-30	35-37.3	7.5-7.8			fish	Ramos and Gonzales, 1983
P. orientalis	+	tank	8 mo	6.4	1:1	50%/wk	recirculating	20 ± 2	28-30		subdued	8 hr	mussel & shrimp	Arnstein & Beard, 1975
P. paulensis	—	wild					flow-through	25.5-27.5	34-35	7.6-8.2	outdoor		mussel & white fish	Agarez & Barros, n.d.

Table 3. (continued).

Species	Ablation	Broodstock source	Age	Stocking density (no/m²)	Sex ratio (♀:♂)	Daily water exchange rate	Water management	Temp. (°C)	Salinity (ppt)	pH	Light intensity & quality	Photoperiod (hr light)	Food	Reference
P. paulensis	+	wild				10-15%	recirculating	24.5-27	33-35	7.8-8.2	2,500 lux	16 hr	clam, fish & annelid worms	Marchiori & Boff, 1983
P. plebejus	+	wild		11-17	7:1	2.5-5%	recirculating	26-28	32.5-33.5	8.0-8.5	dim, blue	12 hr	prawn tail	Kelemec & Smith, 1980
P. semisulcatus	?	captive		16-24	1:1	200-300%	flow-through	25-29	34.5	8.2	10-40%		art. diet	Aquacop, 1975
	±	wild pond	2 yr	12-15/m³	1.8-2.5:1	250%	flow-through	19.5-27.3	40		0.1-0.3 μE/m²/sec		*Artemia* biomass, fish, shrimp & squid	Browdy & Samocha, 1985
		pond	17 mo	18/3m³	2.6:1	250%	flow-through	22.4-27.5	40	7.82-8.08	0.1-0.3 μE/m²/sec		green mussel	Browdy & Samocha, in press

penetration of blue and green light compared to other wavelengths (Jerlov, 1970). Various studies have tried to approximate light conditions in the natural habitat inside maturation tanks.

Light intensity. Decreasing levels to 10-60% of incident light through the use of covers made of plastic, cloth, etc. discourages algal growth in tanks and decreases the solar energy which may inhibit maturation in nonburrowing species such as *P. merguiensis* (Aquacop, 1983a). Reduced light levels led to fast maturation in nonablated and ablated *P. monodon* (Emmerson, 1983; Hillier, 1984). Covered tanks also minimize disturbance of broodstock (Primavera, 1983).

Light quality. Unablated *P. duorarum* did not mature in tanks provided with blue, green and white light (Caillouet, 1972). Similarly, unablated *P. monodon* attained only partial maturation under blue and natural light but not under red light (Pudadera and Primavera, 1981). However, nonablated *P. indicus* kept under dim green and blue light showed improved growth and condition and increased spawning activity after a depression of all three during the initial 'settling down' period (Emmerson et al., 1983). In contrast, initially high spawning levels of females in the control (natural light) tank decreased after the second month as a consequence of a steady decline in prawn condition.

Photoperiod. Unablated *P. duorarum* failed to mature under varying light-dark combinations including continuous light and continuous darkness (Caillouet, 1972). Similarly, increasing photoperiod to 19 hr (light) failed to induce maturation in unablated P. *monodon* (Beard and Wickins, 1980). In contrast, both ablated and unablated *P. plebejus* produced more maturations and spawnings with day length of 14.5 hr compared to 12 hr (P.J. Crocos, pers. comm.).

Unablated *P. japonicus* produced the greatest number of spawnings over a 7-month period when daylength was gradually increased from 12.75 to 14.75 hr compared to shorter and longer photoperiods (Laubier-Bonichon and Laubier, 1979). Slightly different results were reported by Caubere et al., (1979) with nonablated *P. japonicus* producing more nauplii when photoperiod was gradually increased to 16 hr over a 6-month period compared to an abrupt increase to 16 hr over 3 months. However, for the duration of both studies, temperature was also increased from 15°C to 28°C so that maturation cannot be attributed solely to photoperiod. Lumare (1979) observed a longer latency period in ablated *P. kerathurus* maintained at a photoperiod of 12 hr compared to those in natural daylight (9 hr) but noted that the former could have been stressed by abrupt exposure to the artificial photoperiod.

Most maturation tank systems rely on natural photoperiod (Table 3). Controlled photoperiod in tanks may have longer daylengths of 12-16 hr for *P. monodon* (Simon, 1982), *P. paulensis* (Marchiori and Boff, 1983) and *P. plebejus* (Kelemec and Smith, 1980) and shorter periods of 8 hr for subtropical and temperate species such as *P. japonicus* and *P. orientalis* (Arnstein and Beard 1975; Kanazawa, 1982). The role of photoperiod in the control of maturation is probably not as critical for species distributed along the equator and therefore not exposed to significant differences in daylight hours as it is for subtropical penaeids.

Temperature. A comparison of temperature regimes maintained in maturation tanks shows an upper range of 26-32°C for most penaeid species and a lower one of 16-28°C for subtropical species such as *P. japonicus* and *P. orientalis* (Tables 3 and 4). For the latter group, ablated females mature even at the lower temperature limits, suggesting a greater need for fine tuning of environmental parameters in the absence of ablation. Nonablated *P. orientalis* had a mean ovarian weight of 1.56 g at a higher temperature of 18°C in contrast to ablated females with 10.31 g mean ovarian weight at only 11°C (Liang et al., 1983). Similarly, ablated *P. japonicus* started to mature even at 18°C (Kanazawa, 1982) whereas unablated females produced more spawnings and more eggs and larvae per spawning at higher temperatures of 24°C and 26°C compared to 20°C (Laubier-Bonichon and Laubier, 1979). In the latter study, however, photoperiod was also manipulated so the effect of temperature on maturation is not clearcut. In reproductively active ablated *P. japonicus,* a

rest period was induced by decreasing temperature to below 17.5°C Lumare, 1979). In both ablated and nonablated *P. esculentus*, more maturations were obtained at 26°C compared to 21°C (P.J. Crocos, pers. comm.).

Salinity. There were no significant differences in maturation rates of unablated *P. indicus* kept in tanks at 22, 32 and 42 ppt although females maturing at 32 ppt showed significantly higher fecundity and hatch rates (A. Openiano, pers. comm.). Similarly, manipulation of salinity did not induce maturation in unablated *P. duorarum* (Caillouet, 1972). On the other hand, Ruangpanit et al. (1984) observed a higher maturation rate and proportion of *P. monodon* females with fertile eggs after ablation in prawns collected from the Indian Ocean which is a spawning ground with 33 ppt salinity compared to those from Songkhla Lake, a nursery area of the species with 22-28 ppt salinity. However, the differences in depth (20-30 m in the Indian Ocean and 1-1.5 m in Songkhla Lake) and other environmental factors make this observation inconclusive.

Most maturation systems depend on available seawater with ambient salinity of 24-36 ppt (Table 4) with lower levels experienced during typhoons or heavy rains.

pH. Ablated *P. indicus* females reached early maturation then resorbed their ovaries when pH of recirculated water was allowed to decline from 8.2 to 7.2 in plastic-lined pools (Muthu et al., 1984). Successful maturation, spawning and hatching of viable naupli were obtained only from ablated females kept in pools where pH was maintained at around 8.2 by daily addition of sodium carbonate.

Nutrition

Recent studies on nutritional requirements for penaeid maturation have focused on lipids which provide energy, as well as essential nutrients such as sterols and phospholipids.

Nutritional studies. In wild *P. japonicus,* Teshima and Kanazawa (1983) observed an increase in ovarian lipid concentration from slightly mature to yellow ovarian stages, reaching constant levels in mature ovaries and declining after spawning. In contrast, lipid levels in the hepatopancreas declined in mature ovaries after reaching a maximum in the yellow ovaries suggesting a possible movement of lipids from the hepatopancreas to ovaries during maturation. Ovarian lipid concentration in wild *P. aztecus* showed an increase from early developing to ripe stages and a decline in spent females (Chamberlain and Lawrence, 1983). There was also an increase in ovarian carbohydrate levels from nearly ripe to ripe stages but no changes in protein concentration for all maturation stages.

Ovarian lipid concentration in immature *P. monodon* increased upon reaching full maturity from 5.8 to 17.0% in wild (unablated) females (Millamena et al., 1984) and from 7.5 to 21.9% in wild ablated females (O. Millamena, pers. comm.). The fatty acid profile showed 12.14-24.87 % and 11.81-24.50% for total fatty acids in wild (unablated) and wild ablated females, respectively, to consist of 20:4ω6 (arachidonic acid), 20:5ω3 (eicosapentaenoic acid) and 22:6ω3 (docosahexaenoic acid). The same polyunsaturated fatty acids (PUFA) were reflected in the spawned eggs, indicating their importance in the reproductive process. Similarly, high levels of these PUFA's were found in wild *P. setiferus*, *P. stylirostris* and *P. vannamei* (Middleditch et al., 1979, 1980).

Food sources. Mollusks including mussel, clam, cockle and squid are the most common food sources for penaeid broodstock (Tables 3 and 4). Other food items used are fresh or frozen marine worms, mysids, shrimp and fish, and dried pellets. These various items may be given alone or in combination. The broodstock are fed *ad libitum* or according to a daily feeding rate of approximately 3-5% for dry feed (pellets) and 10-30% for wet (fresh or frozen) feed. Feed is given once up to four times a day and the daily ration divided accordingly.

A mussel-pellet and a all-mussel feeding combination gave better maturation and hatching rates than a squid-pellet or all-pellet feeding for ablated P. *monodon* (Primavera et al., 1979). Aquacop (1979) obtained best results using a squid-containing pellet with 60% protein. However, the feeding of fresh trocа univalves to early maturing ablated P. *monodon* has a positive effect on maturation and egg viability (Aquacop, 1977b). Females that mature on pellets alone spawn unfertilized eggs although they undergo successful mating and are positive for sperm.

These findings point to the need for natural food sources, particularly those rich in PUFA's, e.g. mollusks and marine worms, for penaeid maturation.

Maturation systems

Majority of penaeid maturation systems use tanks incorporated within the hatchery complex whereas a few have experimented with pens and cages (Fig. 3). The advantages offered by land-based tanks include easy monitoring and

BROODSTOCK SOURCE	MATURATION	RETRIEVAL OF:
		Mature females
WILD	TANK	Eggs
		Nauplii
	PEN	Mature females
CAPTIVE (pond/tank)		
	CAGE	Mature females

Fig. 3. Broodstock source, maturation system and retrieval in penaeid species.

spawner retrieval, convenience in cleaning and maintenance, and better security against poachers (Primavera and Gabasa, 1981).

Tanks

Construction. Tank size ranges from 500 ℓ to 50 m^3 and construction materials include cement, ferrocement, fiberglass and aluminum lined with plastic sheets. Size of the tanks is a compromise between biological requirements of the animals and convenience of the hatchery staff.

Maturation rates of various penaeids were higher in bigger tanks (Vicente et al., 1979; P.J. Crocos, pers. comm.) although Beard and Wickins (1980) obtained maturation in *P. monodon* in only 125 ℓ of water (0.83 × 0.72 × 0.2 m). Better maturation of ablated *P. monodon* in large round tanks compared to smaller rectangular tanks may have been due to less disturbance in the large tanks during routine procedures (Hillier, 1984).

Similarly, mating is more successful in larger and deeper tanks (section IV, C) although very deep water presents practical difficulties for daily operations. The popularity of a 10-12 m^3 circular tank with 0.8-1.0 m water depth is due to the convenience in maintenance and daily monitoring of broodstock for ovarian development as well as satisfactory maturation performance.

Physicochemical parameters. Except for manipulation of light and temperature, physicochemical parameters in maturation tanks are dependent on incoming seawater (Tables 3 and 4). Ranges are 24-36 ppt salinity; 26-32°C and 16-28°C temperature for tropical and subtropical/temperate species, respectively; 7.5-8.5 pH; and dissolved oxygen at saturation levels of 5-7 mg/ℓ with flowthrough water or continuous aeration.

As discussed earlier (section II, B), most maturation tanks depend on a natural light source with intensity reduced to 10-60% of incident light through the use of dark covers. If artificial light is used, photoperiod and spectral quality can also be controlled in addition to intensity. Tanks are generally located inside a roofed structure, with or without walls.

Water quality. Good water quality with excellent maturation results can be achieved with a flowthrough water system which gives a daily exchange rate of 100-400% of total water volume. However, it needs an unlimited supply of clear, unpolluted seawater. Where natural sources are limited, during typhoon months when seawater is turbid or when heated water is used for temperature control, there is a need to recirculate water through filters, often with the aid of air-water-lifts.

Filters may be biological and/or mechanical to remove metabolites, e.g. ammonia and particulate matter, respectively. They are often installed external to the tank but they may also be built-in as a sand-gravel substrate. The water quality and exchange rate in recirculating tanks will depend on the efficiency of these filters.

In addition to flowthrough and recirculating water, maturation tanks may use simple aeration to circulate water in conjunction with regular or periodic water replacement (20-50% of total volume every 1-7 days). Of the three management systems, the last requires the least input but is the most vulnerable to fouling.

Muthu and Laxminarayana (1977) had negative results with ablated *P. monodon* and *P. indicus* in plastic-lined pools with airstones. Only after seawater quality improved with the addition of a subgravel filter with air-lift recirculation were ovarian maturation and spawning observed. In another experiment, however, ablated *P. indicus* failed to attain full maturation in recirculating pools where pH was allowed to decline to 7.2 in contrast to successful maturation, spawning and hatching when pH was maintained at 8.2 (Muthu et al., 1984). Aquacop (1975) stresses the importance of oceanic water with a low level of organic and inorganic particles for the successful maturation of various penaeid species in flowthrough maturation tanks.

Prophylactics such as 2.5 ppm furanace, 50-25 ppm formalin, and 1.5-2 ppm streptomycin are used initially and/or regularly after stocking to disinfect tanks and broodstock, control disease and reduce mortality (Simon, 1982; Poernomo and Hamami, 1983).

Substrates. As earlier discussed, a sand-gravel substrate in flowthrough and recirculating tanks can improve water quality by acting as filter. A substrate is also required for burrowing species such as *P. japonicus* whether the water is static, flowing or recirculating.

A comparison of black and white sand substrates showed significantly greater nauplii production and hatch rates from

Table 4. Summary of maturation requirements in tanks for closed thelycum penaeids.

Eyestalk ablation	Required for some species, optional for others
Light intensity	Reduced: 10-60% of incident (natural) light 100-500 lux, 50-70 $\mu W/cm^2$ (artificial)
Light quality	Blue or green light
Photoperiod	Natural Artificial: 12-16 hr light
Temperature	Tropical spp.: 26-32°C Subtropical and temperate spp.: 16-28°C
Salinity	24-36 ppt
pH	7.5-8.5
Water exchange rate	Flowthrough water: 100-400%/day Recirculated and/or replaced water: 5-50%/l-7 days
Stocking density (= 300-400 g/m^2)	50-150 g body wt.: 2-7/m^2 10-60 g body wt.: 10-35/m^2
Sex ratio	1-2♀:1♂
Feed	Mussel, clam, squid and other mollusks; marine worms; shrimp; mysids; fish; cow liver; formulated diets Fresh, fresh/frozen or dry (pellets) In combined or single diets given 1-4X/day
Daily feeding rate	a) Wet feeds: 10-30% of total biomass Dry feeds: 3-5% of total biomass b) *Ad libitum* or to satiety

ablated *P. monodon* in tanks with white sand (Pudadera et al., 1980a). Moreover, white sand provides greater contrast and is therefore more convenient for regular monitoring of females and daily cleaning of tanks. On the other hand, non-ablated *P. indicus* kept in tanks with inner walls painted black (without substrate) produced more spawns, greater average fecundity and hatch rates than females in white tanks (Emmerson, 1980).

For maturation of nonburrowing penaeids, substrates are optional. However, necrosis and injuries to appendages as a result of crawling and other benthic activities may be more frequent on a bare tank particularly if broodstock are maintained for a long time. Such damage can be minimized if the tank bottom has a smooth finish.

Stocking density. In general, lower stocking densities produce better maturation and survival rates in broodstock. Stocking density depends on water quality and exchange rate and on the size of the animals.

Larger species such as *P. monodon* weighing 50-150 g are stocked at 2-7/m^2 (Aquacop, 1977a, 1983a; Primavera, 1978, 1983; Simon, 1982; Poernomo and Hamami, 1983; Hillier, 1984). Smaller-sized species such as *P. indicus, P. japonicus, P. merguiensis* and *P. plebejus* with a body weight of 10-60 g have a higher density of 10-35/m^2 (Aquacop, 1975, 1983a; Lumare, 1979, 1981; Kelemec and Smith, 1980; Primavera et al., 1982). Whether few or many animals, the biomass should not exceed 300-400 g/m^2 (Table 4).

Tank area is more important than volume because of the benthic nature of penaeids. However, water depth may be critical for such activities as mating (section IV, C).

Sex ratio. In penaeid hatcheries, males are required for mating and spermatophore transfer but not for maturation. All-female ablated populations of *P. monodon* (Beard and Wickins, 1980; Pudadera et al., 1980b) and *P. notialis* (Ramos and Gonzales, 1983) matured in the absence of males. However, the spawned eggs of *P. monodon* were not fertilized and did not hatch indicating a lack of sperm (Pudadera et al., 1980b).

Generally, sex ratios are maintained at 1 ♀:1 ♂ to ensure mating success in tanks. However, a 2 ♀:1 ♂ ratio produced the highest spawning rate, fecundity and total number of nauplii compared to 1:0, 1:1 and 4:1 female to male ratios (Pudadera et al., 1980b). Higher sex ratios in favor of females (1.5-3♀:1♂) are more economical because they maximize egg and larval production per tank. If female broodstock mortality is high, the ratio gradually evens out.

Tank monitoring and retrieval. The end-products of maturation may be retrieved from the tank as gravid females, spawned eggs or hatched nauplii (Fig. 3). The main advantage of female retrieval is that it allows individual records including data on fecundity, hatching and spawner measurements which are important for experimental work.

Monitoring light-colored species such as *P. indicus* for ovarian maturation can be done during the day by directly looking at the prawns if the water is clear enough. In the case of *P. monodon* and other dark-shelled species, a source of light is needed to show off the outline of the ovaries for mature females. This can be done by scooping out the females and holding against the light or by the less stressful method of flashing the beam of an underwater light against the female thereby avoiding unnecessary handling.

Efficiency in spawner retrieval depends on tank size and frequency of sampling. Smaller tanks of less than 20 m^3 are more manageable and more frequently sampled than larger tanks of 20-50 m^3. Also, nightly monitoring of a 12 m^3 tank yielded 48 spawners producing 6.8 × 10^6 nauplii of *P. monodon* compared to only 3.0 × 10^6 nauplii from 29 spawners with thrice weekly monitoring (Pudadera et al., 1980a).

Egg collectors have been installed in tanks for *P. japonicus* (Laubier-Bonichon and Laubier, 1979; Lumare, 1981) and *P. monodon* (Simon, 1982) either alone to minimize the tedium of retrieving numerous females particularly in commercial hatcheries, or to retrieve the eggs of any stray spawners missed out during regular tank monitoring. Nauplii collectors devised for *P. indicus* were found unsatisfactory due to proliferation of bacteria and sea anemones (A.T. Young, pers. comm.).

The observation of individuals through various tags and marks has yielded important information on the maturation and molt cycles of penaeids. Tags of brass, silicone or cellophane around the unablated eyestalk of *P. monodon* (Rodriguez, 1976; Primavera, 1978; Aquacop, 1983a; Poernomo and Hamami, 1983) and aluminum bands around the unablated or ablated eyestalk of *P. plebejus* (Kelemec and Smith, 1980) with coded numbers, letters and colors have allowed the monitoring of maturation in individual females. To chart the molt cycle, however, additional tags attached to the cephalothorax (Aquacop, 1983a) and a coded system of cutting the uropods (Hillier, 1984) have been used for *P. monodon.*

Pens and cages

The offshore maturation pen requires a cove or bay protected from wind and wave action and seawater free from industrial and agricultural pollution (Primavera and Gabasa, 1981). The SEAFDEC Aquaculture Department prototype consists of a 16 × 16 × 4 m framework of bamboo posts, braces and mattings and an inner net which holds the *P. monodon* broodstock. Maturation cages made of nylon netting and installed inside a pond (Haider, 1978; B. Pudadera, pers. comm.) are so far experimental.

As earlier mentioned, tanks are preferred over pens and cages because of the greater security and convenience in broodstock monitoring and tank maintenance. Moreover, tanks can be located anywhere a prawn hatchery is put up unlike pens which are site-specific.

Other aspects of reproduction

In addition to maturation, the complete spectrum of controlled reproduction in penaeids includes spawning, hatching of eggs into viable larvae and the production of postlarvae to constitute the next batch of broodstock (Fig. 4). In turn, hatching of eggs presupposes incubation, fertilization, mating or spermatophore transfer, and male maturation.

Constitution of broodstock

The source of broodstock may be wild immature adults/subadults caught from estuaries or "sourced" by trawlers from offshore, or spent wild spawners recycled from

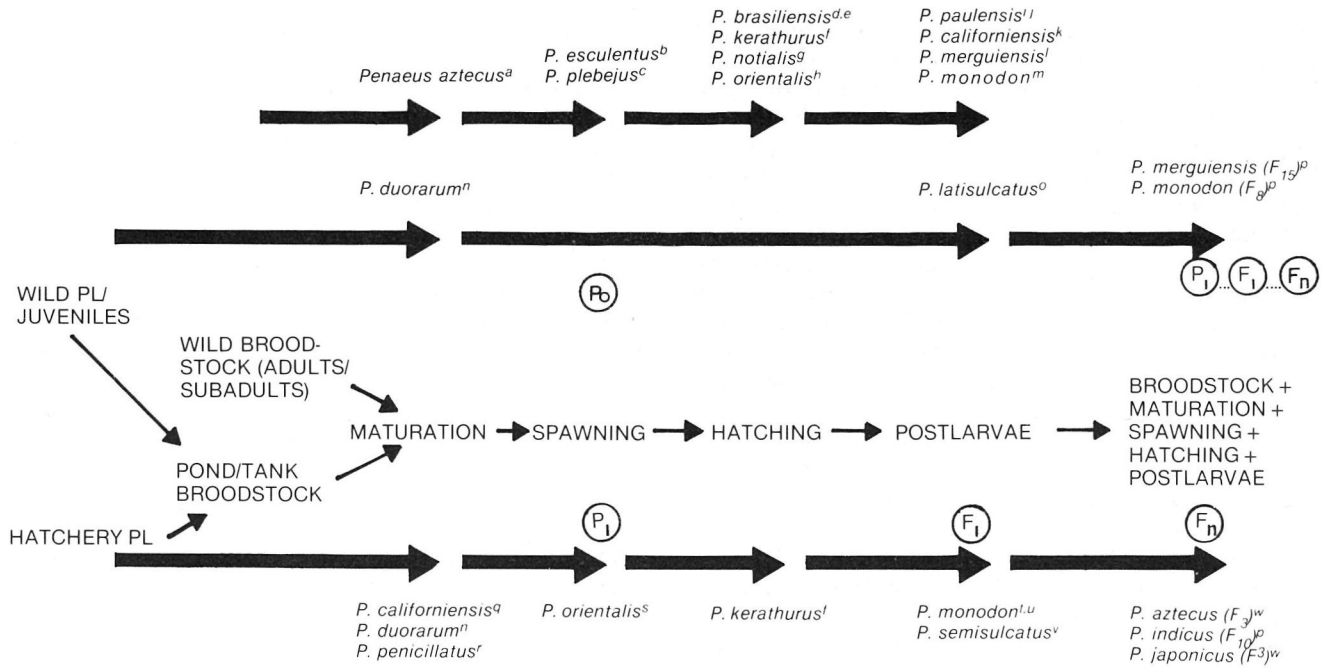

Fig. 4. Reproductive phase achieved in captivity in closed thelycum penaeids ([a]Duronslet et al., 1975; [b]P. Crocos, pers. comm.; [c]Kelemec and Smith, 1980; [d]Martino, 1981; [e]Barros et al., 1982; [f]Lumare, 1979; [g]Ramos and Flores, 1983; [h]Liang et al., 1983; [i]Marchiori and Boff, 1983; [j]Agarez and Barros, n.d., [k]Moore et al., 1974; [l]Nurjana and Won, 1976; [m]Ruangpanit et al., 1981, 1984; [n]Caillouet, 1972; [o]Shokita, 1970; [p]Aquacop, 1983a; [q]Broom, 1972; [r]Liao, 1973; [s]Arnstein and Beard, 1975; [t]Santiago, 1977; [u]Beard and Wickins, 1980; [v]Browdy and Samocha, 1985; [w]Aquacop, 1977a).

the hatchery. Or they may be captive broodstocked reared in ponds and tanks from hatchery or wild fry (Fig. 3).

Hatchery postlarvae grown to broodstock constitute the first parental (P_1) generation completely reared in captivity when they mature and spawn (Fig. 4). In turn, their offspring become the first filial (F_1) generation that grow to be the P_2 generation when they reproduce. The wild spawners or wild broodstock (matured in captivity) that produce the original hatchery postlarvae are referred to as the P_0 generation, same as wild fry that are reared to broodstock in captivity, because part of their life has been spent in the wild.

In French Polynesia, the rearing of *P. monodon* broodstock from young postlarvae to 60 g body weight over 9-12 months involves a series of 3-stage pond transfers during which density is gradually decreased from 20/m^2 to 1-2/m^2 and various artificial pellets and fresh feeds are given (Aquacop, 1983a). During the last stage (6 to 9 months of age), the supply of fresh feeds to the broodstock in ponds is critical to future maturation performance. *P. monodon* given fresh feed during this time show adequate serum protein concentration and a high spawning index whereas those fed pellets alone have a low serum protein level and few or no spawnings (Aquacop, 1983b). For *P. indicus* and *P. merguiensis,* standard pond grow-out technology is employed at lower stocking densities (MSU-IFRD, 1975; Aquacop, 1983a).

The minimum age at first ovarian maturation of captive broodstock is 4-8 months for *P. indicus* and *P. merguiensis* (Aquacop, 1975; Beard et al., 1977; Primavera et al., 1982; Emmerson, 1983), 8-9 months for *P. aztecus* (Aquacop, 1983a) and *P. orientalis* (Arnstein and Beard, 1975), 7-12 months for *P. japonicus* (Aquacop, 1975; Caubere et al., 1979; Laubier-Bonichon and Laubier, 1979) and 9-15 months for *P. monodon* (Aquacop, 1977a; Santiago, 1977; Primavera et al., 1978). Five-month-old *P. monodon* matured and spawned after ablation (Primavera, 1978) but the poor quality of larvae produced points to the need for older females that may be more receptive to induced maturation. In the wild, *P. monodon* attain full maturity and spawning at around 10 months (Motoh, 1981).

Spawners from captive broodstock are generally smaller than those from the wild. Ablated *P. monodon* had a minimum size of 32 g (Poernomo and Hamami, 1983) and 45 g (Aquacop, 1977a) compared to 75 g for wild spawners (Primavera, 1978). On the other hand, only female *P. monodon* with carapace length (CL) of at least 52 mm out of a range of 42-70 mm matured after ablation (Muthu and Laxminarayana, 1977) which is greater than the minimum CL of 48 mm for wild spawners (Motoh, 1981). Minimum size at first ovarian maturation is 23 mm CL for *P. semisulcatus* (Thomas, 1974) and *P. merguiensis* (Crocos and Kerr, 1983) and 130.2 mm total length for *P. indicus* (Rao, 1968). *P. indicus* with 24-44 mm CL were ablated but only females with 30 mm CL and above matured (Muthu and Laxminarayana, 1977).

The choice of spawner source (wild spawner vs. wild broodstock vs. pond broodstock) depends on a number of factors foremost among which is expense. In the Philippines, a wild *P. monodon* spawner fetches from P100 to P1,000 (P18:US $1) apiece compared to only P10 to P40 each for wild immature females (Primavera, 1984). Hatchery production target is also important with large hatcheries relying on wild or captive broodstock to fill part or most of their spawner needs while small hatcheries may depend solely on wild spawners.

Also, hatcheries rearing native species can rely on wild spawners or wild broodstock whereas introduced or exotic species will have to depend on captive sources, e.g. *P. japonicus* in France and *P. monodon* in Brazil. Hatcheries with proximity to sources of wild spawners or wild broodstock may not need captive broodstock. With no abundant natural populations of *P. monodon*, Taiwan has had to import up to 40% of its spawner needs (Liao and Chao, 1983) mostly from the Philippines (Primavera, 1984). Taiwanese and many Philippine hatchery operators spare no expense to obtain wild *P. monodon* spawners in the belief they are superior to ablated females in terms of quantity and quality of eggs and larvae produced (section IV, F).

Male maturation

As with females, male maturity has two aspects — functional maturity or the ability to mate with the completion of the secondary sexual organs and physiological maturity or the ability of sperm to fertilize eggs with the development of the gonads. Male penaeids are functionally mature when their petasmata (accessory structures on the first pair of pleopods) are joined to each other by means of interlocking hooks.

However, more important is gonadal maturation and the presence of fully developed spermatozoa with spikes. These spikes are non-motile with an ultrastructure different from flagella (Clark et al., 1973) and are characteristic of other penaeid species. Because checking for spikes requires microscope work and sacrificing the male, many workers prefer to look for the swelling and whitish coloration of the terminal ampoules near the fifth pair of pereiopods as an indicator of gonadal maturity.

Ruangpanit et al. (1984) noted immature males without sperm from both pond and wild *P. monodon*. Alikunhi et al. (1975) reported maturation of male *P. monodon* from ponds 7-8 days after ablation but did not specify criteria for determining maturation. Primavera (1978) reported the presence of mature (spiked) sperm in *P. monodon* of 40 g and more from both wild and ponds although more recently, 10-month-old pond *P. monodon* were observed with immature (spikeless) sperm (Primavera, unpub.). Motoh (1981) reports that sperm from wild *P. monodon* with CL below 37 mm have no spikes. Among wild *P. merguiensis*, the joining of petasmata occurs between 20 to 25 mm CL (Tuma, 1966).

Male maturation should not be taken for granted because nonhatching of eggs may sometimes occur even when mating has taken place with the failure traceable to immature sperm.

Mating (spermatophore transfer)

Courtship and mating (precopulatory and copulatory) behavior has been described for *P. japonicus* (Hudinaga, 1942) and *P. monodon* (Primavera, 1979). In the latter, an elaborate series of stages is involved including parallel swimming, male turning ventral side up, then perpendicular to, and finally making a U-shape around, the female during which the sperm sacs are presumably inserted inside (transferred to) the thelycum. ("Spermatophore transfer" more appropriately denotes mating or copulation among penaeids than the terms "impregnation" or "insemination" which are better applied to mammals.)

The prerequisite to mating in closed thelycum penaeids is the molting of the female (Fig. 2) in contrast to open thelycum species which require ovarian maturation and imminent spawning of the female (Aquacop, 1977a).

In both cases, mating probably depends on one or more pheromones released by the female to attract males (Table 5).

Complete darkness (Aquacop, 1980) as well as bright floodlights (Primavera, unpub.) are reported to hinder mating in *P. monodon*. Salinity may have no effect on copulation judging from the presence of sperm in the thelycum of *P. monodon* caught from estuaries and brackishwater ponds.

Mating requires a minimum water volume and depth with success and frequency limited in small tanks for *P. monodon* (Primavera, 1979; Poernomo and Hamami, 1983), *P. japonicus* (Lumare, 1981) and *P. esculentus* (P.J. Crocos, pers. comm.). The absence of (fertilization and) hatching possibly due to unsuccessful spermatophore transfer was observed in *P. monodon* (Liao, 1973; Primavera et al., 1979; Emmerson, 1983). Such failure of mating could be traced to absence of males in *P. monodon* (Pudadera et al., 1980b), shallow water depth (25 cm) in *P. orientalis* (Arnstein and Beard, 1975), too few males (7 ♀:1 ♂) and/or crowding due to numerous air-lift pipes and high stocking density (18/m^2) in *P. plebejus* (Kelemec and Smith, 1980). Flowthrough water may also dilute pheromonal levels and decrease mating frequency.

Table 5. Role of various factors in controlled reproduction in closed thelycum penaeids.

	Mating	Maturation	Spawning	Fertilization, incubation and hatching
Hormonal/ pheromones	✓	✓	?	?
Nutritional	×	✓	×	×
Environmental (temperature, salinity, light)	✓	✓	✓	✓

Newly-caught wild or pond broodstock are generally mated when stocked in maturation tanks. Hatching and viability of nauplii from initial captive spawnings are dependent on sperm from copulation in the wild or pond environment. However, unsuccessful mating in captivity will eventually lead to nonhatching of eggs due to loss of spermatophores once the female molts as observed in *P. plebejus* (Kelemec and Smith, 1980) and *P. notialis* (L. Ramos, pers. comm.). *P. monodon* spawnings averaged 96% hatch rate up to 10 days after ablation and decreased to 0% 12-66 days afterwards (Muthu and Laxminarayana, 1977).

Completeness of male and female genitalia (minimum age/size), molting of female, light intensity, tank size and depth all appear to play a role in spermatophore transfer. The effect of other factors needs to be studied.

Spawning

The spawning behavior of *P. monodon* has been described by various workers (Villaluz et al., 1972; Aquacop, 1977b; Motoh, 1981). The presence of pinkish to orange scum along the walls of spawning tanks is generally an indication of spawning in penaeids with *P. kerathurus* a notable exception (Lumare, 1979). Very little or no scum has been observed with spawns from ablated *P. monodon* in tanks provided with gentle aeration (Primavera, unpub.) and may be associated with reduced stress on the ready-to-spawn females. Trays or plates are installed on the bottom of spawning tanks to prevent the females of *P. japonicus* (Lumare, 1981), *P. indicus* (Primavera et al., 1982), and other species (Aquacop, 1975) from eating their eggs.

Non-spawning and regression of ovaries due to stress and "overripe" ovaries invaded by haemocytes have been reported for *P. merguiensis* (Beard et al., 1977). On the other hand, regression of ovaries has been observed in both stressed and undisturbed *P. monodon* females (Aquacop 1977b, 1980). Gravid *P. monodon* that do not spawn for 2-3 successive nights but retain the outline of apparently ripe ovaries may have the "milky ovary" disease caused by a microsporidian.

White light and low temperature were found to inhibit spawning in *P. plebejus* (Kelemec and Smith, 1984) whereas temperature shock (abrupt increase) has been used to induce spawning. Spawning activity of wild *P. latisulcatus* appears to be related to water temperature (Penn, 1980). Although Aquacop (1975) mentions a lunar periodicity in spawnings of *P. merguiensis* broodstock in tanks, asynchronous spawning relative to the moon phase has been observed for wild populations of *P. latisulcatus* (Penn, 1980) and *P. merguiensis* (Crocos and Kerr, 1983).

Fertilization, incubation and hatching

The events following spawning have been described by Clark et al. (1984) in detail for *Sicyonia ingentis,* a shrimp closely related to penaeids. These include primary and secondary binding of sperm, a biphasic acrosomal reaction which is Ca^{++}-dependent, ovum jelly extrusion, fertilization or sperm-egg fusion and hatching membrane formation. During ovum jelly extrusion, also called the cortical reaction, a stratified corona around the egg is formed with the dehiscence of the cortical rods as observed in *P. aztecus* (Clark et al., 1982), *P. japonicus* (Hudinaga, 1942) and *P. monodon* (Primavera and Posadas, 1981).

The jelly layer or corona formed by the cortical reaction supposedly facilitates capture of the non-motile sperm by the egg in *P. orientalis* (Oka, 1967 cited by Wickins, 1976). In *P. aztecus,* ovum jelly extrusion is Mg^{++}-dependent and in penaeid eggs in general, the reaction is stimulated by exposure to seawater and not by fertilization (Clark and Lynn, 1977 cited by Clark et al., 1984). Abnormal spawnings of *P. monodon* eggs laid in masses on the tank bottom remain unfertilized and unhatched (Villaluz et al., 1972) perhaps due to a failure of the cortical reaction (Aquacop, 1977a).

Salinity in spawning tanks has ranged from 28 to 35 ppt for eggs of *P. monodon* (Villaluz et al., 1972; Primavera and Borlongan, 1978; Simon, 1982; Hillier, 1984) and P. *semisulcatus* (Tseng and Cheng, 1981). Among various temperature-salinity combinations, Reyes (1981) obtained highest mean hatch rate of *P. monodon* eggs incubated at 33 ppt at temperatures of 23°C and 33°C, whereas 23 ppt and 28 ppt at any given temperature level produced weak larvae. Similarly, *P. indicus* eggs showed a significantly higher hatch rate and shorter incubation period at 33 ppt compared to 22 ppt and 42 ppt (A. Openiano, pers. comm.). At 20-25 ppt, the eggs of *P. indicus* and *P. semisulcatus* show retarded development and swelling to the point of bursting at 10-15 ppt (Tseng and Cheng, 1981) whereas they shrink at 50 ppt.

A temperature range of 26-29°C has been recorded for incubation of *P. monodon* eggs (Villaluz et al., 1972; Primavera and Borlongan, 1978; Hillier 1984). Increasing temperature levels of 23, 28 and 33°C had no effect on hatch rate of *P. monodon* eggs but significantly decreased incubation period (Reyes, 1981).

In *P. semisulcatus*, incubation water pH of 7-8 gave 40-70% hatch rate while pH of 6 and 9 led to abnormal development with less than 20% hatch rate (Tseng and Cheng, 1981). Ethylene dinitro tetraacetic acid (EDTA), an agent which chelates heavy metals, is added to spawning tanks at 10 ppm (Simon, 1982; Hillier, 1984). Spawning or incubation tank density should not exceed 2,500-3,000 eggs/ℓ otherwise hatching will be poor (Primavera, 1983). A low aeration rate of 4 bubbles/sec increased spawn quality, fecundity and hatch rate of wild *P. indicus* spawners (Emmerson, 1980).

Comparison of fecundity, egg and larval quality

Lower fecundity in females matured in captivity compared to wild spawners has been observed for *P. californiensis* (Moore et al., 1974), *P. indicus* (Emmerson, 1980) and *P. japonicus* (Lumare, 1981). Similarly, ablated *P. merguiensis* produced a mean of 91,000 nauplii/spawn compared to 210,000-446,000 nauplii/spawn from wild spawners (Nurjana and Won, 1976). A range of 60,000 to 600,000 eggs/spawn has been observed for ablated *P. monodon* (Santiago, 1977; Vicente et al., 1979; Aquacop, 1983a; Poernomo and Hamami, 1983; Primavera, 1983) compared to 250,000-800,000 eggs/spawn for wild spawners (Motoh, 1981).

The lower fecundity of captive females may be due to the generally smaller sizes of broodstock compared to wild spawners (section IV, A) and uneven development of right and left ovarian sides in unilaterally ablated females as observed for *P. monodon* (M.N. Lin, pers. comm.). Even with adjustment made for female size, the lower fecundity of domestic unablated *P. indicus* is due to narrower ovary width compared to wild spawners, and to breaks in the ovary caused by collisions with tank walls (Emmerson, 1980).

More important than quantity is the quality of eggs and larvae. Aquacop (1977b) has classified *P. monodon* eggs into unfertilized, normal fertilized and abnormal fertilized eggs. These groupings approximate the egg types described by Primavera and Posadas (1981) based on morphology and hatch rates. A highly linear relationship was established between the proportion of good (A_1) eggs and hatch rate for

P. monodon. Although many Philippine hatchery operators tend to believe that fry from ablated females is weaker than from wild spawners, others have observed both good and poor quality eggs from wild spawners (SEAFDEC, 1984). Half-spent or partial spawnings of *P. semisulcatus* produced poor eggs with irregular cytoplasmic formation and autolysis (Tseng and Cheng, 1981). On the other hand, Primavera and Posadas (1981) found that wild *P. monodon* spawners had the highest proportion of good eggs followed by ablated wild females with ablated pond females producing many bad eggs.

Ruangpanit et al. (1984) observed relatively low survival rates (4-8.5%) from nauplii to postlarvae which may indicate a greater susceptibility to bacterial and fungal infection of *P. monodon* larvae from ablated wild stock. All these point to the need to improve egg and larval quality in both wild and pond broodstock.

Artificial spermatophore transfer; in vitro fertilization

Compared to closed thelycum species, the failure of mating and consequent absence of spermatophores is more frequent in open thelycum penaeids from which spermatophores are more easily dislodged. However, low frequency of mating may also be observed in closed thelycum species, e.g. *P. monodon* (Lin and Ting, 1984) perhaps due to diseased males or their short supply in captivity.

The artificial transfer of spermatophores developed to solve this problem consists of two processes — extraction and insertion. Extraction of spermatophores may be done by means of manual pressure on the base of the fifth pair of pereiopods; forceps inserted through the genital pores; siphoning out; or by the use of low electrical charges as tried on *P. japonicus* (Laubier-Bonichon and Ponticelli, 1981; Lumare, 1981; Ponticelli, 1981) and *P. monodon* (Lin and Ting, 1984; Muthu and Laxminarayana, 1984). The use of electricity prevents injury to the male and permanent damage to the seminal vesicles (Lumare, 1981; Muthu and Laxminarayana, 1984).

The structure of the open thelycum and the pouch-like closed thelycum of *P. japonicus* makes the insertion of spermatophores easier than with other closed thelycum species. With *P. monodon*, treatment must be on newly-molted females in contrast to *P. japonicus* which can be at any molt cycle stage. To reduce stress and mortality, females may be placed in a continuous gill irrigator that allows gas exchange (Tave and Brown, 1981) or anesthesized by lowering the temperature to 10°C for 5 min (Laubier-Bonichon and Ponticelli, 1981). Tave and Brown (1981) report a spawning rate of 80% for various species while Laubier-Bonichon and Ponticelli (1981) claim a fertilization rate of 80% and more for *P. japonicus*. Out of five *P. japonicus* tested, four females retained the spermatophores, two spawned and one hatched viable nauplii (Ponticelli, 1981).

In contrast, Lumare (1981) produced very poor results with 7.5% mean fertilization rate and 3.3% mean hatch rate from artificially tested female *P. japonicus* compared to 67.7% mean fertilization rate and 40.1% mean hatch rate from naturally mated females. Similarly, Muthu and Laxminarayana (1984) obtained nauplii with a low hatch rate of 2.4% from only one out of 10 artificial spermatophore transfers performed on three ablated *P. monodon* females. Higher hatch rates of 71.87% and 82.35% were obtained by insertion of one and two spermatophores, respectively, in *P. monodon* by Lin and Ting (1984).

In vitro fertilization has also been tried to solve the problem of lack of mating. Clark et al. (1973) obtained a hatch rate of 10% by mixing ampoules of mature males with gravid ovaries of female *P. aztecus*. Lin and Ting (1984) obtained successful fertilization with 49.4-63.1% hatch rate only when the sperm homogenate was added right before, and not right after or two hours before, spawning in *P. monodon*.

Future directions

Out of some 109 penaeid species of present or potential commercial value (Holthuis, 1980), almost a third have been reared in grow-out ponds and tanks (Table 6). Twenty-three species have been matured in captivity but a full closing of the cycle has been achieved for only seven species. This is because the state-of-the-art in most hatcheries is the successful production of penaeid larvae and postlarvae from either wild spawners or wild immature/spent females matured/rematured in captivity (Fig. 4).

Table 6. Comparison of total number of commercial and cultured penaeid species.

	Total	Closed thelycum
A. No. of penaeid species of present or potential commercial value (Holthuis, 1980)	109	
B. No. of penaeid species cultured		
Grow-out (ponds and tanks)	34 (?)	–
Larval rearing	30	18
Maturation	23	17
Full closing of cycle (F_1 generation)	7	5

The improvement of reproductive performance including egg and larval quality from captive pond broodstock remains a major area for future research and includes the determination of minimum/optimum age and size for maturation. The complete characterization of the hormonal, nutritional and environmental requirements for maturation should lead to the development of alternatives to ablation, e.g. photoperiod manipulation or the use of hormones, or should at least enhance the eyestalk ablation technique.

Aside from maturation, the other major bottleneck in controlled reproduction of penaeids is successful spermatophore transfer. The present emphasis on female maturation should be extended to other aspects, particularly mating (Table 5). Studies on biology (molting, fertilization including cortical reaction) and biochemistry provide baseline information for the broodstock and maturation aquaculturist. Investigations of wild stocks complement laboratory studies in elucidating the interrelationships among molting, mating, maturation and spawning.

Lastly, the techniques of artificial spermatophore transfer and *in vitro* fertilization are useful not only in solving the immediate problem of lack of copulation but also for future genetic studies and hybridization work.

Addendum

Since the December 1984 conference, substantial data on maturation and spawning in *P. semisulcatus* have been reported by Browdy and Samocha (1985, in press) bringing to 8 and 6 the total number and the number of closed thelycum species, respectively, whose life cycle has been completed in captivity (Table 6). The P_2 generation was achieved with both ablated and unablated broodstock of *P. semisulcatus* maintained in 3 m^3 tanks with 40 ppt flowthrough water and fed with frozen *Artemia*, fish, shrimp and squid.

The average daily numbers of spawns and eggs produced by an ablated female was double that of unablated controls. Egg production in ablated females was consistent for 70-80 days followed by a decline while that of unablated females was more erratic with a decline after 100-110 days. Ablated females had fewer eggs in an average spawn than unablated ones but the quality as measured by rates of fertilization, hatching and metamorphosis to zoea remained the same.

There was no significant difference in spawn size or quality over the first three spawnings of both ablated and unablated females. There was a reduction in spawn size but not in quality of successive spawns in a single molt cycle. Similarly, there was a reduction in fecundity of pond broodstock over successive generations. Ablation did not affect survival of broodstock with relatively high rates attributed to the use of electrocautery, ablation of females during the intermolt, application of prophylactics, and reduced light intensity. Relatively successful spermatophore transfer (84-90%) was achieved at 1.8-2.5 ♀:1♂. Ablation significantly reduced the success of mating and molt cycle duration.

The maximum number of spawns in one molt cycle was 6 and 4 for ablated and unablated females, respectively. A single mating was sufficient to fertilize up to four spawns in a single molt cycle indicating that closed thelycum penaeids have the physiological capability to fertilize several spawns over the molt cycle.

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A Brief Review of the Larval Rearing Techniques of Penaeid Prawns*

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Abstract As early as half a century ago, Hudinaga successfully spawned and attempted to rear the larvae of *Penaeus japonicus.* Publications in the 1960 s, 70's and 80's on breakthroughs in larval rearing of one penaeid species after another indicated that practical prawn farming had become a reality. At present, there are 24 *Penaeus* species and seven *Metapenaeus* species whose larval rearing techniques are partially or fully established. Among them, only nine species are propagated on a large commercial scale. The other species are now produced only on a small scale or experimentally.

There are many published papers dealing with larval rearing techniques of penaeid prawns. However, it is recognized that numerous details and problems remain unsolved pending further investigation and improvement. *P. japonicus* is the species which boasts the longest research history and the most successful larval rearing techniques. Nevertheless, there is little which scientists are able to do with the serious "white-turbid midgut gland disease" which has plagued the postlarvae of *P. japonicus* for the past several years. Similarly. *P. monodon* larval culture in the Philippines was once seriously affected by a fungus disease cause by *Lagenidium* sp., which resulted in poor survival rate.

Suitable larval rearing methods differ from one species to another, all showing varying degrees of modification from the major principles of larval rearing techniques of penaeid prawns. For example, a hatchery can easily obtain several hundred spawners of *P. japonicus,* but this is never the case with *P. monodon.* Therefore, the community culture method for rearing larvae in large tanks is preferred for the former species, while the separate tank method, also called the monoculture method, is best for the latter.

In general, larval rearing techniques of prawns is at its rapid growing stage. The status of larval rearing including rearing methods, feeding regimes and rearing systems, are herein summarized and introduced. The high priority problems to be solved, such as 1) selection of spawners, 2) improvement of rearing techniques, 3) larval diseases, 4) shipping methods, and 5) social impact are discussed and the prospects of larval rearing are described.

Introduction

As early as half a century ago, Hudinaga successfully spawned and reared larvae of *Penaeus japonicus* to the mysis stage (Hudinaga, 1935). In 1942, one of his famous papers entitled "Reproduction, development and rearing of *Penaeus japonicus* Bate" was published and became the primary foundation for prawn research. Unfortunately, World War II interrupted further development for more than 10 years. It was not until the late 1950's that several Americans became highly interested in penaeid hatchery work. In collaboration with Hudinaga, two species of American penaeids, white shrimp, *P. setiferus,* and brown shrimp, *P. aztecus,* were spawned and successfully reared in 1963 (Hanson and Goodwin, 1977).

However, two publications of Hudinaga and Kittaka, namely "Studies on food and growth of larval stages of a prawn, *Penaeus japonicus,* with reference to the application to practical mass culture" in 1966 and "The large scale production of the young kuruma prawn, *Penaeus japonicus* Bate" in 1967, contributed to the breakthrough in the mass production of penaeid prawns. It is on these two publications that the fundamentals of the prawn industry were based.

*Contribution B No. 32 of the Tungkang Marine Laboratory

Status

Twenty-four *Penaeus* species and seven *Metapenaeus* species can now be partially or fully artificially propagated (Table 1). Among these 31 species, *P. aztecus, P. duorarum, P. japonicus, P. monodon, P. orientalis, P. setiferus, P. stylirostris, P. vannamei* and *Metapenaeus ensis,* are the only nine species on which the practical commercialized propagation is carried out on a large scale.

Larval rearing methods

There are many different larval rearing methods in the world due in part to the wide variety of prawn species under culture. Other contributing factors are geography, climatic patterns, feeding regimes, and even personal preference (Hudinaga and Kittaka, 1966, 1975; Mock and Murphy, 1971; Salser and Mock, 1974; Shigueno, 1975; Heinen, 1976; Wickins, 1976; Aquacop, 1977; Liao, 1981). Hundreds of *P. japonicus, P. aztecus, P. duorarum* and *P. setiferus* spawners can be easily collected thus providing the hatchery with the necessary criterion to select the community culture method, whereby it is possible to rear a tremendous number of larvae in a hatchery tank of 100 tons or larger. In the community culture method, fertilizer is added directly to the tank for diatom growth, thus a food chain is formed in the larval rearing

tank. The diatoms become the primary producer, providing food for prawn larvae and zooplankton. The larval prawn also consume these zooplankton. On the other hand, only a limited number of *P. monodon* spawners can be collected at any one time and, in addition, the larvae are slightly sensitive to direct application of fertilizer. Therefore, the community culture method is less suitable than the separate tank (monoculture) method for *P. monodon*. Comparisons between the community culture and separate tank (monoculture) methods are listed in Table 2.

Feeding regimes

Recent studies on the larval feed of penaeid prawns have made incredible progress (Furukawa et al., 1973; Griffith et al., 1973; Kittaka, 1976; Jones et al., 1979a, b; Liao et al., 1983). Today, even the application of manufactured microcapsules or the so-called microparticulate feed, is very promising (Jones, 1979a, b). Nevertheless, one should not forget the pioneer's hard work in the early history of the prawn industry. As early as 1934, Hudinaga succeeded in inducing the parent prawn of *P. japonicus* to spawn in the laboratory

Table 1. List of penaeid prawns partially or fully artificially propagated.

Species	Common name	Status[a] E	S	c	Culture area	Distribution[b]	Reference
Penaeus aztecus Ives	Northern brown shrimp			+	USA	W.A.	Cook & Murphy, 1966
P. brasiliensis Latreille	Red-spotted shrimp		+		Taiwan	W.A.	Unknown[c]
P. californiensis Holmes	Yellow-leg shrimp	+			USA	E.P.	Unknown
P. canaliculatus (Olivier)		+			—	I.W.P.	Choy, 1984
P. duorarum Burkenroad	Northern pink shrimp			+	USA	W.A.	Ewald, 1965
P. esculentus Haswell	Brown tiger prawn	+			—	I.W.P.	Fielder et al., 1975
P. indicus Milne Edwards	Indian white prawn		+		S.E. Asia	I.W.P.	Muthu et al., 1974
P. japonicus Bate	Kuruma prawn			+	Brazil, Italy Japan, Korea, Taiwan	I.W.P.	Hudinaga, 1942
P. kerathurus (Forskal)	Caramote prawn	+			Italy	E.A.	Lumare et al., 1971
P. latisulcatus Kishinouye	Western king prawn	+			—	I.W.P.	Shokita, 1970
P. marginatus Randall	Aloha prawn	+			—	I.W.P.	Gopalakrishnan, 1976
P. merguiensis De Man	Banana prawn		+		Indonesia, Malaysia	I.W.P.	Unknown
P. monodon Fabricius	Giant tiger prawn			+	India, Indonesia, Philippines, Taiwan	I.W.P.	Liao et al., 1969
P. occidentalis Streets	Western white shrimp	+			Panama	E.P.	Ting et al., 1977
P. orientalis Kishinouye	Oriental shrimp			+	China, Korea	W.P.	Oka, 1967
P. paulensis Perez-Farfante	Sao Paulo shrimp	+			—	W.A.	Unknown
P. penicillatus Alcock	Red-tail prawn		+		Taiwan	I.W.P.	Liao, 1973
P. plebejus Hess	Eastern king prawn		+		Australia	S.W.P.	Kelemec & Smith, 1980
P. schmitti Burkenroad	Southern white shrimp	+			South America	W.A.	Unknown
P. semisulcatus De Haan	Green tiger prawn	+			Kuwait, Taiwan	I.W.P.	Liao, 1970
P. setiferus (Linnaeus)	Northern white shrimp			+	USA	W.A.	Heegaard, 1953
P. stylirostris Stimpson	Blue shrimp		+		Colombia, Ecuador, Panama	E.P.	Unknown
P. teraoi Kubo	White-beared shrimp	+			—	I.W.P.	Liao, 1970
P. vannamei Boone	White-leg shrimp			+	Colombia, Ecuador, Panama	E.P.	Unknown
Metapenaeus affinis (H. Milne Edwards)	Jinga shrimp	+			India	I.W.P.	Thomas et al., 1974
M. bennettae Racek and Dall	Greentail prawn	+			Australia	S.W.P.	Racek, 1972
M. brevicornis (H. Milne Edwards)	Yellow shrimp	+			India	I.W.P.	Sudhakaro, 1978
M. dobsoni (Miers)	Kadal shrimp	+			India	I.W.P.	Enomoto & Makino, 1970
M. ensis (De Haan)	Greasyback shrimp			+	S.E. Asia	I.W.P.	Unknown
M. joyneri (Miers)	Shiba shrimp	+			—	I.W.P.	Liao, & Huang, 1973
M. monoceros (Fabricius)	Speckled shrimp			+	S.E. Asia	I.W.P.	Funada, 1966
M. stebbingi Nobili	Peregrine shrimp	+			—	I.W.P.	Hasan & Haq, 1975

[a]Status (of development): E — Experimental; S — Small scale; C — Commercial scale.
[b]Distribution: W.A. — Western Atlantic; E.P. — Eastern Pacific; I.W.P. — Indo-West Pacific; E.A. — Eastern Atlantic: W.P. — Western Pacific; S.W.P. - South-Western Pacific.
[c]Unknown: Origins presently being verified but cannot be substantiated at this time.

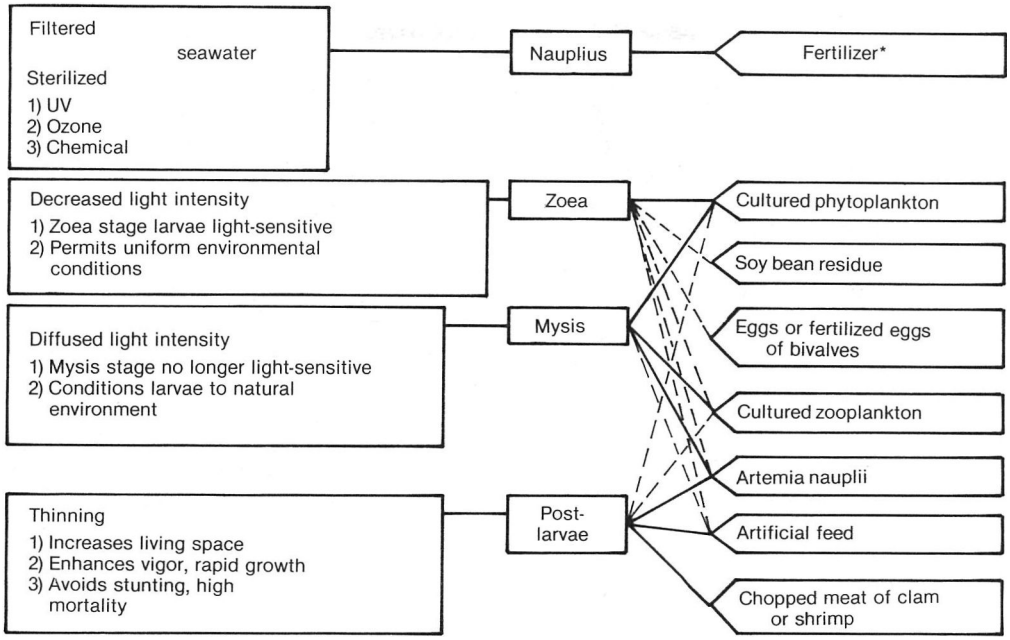

Fig. 1. Schematic representation of feeding regimes for developmental stages of penaeid prawn and related culture parameters. ____ most prominent feeding regime; – – occasional feeding regime. *Community culture method only.

for the first time, but it was not until 1940 that he was able to get a considerable number of larvae to metamorphose into mysis (Hudinaga, 1935, 1942). It was found that larvae in their nauplius stage were not difficult to keep alive, but upon reaching the zoea stage they became weak and died. Larvae in the mysis stage, however, were much stronger than in the zoea stage and could easily be kept alive for a long time. After the mysis stage, the postlarvae became even stronger, rendering their handling much easier and simpler. Therefore, in the culture of *P. japonicus,* and especially in order to raise the desired number of postlarvae, the most important matter is to rear them successfully through the zoea stage. The same was found to be true with many other penaeid prawn species through practical experience. One of the major factors that contributed to Hudinaga's breakthrough in successful rearing of zoea was the culture method of *Skeletonema* established by Matue. Hudinaga himself was greatly-indebted to Matue for valuable information with regards to the pure culture of *Skeletonema costatum* (Hudinaga, 1942, 1969).

As the zoea stage of penaeid prawns is the most difficult rearing period, it is believed that the smooth rearing means giving suitable feed in order to guarantee high survival of zoea and subsequent stages. In view of this, many research papers focused on the availability of a variety of feed for each larval stage (Table 3).

Larval sizes differ among species of penaeids and especially between those of the genera *Penaeus* and *Metapenaeus,* and therefore they feed on food particles of different sizes. In general, as shown in Fig. 1, zoea larvae prefer phytoplankton or tiny vegetable feed, but start to consume zooplankton when they reach the last substage of zoea. Mysis larvae prefer zooplankton, as do postlarvae (P_1-P_5). Postlarvae older than P_5 no longer pay attention to small food particles but actively start to search for larger food.

Larval rearing systems

Like larval rearing methods, the larval rearing systems differ according to species cultured and personal preference. The Japanese or Shigueno system is characterized by 100-ton or larger tanks, which are mainly used for larval rear-

Table 2. Comparison between community culture and separate tank (monoculture) methods.

	Community culture method	Separate tank (monoculture) method
1. Species	*Penaeus aztecus, P. duorarum, P. japonicus, P. setiferus*	*P. monodon*
2. Size of rearing tank for spawning and hatchery	Large tank (100-200 tons)	Small tank (0.5-20 tons)
3. Number of spawners	Many	Few
4. Fertilizer	Used	Not used
5. Light intensity	Normal sunlight	Subdued light
6. Production costs	Low	High
7. Risk	High	Low
8. Prospect for future development	Promising	Limited

ing of *P. japonicus* (Hudinaga and Kittaka, 1967; Shigueno, 1975). The Galveston system of 1- to 2-ton conical tanks is used for *P. stylirostris, P. vannamei* and *P. monodon* (Mock and Neal, 1974; Aquacop, 1975; Platon, 1978; Mock et al., 1980) and the Taiwanese system of 0.5- to 2-ton round tanks with flat bottom is used for *P. monodon* (Liao et al., 1969; Liao and Huang, 1973; Liao, 1981). There are both advantages and disadvantages of each system. For example, tanks of the Japanese system are very suitable for the community culture method, but there is a high risk of losing a great number of larvae if diseases occur. When the supply of spawners is unsteady, the larger size tanks are sometimes wasteful and inconvenient for rearing a limited number of larvae. They are also less flexible than smaller tanks for purposes of discarding larvae, cleaning tanks, and disinfecting equipment.

Two recently developed systems of larval rearing are shown in Fig. 2A and B. First, a ladder system hatchery is designed to take advantage of sloping ground and water level. Second, a hatchery of separate, medium-sized covered tanks with the advantage of being able to discard limited quantities of larvae is designed to suit warm tropical areas where prawns are easily exposed to epidemic disease and abandonment may be necessary. Additionally, three kinds of aeration set-up are shown for comparison (Fig. 2C).

Larval rearing practices

Among the penaeid prawns cultured today, *P. japonicus* is by far the most studied and therefore its larval rearing techniques are best established. It is the most important cultured prawn species in Japan where 500 million postlarvae are used each year for sea ranching and only 200 million postlarvae are used for aquaculture purposes. *P. japonicus* is also propagated in Brazil, Korea, Italy and Taiwan. The advantages of its hatchery work are (1) the availability of sufficient number of spawners at one time, (2) the established hatchery techniques, and (3) the strong tolerance of larvae to environmental factors.

The hatchery technique for *P. monodon* is more difficult than that of *P. japonicus.* However, *P. monodon* is the most treasured species in Southeast Asia and the most suitable species for culture worldwide (Forster and Beard, 1974; Liao, 1977, 1981; Motoh, 1981; Liao and Huang, 1982; Liao and Chao, 1983). It is now cultured mainly in Taiwan, Philippines, Indonesia, Thailand and India. In Taiwan, the total

Table 3. Food items and feeding regimes for various developmental stages of penaeid prawn.

Food item	Zoea	Mysis	Postlarvae (early: P_1-P_{10})	Postlarvae (later: P_{11}-P_{25})	References
Vegetable sources					
Skeletonema sp.	+ +	+ +			Hudinaga, 1942
Tetraselmis sp.	+	+			Beard et al., 1977
Isochrysis sp.	+	+			Beard & Wickins, 1980
Chaetoceros sp.	+	+			Hirata et al., 1975
Dunaliella sp.	—	—			SEAFDEC, 1981
Spirulina sp.	—	-			Tang, 1977
Chlamydomonas sp.	—	—			Hudinaga & Kittaka, 1975
Marine Chlorella	—	—			Hudinaga & Kittaka, 1975
Soy bean residue	+	+			Hirata et al., 1975
Animal sources					
Eggs or fertilized eggs of oyster	+ +	+ +			Liao, 1969
Eggs of *Mytilus*	+ +	+ +			Kittaka, 1975
Rotifer	+ +	+ +			Liao, 1969
Artemia salina	+ +	+ +			Hudinaga, 1969
Brine shrimp flakes	+ +	+ +			Unknown*
Moina sp.			—		Kittaka, 1975
Copepoda			+ +	+ +	Shigueno, 1968
Gammarus sp.			—	+ +	Kittaka, 1975
Balanus sp.			+ +	+ +	Kittaka, 1975
Nematoda			—	—	Liao, 1969
Annelida				+ +	Liao, 1969
Clam meat				+ +	Liao, 1969
Shrimp meat				+ +	Liao, 1970
Fish meat				+	Liao, 1969
Other sources					
Yeast					Furukawa et al., 1973
Milled feed		+	+	+	Shigueno, 1975
Sprayed dried feed		+	+	+	Shigueno, 1975
Microencapsulated diet		+	+	+	Jones et al., 1979a, b

Note: ++ Good; + Available; — Poor.
*Unknown: Origins presently being verified but cannot be substantiated at this time.

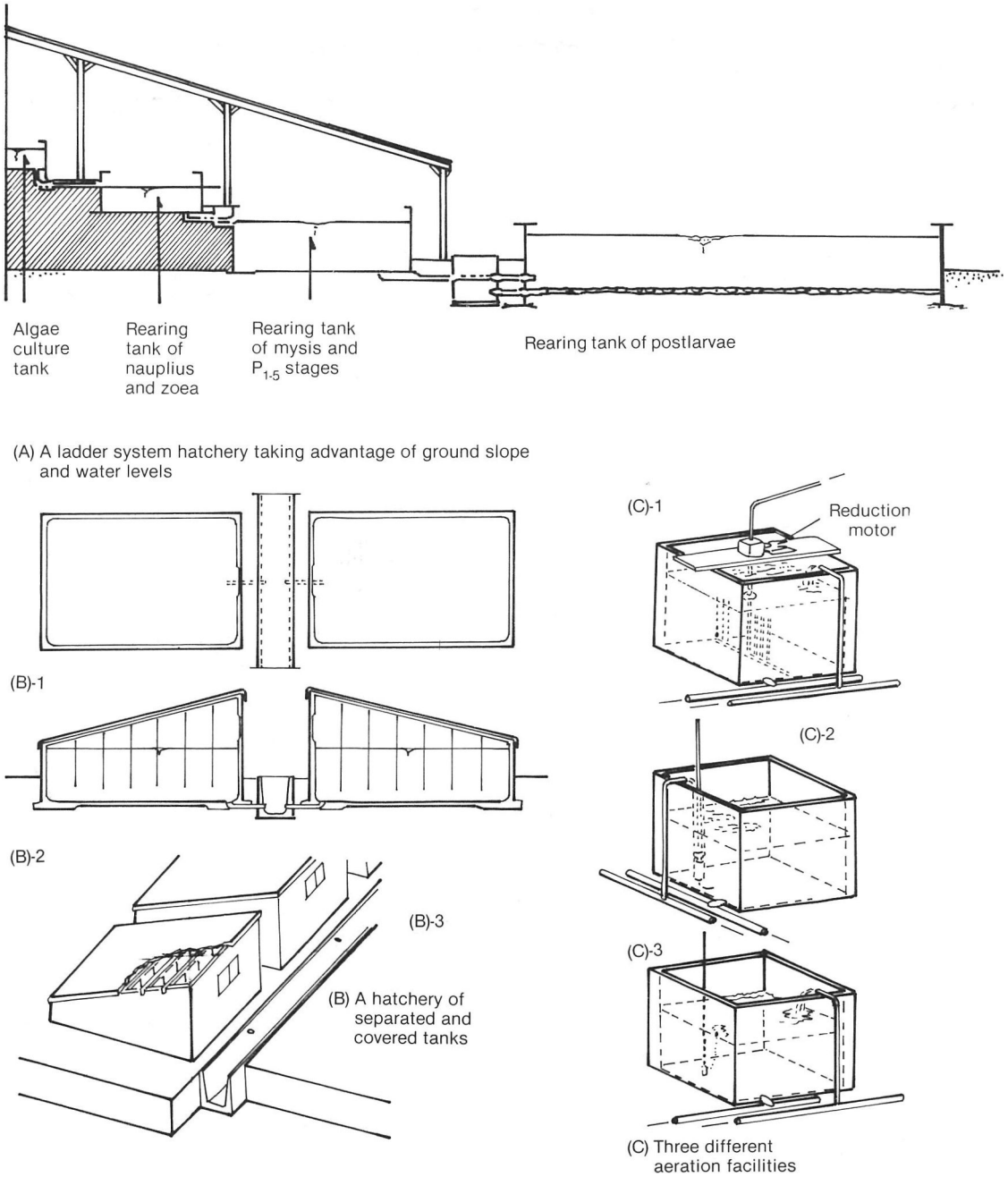

Fig. 2. Schematic diagram of penaeid prawn larval rearing system.

number of commercial hatcheries is more than 1,200 with an annual production of postlarvae as high as 600 million, more than enough to satisfy total domestic demand. The culture of *P. monodon* has great potential and bright prospects. The people in Malaysia, Sri Lanka, Japan, South Africa and Brazil are eager to try the culture of this prawn.

Penaeus stylirostris and *P. vannamei* are naturally abundant in Central and South America. The center of their culture is Ecuador. In 1976, there were only two farms with a total area of 63 ha. In 1984, the number of farms had increased to 465 and the total area to 59,350 ha. Before 1980, 100% of the prawn fry used for culture were collected from the wild. As a result of the rapid expansion of prawn culture and the destruction of the mangrove ecosystem, only one-third of the total fry demand could be met during the dry season of 1984. To further develop the prawn industry of Ecuador, artificially propagated larvae are absolutely needed. For the present, three recently established hatcheries are able to produce not more than 180 million P_{5-10} contributing only 5.5% of the estimated annual need of 3.3 billion fry. It is believed that five hatcheries under construction will soon be able to supply part of the remaining fry requirement by the end of 1985 (T.L. Huang, pers. comm., 1984).

Penaeus aztecus, P. duorarum and especially *P. setiferus*

have comparatively easy larval rearing techniques (Kittaka, 1977). The small size of otherwise marketable adults and some lingering culture problems have kept the rearing of these three species at an early developmental stage. With mainland China as its culture center, probably 300-400 million postlarvae of *P. orientalis* are produced yearly, when estimated from the annual production of 3,000-4,000 tons. There is a possibility that *P. indicus, P. merguiensis, P. brasiliensis* and *P. schmitti* rank as potential aquaculture candidates for the near future.

Table 4 lists the distinctive characteristics of three major sizes of hatcheries i.e., large, medium and small hatcheries. Tables 5 and 6 list the number of postlarval prawns needed for desired harvest at various market sizes and survival rates and the number of postlarval prawns needed for various scales of grow-out ponds at different stocking densities for convenient reference.

Existing problems

Although research on prawns is far behind that of fishes, the development of the prawn industry is progressing well, even better than other aquaculture industries, mainly because prawns are a precious cosmopolitan food item. However, there are existing problems that need to be studied and solved before a truly successful prawn industry can be attained.

Table 4. Distinctive characteristics of three major sizes of hatcheries.

Size	Large	Medium	Small
Ownership	Company	Family or partner	Family
Personnel	Consultant, supervisor, technicians and workers	Owner and experienced workers	Owner and worker
Size (unit of pond)	600-800 m^2 plus accessory tanks (40-60 tons)	(1-20 tons)	(1-5 tons)
Electricity (generator power)	100 kw	50 kw	5 kw
Water storage	600 tons	200 tons	10-50 tons
Water treatment	Filtered at the source or UV light-treated	Filtered at the source or UV light-treated	Filtered at the hatchery
Number of spawners/yr	500 spawners	200-300 spawners	40-50 spawners
Sources of spawners	Private shrimp trawler or broker	Fishermen or broker	Fishermen or broker
Length of active operation (mo/yr)	11	10-11	6-8
Maximum capacity ($\times 10^6$ fry/yr)	10	5	1
Nursery	Necessary	Necessary	Not necessary
Shipping	Airplane, truck or exfarm	Truck or exfarm	Truck or exfarm

Selection of spawners

There is a close relationship between the physiological condition of a spawner and the quality of its eggs, survival of larvae and health during its subsequent culture period. The criteria for selecting the best spawners with good genetic makeup and perfect physical condition should be determined.

Many uncertain descriptions about unilaterally eyestalk-ablated spawners have been made, e.g. 1) there is a maximum of 2-3 or 4-5 spawnings after each ablation, 2) larvae obtained from the later spawnings are poorer in health than those from earlier ones, and 3) larvae obtained from eyestalk-ablated spawners are weaker and have lower survival rates than those of non-ablated spawners. There should be some scientific evidence to accept or reject each of the above mentioned statements.

Another observation that merits further investigation is that certain stimuli, such as transfer from one place to another or even from one tank to another, usually cause spawners to release their eggs during that same night. Based on this fact, spawning in captivity generally results in a premature release of eggs which is believed to be the cause of the poor survival rate of larvae. The problem is how to bring about a natural spawning when the eggs are ripe instead of stimulating a premature release of eggs to ensure optimum survival.

In summary, the appropriate methods for obtaining healthy and non-ablated spawners with the guarantee of getting ripe eggs and thus, high larval survival need to be precisely and promptly studied.

Improvement of rearing techniques

There has been established no standard larval rearing method for each cultured species of penaeid prawn. Taking *P. monodon* as an example, some culturists in Taiwan have adopted the dark-room type hatchery, where the newly hatched eggs are successfully reared in darkness through all the larval stages, while others, making use of the common open type hatcheries for prawn larval rearing, cover the rearing tanks only during the light-sensitive zoea stage. These two methods are quite different as far as suitable light intensity for larvae is concerned, yet both produce postlarvae at comparable rates. It would be more logical if the ranges of tolerance to light intensity, water salinity and other parameters for each larval stage are well studied, so that a standard rearing method could be established. The advantageous community culture method is a common milestone for which the culturists should strive in the culture of various prawn species.

Generally speaking, a large majority of hatchery owners prefer to aim for high survival rates of larvae using a policy of overprotection i.e., an overdose of drugs is administered regardless of the state of health. It is suggested that hatcheries should not concentrate only on high survival rates but should try to follow the principle of natural selection. Unhealthy larvae, which in any case will die if no special treatment is undertaken, should preferably be removed. Such a wise decision will ensure good growth of the survivors

Table 5. Number of postlarvae (× 10^{n*}) needed to attain desired harvest levels at various market sizes and survival rates.

Harvest (× 10^{n*} mt)	Market size (g)	Survival rate (%)										
		5	10	20	30	40	50	60	70	80	90	95
1	20	1,000,000	500,000	250,000	166,667	125,000	100,000	83,333	71,429	62,500	55,556	52,632
	30	666,667	333,333	166,667	111,111	83,333	66,667	55,556	47,619	41,667	37,037	35,088
	40	500,000	250,000	125,000	83,333	62,500	50,000	41,667	35,714	31,250	27,778	26,316
1.5	20	1,500,000	750,000	375,000	250,000	187,500	150,000	125,000	107,143	93,750	83,333	78,947
	30	1,000,000	500,000	250,000	166,667	125,000	100,000	83,333	71,429	62,500	55,556	52,632
	40	750,000	375,000	187,500	125,000	93,750	75,000	62,500	53,571	46,875	41,667	39,474
2	20	2,000,000	1,000,000	500,000	333,333	250,000	200,000	166,667	142,857	125,000	111,111	105,263
	30	1,333,330	666,667	333,333	222,222	166,667	133,333	111,111	95,238	83,333	74,074	70,175
	40	1,000,000	500,000	250,000	166,667	125,000	100,000	83,333	71,429	62,500	55,556	52,632
2.5	20	2,500,000	1,250,000	625,000	416,667	312,500	250,000	208,333	178,571	156,250	138,889	131,579
	30	1,666,670	833,333	416,667	277,778	208,333	166,667	138,889	119,048	104,167	92,593	87,719
	40	1,250,000	625,000	312,500	208,333	156,250	125,000	104,167	89,286	78,125	69,444	65,790
3	20	3,000,000	1,500,000	750,000	500,000	375,000	300,000	250,000	214,286	187,500	166,667	157,895
	30	2,000,000	1,000,000	500,000	333,333	250,000	200,000	166,667	142,857	125,000	111,111	105,263
	40	1,500,000	750,000	375,000	250,000	187,500	150,000	125,000	107,143	93,750	83,333	78,947
3.5	20	3,500,000	1,750,000	875,000	583,333	437,500	350,000	291,667	250,000	218,750	194,444	184,211
	30	2,333,330	1,166,670	583,333	388,889	291,667	233,333	194,444	166,667	145,833	129,630	122,807
	40	1,750,000	875,000	437,500	291,667	218,750	175,000	145,833	125,000	109,375	97,222	92,105
4	20	4,000,000	2,000,000	1,000,000	666,667	500,000	400,000	333,333	285,714	250,000	222,222	210,526
	30	2,666,670	1,333,330	666,667	444,444	333,333	266,667	222,222	190,476	166,667	148,148	140,351
	40	2,000,000	1,000,000	500,000	333,333	250,000	200,000	166,667	142,857	125,000	111,111	105,263
4.5	20	4,500,000	2,250,000	1,125,000	750,000	562,500	450,000	375,000	321,429	281,250	250,000	236,842
	30	3,000,000	1,500,000	750,000	500,000	375,000	300,000	250,000	214,286	187,500	166,667	157,895
	40	2,250,000	1,125,000	562,500	375,000	281,250	225,000	187,500	160,714	140,625	125,000	118,421
5	20	5,000,000	2,500,000	1,250,000	833,333	625,000	500,000	416,667	357,143	312,500	277,778	263,158
	30	3,333,330	1,666,670	833,333	555,556	416,667	333,333	277,778	238,095	208,333	185,185	175,439
	40	2,500,000	1,250,000	625,000	416,667	312,500	250,000	208,333	178,571	156,250	138,889	131,579
5.5	20	5,500,000	2,750,000	1,375,000	916,667	687,500	550,000	458,333	392,857	343,750	305,556	289,474
	30	3,666,670	1,833,330	916,667	611,111	458,333	366,667	305,556	261,905	229,167	203,704	192,982
	40	2,750,000	1,375,000	687,500	458,333	343,750	275,000	229,167	196,429	171,875	152,778	144,737
6	20	6,000,000	3,000,000	1,500,000	1,000,000	750,000	600,000	500,000	428,571	375,000	333,333	315,790
	30	4,000,000	2,000,000	1,000,000	666,667	500,000	400,000	333,333	285,714	250,000	222,222	210,526
	40	3,000,000	1,500,000	750,000	500,000	375,000	300,000	250,000	214,286	187,500	166,667	157,895
6.5	20	6,500,000	3,250,000	1,625,000	1,083,330	812,500	650,000	541,667	464,286	406,250	361,111	342,105
	30	4,333,330	2,166,670	1,083,330	722,222	541,667	433,333	361,111	309,524	270,833	240,741	228,070
	40	3,250,000	1,625,000	812,500	541,667	406,250	325,000	270,833	232,143	203,125	180,556	171,053
7	20	7,000,000	3,500,000	1,750,000	1,166,670	875,000	700,000	583,333	500,000	437,500	388,889	368,421
	30	4,666,670	2,333,330	1,166,670	777,778	583,333	466,667	388,889	333,333	291,667	259,259	245,614
	40	3,500,000	1,750,000	875,000	583,333	437,500	350,000	291,667	250,000	218,750	194,444	184,211
7.5	20	7,500,000	3,750,000	1,875,000	1,250,000	937,500	750,000	625,000	535,714	468,750	416,667	394,737
	30	5,000,000	2,500,000	1,250,000	833,333	625,000	500,000	416,667	357,143	312,500	277,778	263,158
	40	3,750,000	1,875,000	937,500	625,000	468,750	375,000	312,500	267,857	234,375	208,333	197,368
8	20	8,000,000	4,000,000	2,000,000	1,333,330	1,000,000	800,000	666,667	571,429	500,000	444,444	421,053
	30	5,333,330	2,666,670	1,333,330	888,889	666,6667	533,333	444,444	380,952	333,333	296,296	280,702
	40	4,000,000	2,000,000	1,000,000	666,667	500,000	400,000	333,333	285,714	250,000	222,222	210,526
8.5	20	8,500,000	4,250,000	2,125,000	1,416,670	1,062,500	850,000	708,333	607,143	531,250	472,222	447,368
	30	5,666,670	2,833,330	1,416,670	944,444	708,333	566,667	472,222	404,762	354,167	314,815	298,246
	40	4,250,000	2,125,000	1,062,500	708,333	531,250	425,000	354,167	303,571	265,625	236,111	223,684
9	20	9,000,000	4,500,000	2,250,000	1,500,000	1,125,000	900,000	750,000	642,857	562,500	500,000	473,684
	30	6,000,000	3,000,000	1,500,000	1,000,000	750,000	600,000	500,000	428,571	375,000	333,333	315,790
	40	4,500,000	2,250,000	1,125,000	750,000	562,500	450,000	375,000	321,429	281,250	250,000	236,842
9.5	20	9,500,000	4,750,000	2,375,000	1,583,330	1,187,500	950,000	791,667	678,571	593,750	527,778	500,000
	30	6,333,330	3,166,670	1.583,330	1,055,560	791,667	633,333	527,778	452,381	395,833	351,852	333,333
	40	4,750,000	2,375,000	1,187,500	791,667	593,750	475,000	395,833	339,286	296,875	263,889	250,000

*n = -2, -1, 0, 1 2, 3, . . . n. For example, if the harvest level is 15,000 mt, that is 1.5 × 10^4 rat (n = 4), market size of 30 g and survival rate 80%, then the number of postlarvae needed is 62,500 × 10^4, that is 625 million.

in subsequent culture periods (Liao, 1981). Besides, now that many crops are desired in each pond per year, one should stock the pond with postlarvae of a larger size than is currently used, to shorten the cropping time. Of course, there are additional advantages in shortening each cropping time, such as avoiding poor pond bottom conditions and increasing annual production. The existing problem is to improve nursery techniques for juvenile prawns on a large production scale.

As mentioned previously, many breakthroughs in larval feeding, including the accurate establishment of mass culture of phytoplankton, progressive development of mass culture of zooplankton, and primary development of microencapsulated feed, have been achieved. However, they all need further studies before ideal feeding regimes can be declared. Furthermore, the use of modern equipment in the hatchery facility should be encouraged. Aquaculture engineers should design functional, labor- and energy-saving devices to further improve hatchery production.

Larval diseases

In the initial period of the development of the prawn industry, unsuitable and insufficient food, resulting in substandard nutrition and starvation, were major causes of larval mortality. Occasionally, non-lethal or low mortality diseases caused by protozoan infections occurred, but no serious larval diseases or high mortalities were encountered, hence no papers were written on the subject. In contrast, with increasing popularity and profitability of prawn culture in recent years, hatcheries are often overcrowded with larvae, and this is generally accompanied by the occurrence of diseases. White-turbid midgut gland disease has been reported in *P. japonicus* (Shigueno, 1975), as well as *Lagenidium* infection in all penaeid prawns (Couch, 1942; Cook, 1971; Lightner and Fontaine, 1973; Lightner, 1977; Lightner and Redman, 1981; Lightner, 1983), *Baculovirus penaei* (BP) disease in *P. aztecus, P. duorarum, P. setiferus, P. stylirostris* and *P. vannamei* (Laramore, 1977; Couch, 1978; Overstreet, 1978), and recently also baculoviral midgut gland necrosis (BMN) in *P. japonicus* (Sano et al., 1981), Monodon baculovirus (MBV) disease in *P. monodon* (Lightner and Redman, 1981; Lightner, 1983), and finally infectious hypodermal and hematopoietic necrosis (IHHN) in *P. stylirostris* and *P. monodon* (Lightner, 1983). All of these have proven to be a serious threat to hatchery business, with possibly one exception — it is not yet known if MBV is an important disease. Table 7 summarizes the major diseases in the larval and postlarval stages of penaeid prawns and the corresponding treatments.

It is commonly believed that diseases may increase in variety and occurrence with time, especially with respect to the virus-caused diseases. For the present, only four viral diseases have been identified in prawn larvae, but it is likely that more will be found. The ultimate concern is obviously how to prevent diseases and reduce their devastating effects on larvae so that great losses can be avoided. MBV disease shows its lethal effect only when combined with the serious symptoms of other diseases. It is true that by providing MBV-infected larvae with a suitable environment and food they are better protected from other diseases and hence can

Table 6. Number of postlarvae ($\times 10^{n*}$) needed for various sizes of grow-out ponds at different stocking densities per crop.

Pond area ($\times 10^{n*}$ ha)	Stocking density (postlarvae/m^2)										
	3	5	10	15	20	25	30	40	50	60	70
1	30	50	100	150	200	250	300	400	500	600	700
1.5	45	75	150	225	300	375	450	600	750	900	1,050
2	60	100	200	300	400	500	600	800	1,000	1,200	1,400
2.5	75	125	250	375	500	625	750	1,000	1,250	1,500	1,750
3	90	150	300	450	600	750	900	1,200	1,500	1,800	2,100
3.5	105	175	350	525	700	875	1,050	1,400	1,750	2,100	2,450
4	120	200	400	600	800	1,000	1,200	1,600	2,000	2,400	2,800
4.5	135	225	450	675	900	1,125	1,350	1,800	2,250	2,700	3,150
5	150	250	500	750	1,000	1,250	1,500	2,000	2,500	3,000	3,500
5.5	165	275	550	825	1,100	1,375	1,650	2,200	2,750	3,300	3,850
6	180	300	600	900	1,200	1,500	1,800	2,400	3,000	3,600	4,200
6.5	195	325	650	975	1,300	1,625	1,950	2.600	3,250	3.900	4,550
7	210	350	700	1,050	1,400	1,750	2,100	2,800	3,500	4,200	4,900
7.5	225	375	750	1,125	1,500	1,875	2,250	3,000	3,750	4,500	5,250
8	240	400	800	1,200	1,600	2,400	2,400	3,200	4,000	4,800	5,600
8.5	255	425	850	1,275	1,700	2,125	2,550	3,400	4,250	5,100	5,950
9	270	450	900	1,350	1,800	2,250	2,700	3,600	4,500	5,400	6,300
9.5	285	475	950	1,425	1,900	2,375	2,850	3,800	4,750	5,700	6,650

*n = -2, -1, 0, 1, 2, 3,. . . n. For example, if the total area of grow-out ponds is 15 ha (1.5×10^n ha) (n = 1) and the stocking rate is 25 postlarvae/m^2, then the number of postlarvae needed is 375×10^1 thousand, that is 3.75 million.

attain normal growth. For the present, MBV is known to exist in Taiwan and the Philippines, but the extent of its range in other areas is unknown. Being an enzootic virus, MBV should be eradicated. To avoid further contamination, strict quarantine and burning of the infected larvae should be carried out (Lightner et al., 1983).

In summary, the concept that prevention is more important and effective than cure in controlling a disease is absolutely accurate. Reducing stress due to crowding and application of quarantine measures are as necessary as the continuing research on viruses and determination of the etiology of other diseases.

Shipping methods

Even if the three above-mentioned problems of rearing, spawners and diseases are solved, the large quantities of prawn larvae produced in a hatchery still face the problems of shipping before they can be stocked in culture ponds. Transport may be international which usually takes more than 30 hours and also entails expensive shipping costs. The lack of basic biological knowledge and related transport information makes this procedure difficult and a waste of resources. The failure of live transport is not fair to the billions of tiny creatures, each with the dignity of life for which it has struggled seriously and successfully in the hatcheries. Since the relevant research is weak in both quantity and quality, only limited transport data are summarized in Table 8.

It is known from available data that the nauplius stage is ideal for shipping. Nevertheless, there are two limiting factors. First, great quantities of nauplii are requested within a short time frame, often within as short as one to two days. Second, shipping is limited to as short a time as possible i.e., before the larvae molt into zoea, in order to avoid mortality owing to absence of food for zoea and high consumption of oxygen during metamorphosis.

In general, a polyethylene or PVC bag inflated with oxygen and placed in a styrofoam box, has been adapted for convenient and functional shipping. Additional studies on the proper ratio of larvae, water and oxygen; suitable temperature; proper use of substrate; chemical and live diet organisms; etc. during shipping have to be done one by one in order to determine their practical applications to the prawn industry.

Social impact

As the prawn industry continues to progress, more and more hatcheries are being established. In Taiwan for example, there was only one hatchery in 1968 and then a rapid development occurred over the last 15 years. By 1983, there were more than 1,200 hatcheries. The supply of postlarvae is now greater than the demand, causing the price of postlarvae to plummet making it now far below the break-even point with some hatchery owners losing their capital investment. Although low price of postlarvae is advantageous to the culturist, imbalance of supply and demand has a social impact because of the waste of manpower and resources.

This is a warning for people in Southeast Asia, and Central and South America not to repeat the overproduction model, but to maintain a steady and well coordinated industry.

Prospects

Judging from the above-mentioned status and existing problems, the science of larval rearing techniques for penaeid prawns, although still a "state-of-the-art," is in a stage of rapid development. Nevertheless, there are optimistic and promising prospects for penaeid prawns in most of the countries currently undertaking prawn culture as well as in some countries with great potential. It is believed that this industry will continue to grow at a fast rate for the reasons discussed below.

High requirement for technologies

Since the natural resources of prawns are diminishing, there is a genuine demand for cultured prawns. In turn, the supply of wild postlarvae is insufficient for culture purposes because of the destruction and pollution of their environment, as accurately and vividly exemplified by the Ecuadorian prawn industry. Steady development in the past had totally relied on wild prawn larvae for seed supply but it is becoming more and more dependent on hatcheries, the most reliable source for the future. There is no doubt that hatchery production is the best model for fry supply in many other countries where people realize that natural resources can not be relied upon forever.

The penaeid prawn is an ideal animal for sea ranching. A much greater number of larvae is needed for ranching purposes than for culture. Hereafter, as sea farming fisheries or resource managing fisheries develop, there will be an increasing need for postlarvae and thus a high requirement for larval rearing techniques.

Diversification of cultured species

Food for human consumption will require more variety as the standard of living increases in the world. Although prawns were considered a luxury food item when they first appeared on the table, species diversification is far below that of fish. There are three possible ways towards diversification. First, more indigenous species should be explored and studied to determine the feasibility and advantages of their propagation and culture. Second, selected exotic species should be introduced. For example, the introduction of *P. japonicus* and *P. monodon* to Brazil and *P. brasiliensis* to Taiwan is proving to be very promising. Lastly, trials in producing hybrids by cross-breeding or use of genetic alteration should be considered. People are now looking forward to pioneering trials in this significant area. The more the variety of cultured prawn species, the brighter the prospects.

Specialization of propagation procedure

Hatchery business is complex and complicated. Specialization of each propagation procedure for an ideal cooperative model is suggested. For example in Taiwan, the hatchery business has been divided into six specialized sub-businesses; 1) suppliers of locally harvested or imported spawners; 2) suppliers of hatchery-produced nauplii; 3) brokers for buying and selling nauplii; 4) suppliers of early postlarvae ($P_{11\text{-}13}$); 5) suppliers of late postlarvae ($P_{20\text{-}30}$ and

Table 7. Diseases found in the developmental stages of penaeid prawn larvae and their control methods.

Disease	Affected parts	Symptoms	Treatment		Life stages affected*	References
Bacteria						
Bacterial necrosis	Appendages	Appearing as localized necrosis or discoloration on any appendage, causing high mortality of zoea and mysis stages, affects postlarva to a lesser extent.	Furanace Erythromycin Achromycin	1.1 ppm 1.5 ppm 1.2 ppm	Z, M, PL	Tareen, 1982 Lightner, 1983
Vibrio infection	Hemolymph, midgut gland	In initial stages of one form, some larvae will show yellow-vermilion and red color permeating entire nervous system. Another form exhibits "White-turbid liver," where the midgut gland of the larvae becomes generally white-turbid. Turbidity becomes more apparent and well-defined as the disease progresses.	Furazolidone Terramycin Furanace	2.0 ppm 450 mg/kg biomass 1.3 ppm	PL	Nickelson and Vanderzant, 1971 Lewis, 1973 Shigueno, 1975 Lightner, 1977 Johnson, 1978 Cirpiani et al., 1980 Tareen, 1982 Lightner, 1983
Filamentous bacteria	Gills, pleopods	Commonly found attached to the gill filaments and the pleopods, turning blackish when bacteria mix with dirt. If severely affected, the respiratory function of the gill suffers damage.	Cutrine plus malachite green Potassium permanganate Cuprous chloride	0.5 ppm 10 ppm 8.5 ppm 1.0 ppm	PL	Delves-Broughton and Poupard, 1976 Streenbergen and Schapiro, 1976 Johnson, 1978 Solangi et al., 1979 Lightner et al., 1980 Tareen, 1982 Lightner, 1983
Shell disease	Exoskeleton, muscles	If infected by chitinoverous bacteria, the exoskeleton will display eroded blackened areas. The edges or tips of the exoskeleton parts are typically attacked. Also bacteria can rapidly enter the body through surface breaks to cause internal damage.	Malachite green and formalin combined	0.9 ppm 22 ppm	PL	Cook and Lofton, 1973 Delves-Broughton and Poupard, 1976 Johnson, 1978 Tareen, 1982 Lightner, 1983
Black gill disease	Gills	In initial stages, gill color turns dull orange-yellow or light brown. When advanced, the area darkens until it is finally black.	Malachite green Methylene blue	3.0 ppm 8-10 ppm	PL	Shigueno, 1975 Tareen, 1982
Fungi						
Lagenidium infection	Body cavity, appendages	Only thin-cuticled prawns can be infected, thus larval prawns are highly sensitive. The hyphae appear inside the body of zoea and continue into mysis stage, resulting in massive muscle destruction, and heavy mortality of zoea and mysis.	Treflan[R] Malachite green	0.1 ppm 0.01 ppm	Z, M	Hubschaman and Schmitt, 1969 Lightner and Fontaine, 1973 Lightner, 1977 Johnson, 1978 Gopalan et al., 1980 Tareen, 1982 Lightner, 1983
Ectocommensal protozoa						
Ciliate infection (*Zoothamnium* sp., *Epistylis* sp.)	Gills, eyes, exoskeleton	Heavy infestation by *Zoothamnium* sp. of gills and eyes of larval prawn results in high mortality. *Epistylis* sp. seems to prefer exoskeleton as attachment site and is less harmful. When abundant on gill surface, both can cause hypoxia and death. Additionally, their abundant presence on general body surface of larvae may interfere with locomotion, feeding, molting, etc. Parasite burden increases until ecdysis provides relief.	Malachite green and formalin combined Quinacrine hydrochloride Chloramine-T Methylene blue Saponin 10%	1.0 ppm 25 ppm 0.8 ppm 5.5 ppm 8.0 ppm 5.0 ppm	Z, M, PL	Johnson et al., 1973 Overstreet, 1973 Johnson, 1974 Delves-Broughton and Poupard, 1976 Lightner, 1977 Liao et al., 1977 Johnson, 1978 Lightner et al., 1980 Tareen, 1982 Lightner, 1983

Table 7. (continued)

Disease	Affected parts	Symptoms	Treatment	Life stages affected*	References
Viruses					
Penaeid baculoviruses (BP, MBV, BMN)	Hepatopancreas, anterior midgut	Penaeid baculoviruses infect epithelial cells of the hepatopancreas and, less commonly, anterior midgut, causing high mortality in the postlarval stage.		PL	Johnson. 1978 Sano et al., 1981 Lightner, 1983 Lightner et al., 1983 Couch, 1974
Infectious hypodermal and hematopoietic necrosis (IHHN)	Hypodermis, hematopoietic organs	Prawns dying from acute IHHN show massive destruction of cuticular hypodermis and often of the hematopoietic organs, of glial cells in the nerve cord, and of loose connective tissues such as the subcutis and gut serosa. Only prawns within a size range of 0.05-1.0 g have been observed to have these epizootics, resulting in massive mortalities (often 80 to 90% within 2 weeks of onset).		PL	Lightner, 1983
Miscellaneous diseases					
Abnormal nauplii	Appendages	Occur as a result of poor quality of spawner.		N	Tareen, 1982
Amoebiasis of larvae	Subcutis, muscles	Invasion of muscles and subcuticular tissues located in the abdomen, cephalothorax, antenna, and eyestalks, by unclassified amoeba.		Z	Laramore and Barkate, 1979 Lightner, 1983
Larval encrustation	Exoskeleton	Brown to black encrusted deposits which contain iron salts affect larval penaeids.		Z, M, PL	Lightner, 1983

*N — nauplius, Z — zoea, M — mysis, PL — postlarva.

Table 8. Shipping record of penaeid prawn larvae.

Species	Larval stage shipped	Origin	Destination	Duration (hr)	Container	Aeration	Water (ℓ)	Number (larvae/bag)	Survival rate (%)	Remarks
Penaeus stylirostris	Nauplius	Panama	Tungkang	35	Plastic bag in polystyrene foam box	O_2	10	125×10^3	100	Totalled 500,000 in 4 bags
P. monodon	P_{20-30}	Tungkang	Rio de Janeiro	30	Portable plastic tank	Air from battery pump	20	4×10^3	20	Stopped at Tokyo 2 days
P. monodon	P_{15}	Tungkang	Salvador (Brazil)	85	Plastic bag	O_2	10	$15\text{-}25 \times 10^2$	20-30	
P. penicillatus	P_{6-8}	Tungkang	Salvador (Brazil)	85	Plastic bag	O_2	10	$15\text{-}25 \times 10^2$	60-70	

6) brokers for buying and selling either P_{11-13} or P_{20-40}. Joint ventures and linkages among these six sub-businesses are very functional.

The more detailed the breakdown of a business, the more progressive it becomes. Not only in Taiwan, but also in the world, there seems to be an increasing number of subsidiary businesses surrounding the prawn larval rearing operation. Due to high specialization, there are more job opportunities and a better chance of improving techniques. All these factors combined point towards a very bright future for larval rearing techniques.

Modernization of facilities and international exchange of knowledge

There is a great need for experts in zoology, botany, biochemistry, mechanics, engineering, electronics, veterinary medicine, pharmaceutics, marketing, etc. to start joining the prawn industry and contributing their specialized knowledge. The goal is to modernize facilities and hence larval rearing techniques. Recently, the gradual popularity of related journals, handbooks, proceedings and digests, and the increasing frequency of workshops, colloquia, symposia and

conferences act as a functional tool for international collection and exchange of knowledge and techniques. Therefore, it is deeply believed that there are very promising prospects for larval rearing techniques and the prawn farming industry.

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A Review of the Diseases of Cultured Penaeid Shrimps and Prawns with Emphasis on Recent Discoveries and Developments

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Abstract The development of the commercial culture of penaeid shrimps and prawns has been accompanied by the occurrence of diseases of infectious and noninfectious etiologies. Many of the important penaeid diseases are caused by organisms that are part of the normal microflora and fauna of penaeids. These organisms are opportunistic pathogens that cause disease only under conditions that favor them over the host. Many organisms in this category are ubiquitous, and most have been recognized and/or reported from each of the major penaeid culture areas of the world. Included among this category of pathogens are the filamentous bacteria *Leucothrix mucor*, *Flexibacter* sp. and *Cytophaga* sp. (agents of filamentous gill and surface fouling diseases); the peritrich protozoans *Zoothamnium* sp., *Epistylis* sp., and *Vorticella* sp. (surface epibionts that cause protozoan gill disease and surface fouling diseases), the invasive bacteria *Vibrio alginolyticus* and *V. parahaemolyticus* (agents of various bacterial disease syndromes); and the fungi *Lagenidium callinectes*, *Sirolpidium* sp., and *Fusarium solani* (agents of the most common fungus diseases of penaeids).

Among the most important disease-causing agents are the penaeid viruses. These penaeid viruses may once have been limited in their geographic distribution in wild stocks, but they have become widespread in penaeid culture facilities. With the advent of commercial penaeid hatcheries, the shipment of broodstock and postlarvae from these culture facilities to others in different geographic regions has often resulted in the spread of these agents outside their normal range in wild populations. Included in this category of the penaeid viruses are the baculoviruses: *Baculovirus penaei* (BP), *P. monodon* baculovirus (MBV), baculoviral midgut gland necrosis virus (BMN); the hepatopancreatic parvo-like virus (HPV); the probable picornavirus infectious hypodermal and hematopoietic necrosis virus (IHHNV), and a reo-like virus in *P. japonicus*.

The final group of important diseases of cultured penaeids are the nutritional, physical, and toxic disease syndromes. The ascorbic acid deficiency syndrome called "black death" is the best understood nutritional disease of penaeids. Among the physical diseases occurring in penaeid culture, gas bubble disease and tail cramp are probably the most common. Important toxic disease syndromes include aflatoxicosis and red disease (which may be due to mycotoxins); hemocytic enteritis (due to certain species of filamentous blue-green algae, especially *Schizothrix calcicola*) and toxic syndromes due to toxic algal blooms.

There are five areas of research that should receive emphasis in the next several years in penaeid disease research: 1) Appropriately equipped laboratories in each of the major penaeid culture areas should identify and catalog those diseases occurring in culture facilities in their region; 2) Penaeid diagnostic laboratories should use, or strive to develop for general use, "standardized" diagnostic procedures whenever possible, especially for highly infectious agents such as the penaeid viruses; 3) Penaeid cell culture methods for primary cultures or cell lines must be developed to aid in the development of much needed rapid, sensitive diagnostic tests for the penaeid viruses; 4) Improved methods of disease prevention, control, or chemotherapy are needed for many of the penaeid diseases now adversely affecting the penaeid culture industry; and 5) Approval is needed from those government agencies (such as the U.S. Food and Drug Administration and the Environmental Protection Agency) for the drugs and chemicals used as chemotherapeutics in penaeid culture that may pose a health risk to humans.

Introduction

The rapid growth of the penaeid shrimp culture industry has been accompanied by an increased awareness of the negative impact of disease on the industry. The development of the industry has been accompanied by the occurrence of diseases of infectious and noninfectious etiologies. The relative importance of disease is somewhat dependent on the type of culture system employed. Neal (1973) defined the two general methods of shrimp culture that were practiced a decade ago as intensive and extensive. Today these two types of culture systems may be subdivided into three general types of culture systems: Systems that raise shrimp in high-density, intensively managed tanks and raceways are defined as intensive culture systems. Systems producing moderate densities of shrimp in cages, ponds or tanks are considered to be semi-intensive, while extensive culture is the culture of shrimp in low-density ponds or pens in which little or no management is exercised or possible. Generally, culture systems that include a hatchery for "seed" (postlarvae) production are semi-intensive or intensive, whereas those relying on "wild seed" typically fall into the extensive or semi-intensive class. It is in most semi-intensive and intensive culture systems that the recognition, prevention, and treatment of disease is possible whereas in extensive and many semi-intensive systems, treatment of diseases is impractical even if they are diagnosed. Furthermore, except for certain types of parasitic diseases, it is the very nature of intensive and semi-intensive culture systems (i.e., high shrimp density per unit volume of water used) that encourages the development and transmission of many shrimp diseases. The

same economic incentives for using semi-intensive and intensive culture systems dictate that disease be understood and controlled.

Knowledge of the diseases of penaeid shrimps and prawns has been reviewed a number of times within the past 12 years (Overstreet, 1973, 1982; Sindermann, 1974; Johnson, 1975a, 1978; Lightner, 1977; Couch, 1978, 1983). This review emphasizes recent developments and recent discoveries in shrimp pathology made since the most recent review.

Infectious diseases

Virus diseases

Six virus-caused diseases of cultured penaeids have been reported (Table 1) and several additional diseases have been noted to have associated with them virus-like or chlamydia-like structures (Table 2). Included among the penaeid viruses causing disease in penaeids and documented in the literature are: the three baculoviruses *Baculovirus penaei* or BP (Couch, 1974), baculoviral midgut gland necrosis or BMN (Sano et al., 1981), and *Penaeus monodon* baculovirus or MBV (Lightner and Redman, 1981); the probable picornavirus infectious hypodermal and hematopoietic necrosis virus or IHHNV (Lightner et al., 1983a); the small DNA-containing virus named hepatopancreatic parvo-like virus or HPV (Lightner and Redman, in press a); and a reo-like virus in the hepatopancreas of *P. japonicus* (Tsing and Bonami, 1984).

Table 1. Penaeid viruses and their known natural and experimentally infected hosts[a].

Subgenus	BP	MBV	BMN	IHHNV	HPVREO
Litopenaeus:					
Penaeus vannamei	+ + +			+	
P. stylirostris	+			+ + +	
P. setiferus	+			+ (e)	
Penaeus:					
P. monodon		+ +		+ +	+
P. esculentus					+ +
P. semisulcatus		+		+	+ + +
Fenneropenaeus:					
P. merguiensis		+ +			+ + +
P. orientalis					+ +
Farfantepenaeus:					
P. japonicus			+ + +	+ +(e)	+ +
P. aztecus	+ + +			+ (e)	
P. duorarum	+ + +			+ (e)	
P. kerathurus		+ (?)			
P. marginatus	+ + +				

[a]Abbreviations:
BP = *Baculovirus penaei*
MBV = *P. monodon* baculovirus
BMN = Baculoviral midgut gland necrosis
IHHN = Infectious hypodermal and hematopoietic necrosis
HPV = Enteric parvo-like virus
REO = Reo-like virus
\+ = Infection observed in species, but no signs of disease.
\+ + = Infection may result in moderate disease, mortalities.
\+ + + = Infection usually results in serious epizootic with high mortality rate.
e = Experimentally infected; natural infections not yet observed.

Baculoviruses. The three known penaeid baculoviruses infect the epithelial cells of the hepatopancreas of protozoeal through adult life stages and the midgut epithelium of larvae and postlarvae. Baculovirus infections may result in disease in cultured penaeids that is accompanied by high mortality rates. In hatcheries, BP and BMN often cause serious epizootics in the larval and early postlarval stages of their principal host species (Tables 1 and 3) (Couch, 1981; Sano et al., 1981), and BP may cause disease and mortalities in juvenile and Subadult animals (Couch 1981). Disease epizootics due to MBV in hatchery-reared P. *monodon* are known to occur from late postlarval (PL_{25} to PL_{50}) through the juvenile and adult life stages, although the most serious losses have been observed in the late postlarval stages (Lightner et al., 1983c).

The geographic distribution of these baculoviruses in cultured penaeid shrimp suggests that some are problems to shrimp culturists only in those areas where the virus is apparently enzootic in local wild populations. This appears to be the case for BMN which has only been observed in *P. japonicus* in hatcheries in Japan (Table 3). MBV and BP, however, have been documented to have been introduced into new geographic regions by the transfer of infected postlarvae or broodstock to areas outside the normal range of the host species (Table 3).

Patent acute BP and MBV infections may be readily diagnosed by demonstration of their characteristic occlusion bodies (specialized inclusion bodies of type A baculoviruses) in either wet mounts or histological preparations of the hepatopancreas and midgut (Lightner et al., in press a,b). BP occlusions are distinctive tetrahedral bodies easily detected by bright field or phase microscopy in unstained wet mounts of tissue squashes (Fig. 1), while MBV occlusions are spherical and therefore difficult to distinguish from lipid droplets, secretory granules, etc. The use of a stain like 0.1% aqueous malachite green in preparing wet mounts for MBV diagnosis aids in demonstration of the occlusions. Presumably, the pro-

Table 2. Additional penaeid diseases of possible viral or chlamydial etiology, and possible orphan viruses observed in penaeids.

Agent, condition or disease	Host species	Organ	Associated with disease	Reference
IHHN-like inclusions	*Penaeus japonicus*	HEO & foregut	No	Brock (unpub.)
Picorna or Parvovirus	*P. aztecus*	Heart	No	Foster et al., 1981
Togavirus	*P. duorarum*	HP	No	Lightner (unpub.)
Picorna or Parvorivus	*P. japonicus*	Whole body	Yes	Bonami (pers. comm., Sept. 1984)
Chlamydia-like agent	*P. japonicus*	HP	Yes, with BMN	Lightner (unpub.)

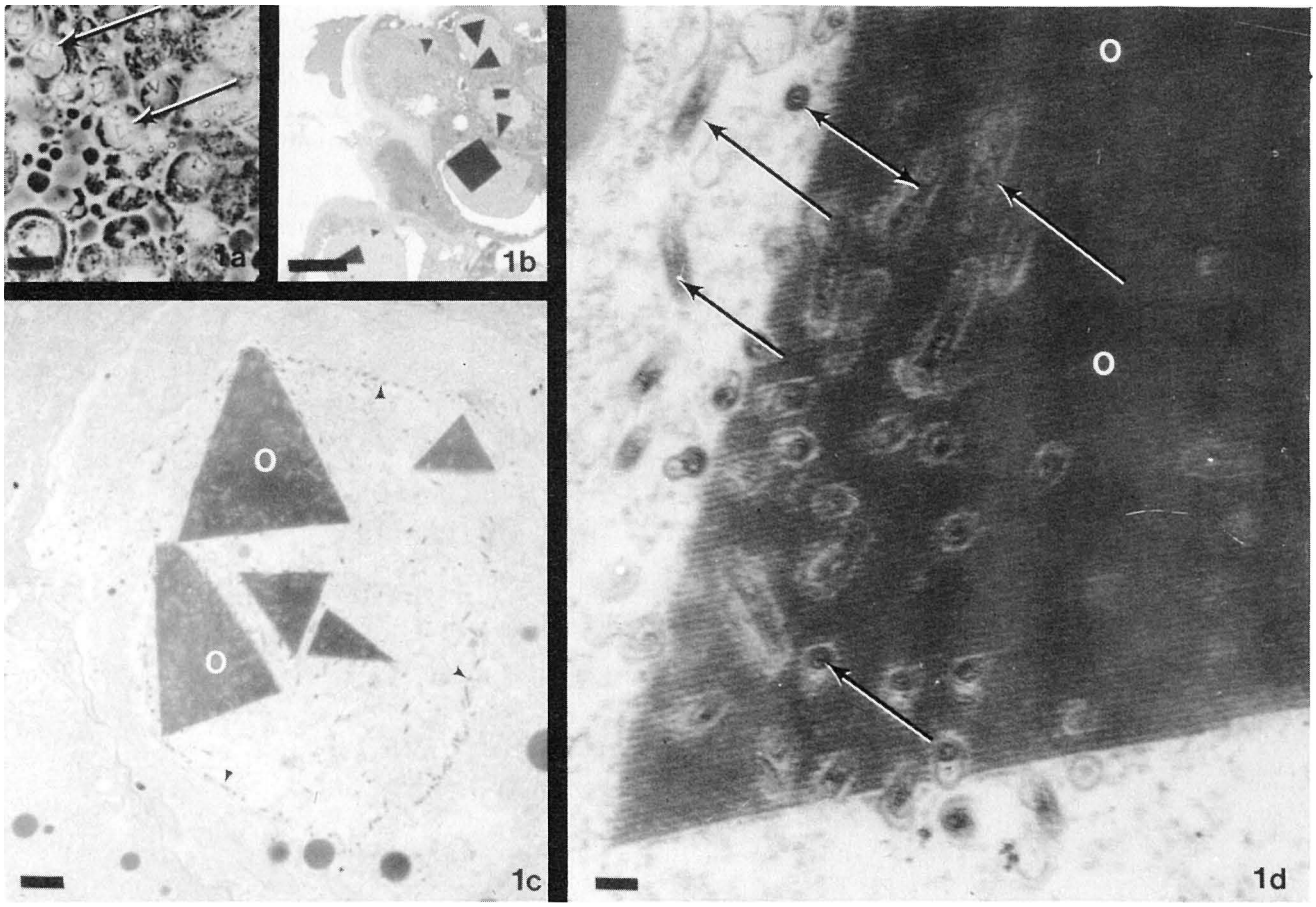


Fig. 1. *Baculovirus penaei* Couch (BP): 1a) Intranuclear polyhedral occlusion bodies (arrows) in a wet mount of the hepatopancreas of a pink shrimp *Penaeus duorarum* (photo courtesy of J. A. Couch, U.S.E.P.A., Gulf Breeze, FL), ×525. Bar is 10μm; 1b) BP occlusion bodies in a plastic histological section of the hepatopancreas of a postlarval brown shrimp *P. aztecus* (toluidine blue), ×800. Bar is 10 μm; 1c) TEM of a BP-infected *P. vannamei* hepatopancreatocyte, showing occlusion bodies (O) and virions (arrowheads), ×5,400. Bar is 10μm; 1d) Higher magnification TEM of a BP occlusion body (O) and virions in *P. vannamei.* Rod-shaped BP virions (arrows) are present free in the karyoplasm and occluded within the tetrahedral occlusion body, × 54,000. Bar is 100 nm.*

tein making up the occlusion absorbs the stain more rapidly than do most of the host tissue components, making the occlusions distinct within a few minutes (Fig. 2). BP and MBV occlusions distinct within a few minutes (Fig. 2). BP and MBV occlusion bodies in histological preparations appear as prominent eosinophilic (with H&E), usually multiple occlusion bodies within the hypertrophied nuclei of hepatopancreatic tubules or midgut epithelial cells.

Unlike BP and MBV, which are Type A baculoviruses because they produce occlusion bodies, BMN is a Type C baculovirus that does not produce an occlusion body (Fig. 3). Hence, diagnosis of BMN infections is dependent upon the clinical signs of the disease, histopathology and transmission electron microscopic (TEM) demonstration of the baculovirus in affected hepatopancreatocytes (Lightner et al., in press b). Sano et al. (1983) have developed a rapid fluorescent antibody test for BMN that reportedly simplifies the diagnosis of BMN.

*For all figures, unless otherwise noted, wet mounts are unstained; histological sections are stained with hematoxylin and eosin; TEM sections are stained with lead citrate and uranyl acetate, and SEM preparations are coated with gold.

The cytopathology of BP, MBV, and BMN is generally similar when studied by light microscopy, differing principally by the lack of occlusion bodies in BMN. Often the affected hepatopancreatocyte nuclei have a peripherally displaced compressed nucleolus and marginated chromatin, giving affected nuclei a "signet ring" appearance (Figs. 1-3), even before occlusion bodies become well developed. Brown and Brenn histologic gram stain (Luna, 1968), although not specific for baculovirus occlusion bodies, tends to stain occlusions more intensely than the surrounding tissue, aiding in demonstrating their presence in low-grade infections.

TEM of BP and MBV-infected cells shows large numbers of rod-shaped baculovirus particles both free and occluded within the proteinaceous crystalline matrix of the occlusion body (Figs. 1 and 2), but only free virus in the nuclei of BMN-infected hepatopancreatocytes (Fig. 3).

IHHN virus. This probable picornavirus (Fig. 4), named IHHNV for infectious hypodermal and hematopoietic necrosis virus, was first recognized in 1981 in Hawaii, in populations of cultured *P. stylirostris* that had been imported from a number of commercial penaeid hatcheries (Lightner et al., 1983a, 1983b). Since its discovery in *P. stylirostris*, IHHNV

has been found to infect a variety of other penaeid species either in natural infections or in experimentally-induced infections (Table 1). IHHN causes serious epizootics in intensively or semi-intensively reared *P. stylirostris*, with accumulative mortalities typically exceeding 90% of the affected populations within 14 to 21 days of onset in 0.05 to 2 g juveniles (Lightner et al., 1983a, 1983b). IHHN has also been documented to cause disease and serious epizootics in larger juvenile and adult *P. stylirostris* and in juvenile and adult *P. monodon* reared in intensive or semi-intensive culture systems (Brock et al., 1983). While IHHNV has been shown to infect and to be carried asymptomatically by *P. vannamei* (Lightner et al., 1983b; Bell and Lightner, 1984), significant mortalities due to IHHNV infection in *P. vannamei* have not been documented. However, more study of IHHN disease in *P. vannamei* may indeed show that under stressful culture conditions, some mortality losses and/or reduced growth rates may occur (Lightner, unpub.).

IHHNV has been detected in penaeid shrimp sampled from a number of shrimp culture facilities located in widely separated geographic locations (Table 4; Bell and Lightner, in press). These observations suggest that IHHNV has become widely distributed in penaeid culture facilities (Bell and Lightner, in press; Table 4) probably as a result of the difficulty of detecting infection by the virus in asymptomatic carrier hosts such as *P. vannamei* or because losses due to the virus in pond-reared stocks are difficult to detect. IHHN is a disease of juvenile or older shrimp; apparently it does not adversely affect the larval or postlarval stages and, hence, its effect does not occur in hatcheries where it would be readily detected. Instead, IHHN produces its most serious epizootics in (*P. stylirostris* and probably *P. monodon*) shrimp of 0.05 to 2 g, the size by which shrimp have typically been moved to nursery or grow-out ponds. Water turbidity and the small shrimp size at this time in the life cycle makes detection of the disease in extensive or semi-intensive cul-

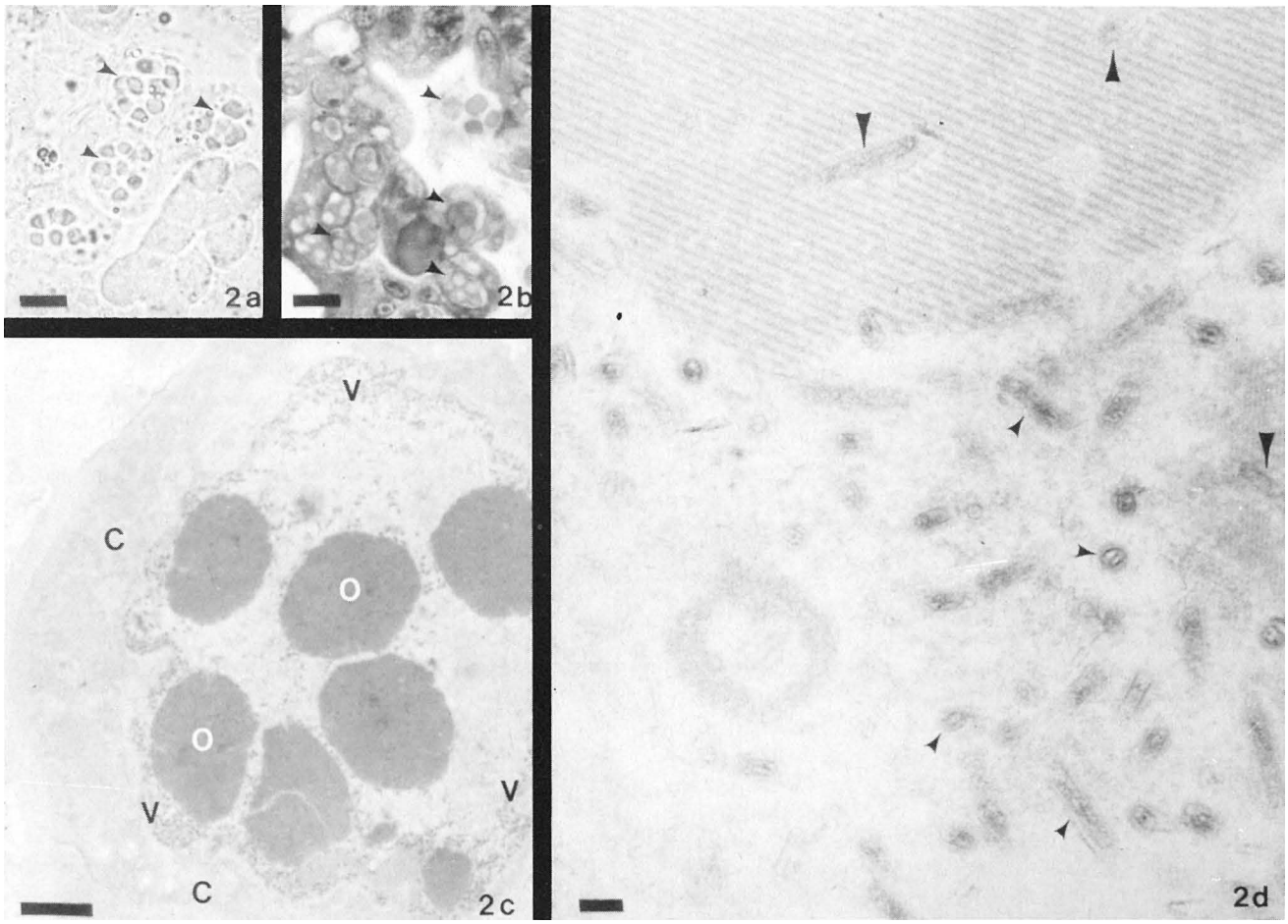


Fig. 2. *P. monodon*-type baculovirus (MBV): 2a) Intranuclear occlusion bodies in a wet mount of an MBV-infected hepatopancreas of a postlarval *P. monodon*. Multiple spherical occlusion bodies (arrowheads) are present in the hypertrophied nuclei of five of the cells shown (malachite green stain). ×5,800. Bar is 1 μm; 2b) Histological section of a *P. monodon* hepatopancreas that is heavily infected by MBV. Multiple occlusion bodies (arrowheads) are present within hypertrophied nuclei, ×600. Bar is 10 μm; 2c) TEM of an MBV-infected hepatopancreatocyte. Conspicuous occlusion bodies (O) and masses of free virions (V) are present in the hypertrophied nucleus, that is surrounded by a thin ring of cytoplasm (C) that is made dense by numerous free ribosomes, ×4,680. Bar is 2μm; 2d) High magnification TEM of MBV virions that are free in the karyoplasm (small arrowheads) or occluded (big arrowheads) within the protein matrix of occlusion bodies (O), ×59,800. Bar is 100 nm.

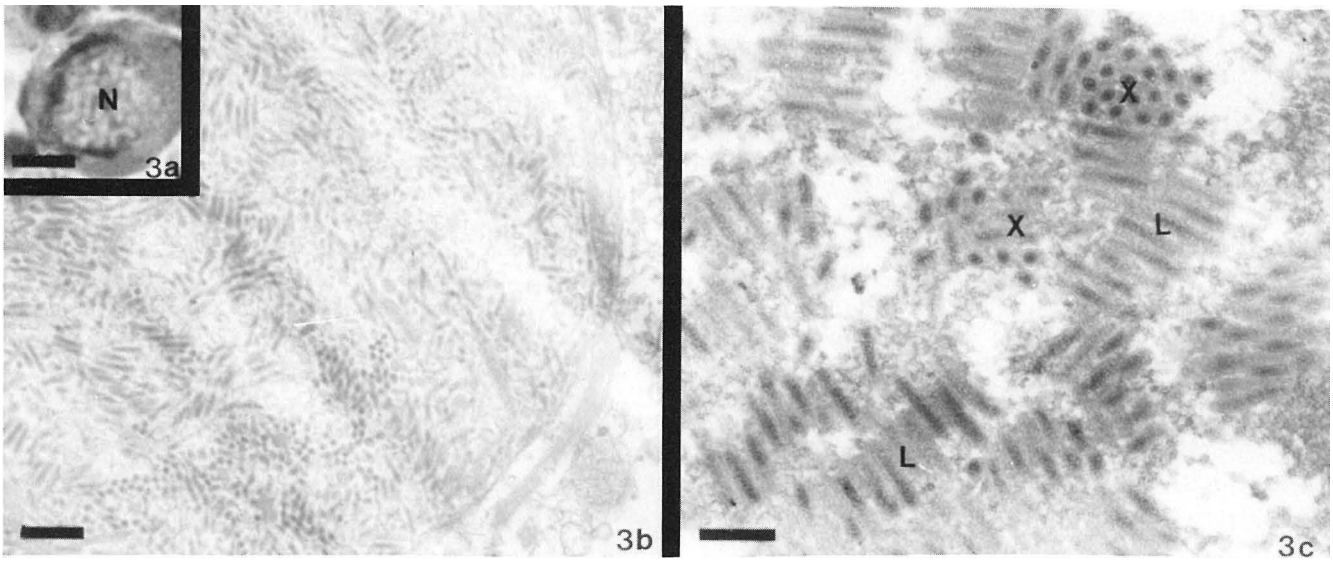


Fig. 3. Baculoviral midgut gland necrosis (BMN): 3a) Histological section of the hepatopancreas of a postlarval *P. japonicus* with BMN, showing a hypertrophied hepatopancreatocyte nucleus (N). Occlusion bodies are not present in BMN-infected cells, × 1,520. Bar is 5μm; 3b) TEM of a BMN-infected hypertrophied nucleus. Virions nearly fill the nucleus, × 16,800. Bar is 0.5 μm; 3c) Higher magnification of packets of rod-shaped BMN virions in cross-section (X) and longitudinal section (L), × 39,600. Bar is 250 nm.

Table 3. Range of the penaeid baculoviruses in captive and cultured host species.

Virus	Host species	Geographic location	Reference
BMN	*Penaeus japonicus*	Japan	Sano et al., 1981
BP	*P. aztecus, P. duorarum, P. setiferus*	Florida, Mississippi	Couch, 1981; Overstreet, 1978
	P. vannamei, P. stylirostris	Panama, Costa Rica, Ecuador, Texas*	Lightner 1983; Lightner (unpub.)
	P. marginatus	Hawaii	Brock (in press)
MBV	*P. monodon*	Philippines, Taiwan, Malaysia, Singapore, Mexico*, Hawaii*, Tahiti*	Lightner et al., 1983c; Lightner (unpub.)
	P. merguiensis	Singapore, Malaysia	Brock et al., 1983; Lightner (unpub.)
	P. kerathurus	Italy	G. Bovo (pers. comm., 1984)
	P. semisulcatus	Persian Gulf	Lightner (unpub.)

*Denotes known example of the introduction of virus to a new geographic region with transfer of infected host species.

ture systems difficult. Complicating the disease further was the discovery that penaeid shrimp surviving IHHNV infections become carriers of the virus for life and pass the virus on to their offspring (Lightner et al., 1983b).

Diagnosis of infection by IHHNV is dependent upon histological demonstration of prominent eosinophilic (with H&E), Feulgen-negative intranuclear inclusion bodies (Fig. 4a) within chromatin-marginated, hypertrophied nuclei of cells in tissues of ectodermal (epidermis, hypodermal epithelium of foregut and hindgut, nerve cord, and nerve ganglia) and mesodermal origin (hematopoietic organs, antennal gland tubule epithelium, mandibular organ, connective tissue, and striated muscle). Usually the midgut, midgut caeca and the hepatopancreas (endoderm-derived tissues) are

Table 4. Known geographic distribution of IHHNV in cultured penaeid shrimp.

Host species	Culture locations positive for IHHNV
Penaeus stylirostris *P. vannamei* *P. monodon* *P. semisulcatus* *P. japonicus* (exp.)* *P. aztecus* (exp.) *P. duorarum* (exp.) *P. setiferus* (exp.)	Hawaii, Tahiti, Florida, Texas, Cayman Islands, Israel, Panama, Costa Rica, Belize, Ecuador, Philippines, Singapore, and Guam. Probable: Taiwan, Brazil, France, Jamaica, and Honduras.

*"exp." denotes experimentally induced laboratory infection by the virus. Natural infections are not known to occur in species.

unaffected, except in severe cases where hepatopancreatic involvement has been observed. These inclusions match closely the characteristics of the Type A intranuclear inclusion body class described by Cowdry (1934). Basophilic chromatin strands are occasionally visible by light microscopy within IHHN intranuclear inclusion bodies. These chromatin strands are a prominent feature of IHHN intranuclear inclusion bodies by TEM (Fig. 4b). IHHN intranuclear inclusion bodies are common early in acute infections, later decreasing in number, and are followed by necrosis and inflammation of target tissues. Affected cells may also have highly vacuolate cytoplasm and small cytoplasmic basophilic inclusions (Fig. 4c). Although the prominent intranuclear inclusions present in shrimp infected with IHHNV are evidence of nuclear involvement, assembly of the virus occurs in the cytoplasm of affected cells (Fig. 4d). The size of the virus (17 to 26 nm in tissue sections and 20 to 22 nm in purified preparations), its morphology, and its replication within the cytoplasm support the tentative classification of IHHNV with the picornaviruses.

HPV. This probable parvovirus named HPV, or hepatopancreatic parvo-like virus (Fig. 5), was first recognized in cultured *P. merguiensis* in Singapore and Malaysia in 1983 (Lightner and Redman, in press a). HPV (or a very similar agent) was subsequently recognized in four additional penaeid species (*P. orientalis, P. semisulcatus, P. esculentus,* and presumed *P. monodon*) in either captive wild populations or in cultured populations (Table 5). Individual shrimp with HPV displayed nonspecific signs including poor growth rate, anorexia, reduced preening activity, increased surface fouling, and occasional opacity of tail musculature. Mortalities accompanied by these signs occurred during the juvenile stages, after apparently normal development through the larval and postlarval stages. Accumulative mortality rates in HPV epizootics in *P. merguiensis* and *P. semisulcatus* reached as high as 50% to 100%, respectively, of the affected populations within four to eight weeks of disease onset.

Table 5. Known geographic distribution of HPV in captive and cultured penaeid shrimp.

Host species	Geographic location	Reference
Penaeus merguiensis	Singapore	
P. orientalis	Qingdao (Yellow Sea region), China	Lightner and Redman (in press)
P. semisulcatus	Persian Gulf	
P. monodon	Philippines	
P. esculentus	Queensland, Australia	Paynter et al. (in press)

The principal lesion in HPV disease, common to all affected species, is a necrosis and atrophy of the hepatopancreas, accompanied by the presence of large prominent basophilic, PAS-negative, Feulgen-positive intranuclear inclusion bodies in affected hepatopancreatocytes (Fig. 5a). These inclusion bodies are diagnostic for HPV, and presumably developed from small eosinophilic intranuclear bodies that were also present in the affected tissues. Electron microscopy of affected hepatopancreatocytes revealed aggregations of 22 to 24 nm diameter particles within the electron-dense granular inclusion body ground substance (Fig. 5b). The virus-like particle size and morphology, the close association of the nucleolus with the developing inclusion body, and the presence of intranuclear bodies within developing inclusion bodies are similar to cytopathological features reported for parvovirus infections in insects and vertebrates.

Reo-like virus. A reo-like virus was present in large viral areas in the cytoplasm of hepatopancreatic R-cells of diseased laboratory-reared *P. japonicus* from the Mediterranean city of Palavas in France (Tsing and Bonami, 1984). Purified virions were non-enveloped, icosahedral particles of about 60 nm in diameter. The disease was reproduced in healthy *P. japonicus* by inoculation with purified virus or by feeding animals pieces of hepatopancreas from infected shrimp. Disease developed slowly in reo-like virus-exposed animals, requiring about 45 days to develop. Secondary infections by agents such as *F. solani* were common in reo-like virus-infected *P. japonicus* (Tsing and Bonami, 1984).

General procedures for virus screening. Three basic diagnostic procedures have been developed for screening penaeid shrimp for virus infections: 1) direct samplings for microscopic (wet mount) examination and/or histopathology; 2) enhancement of infection followed by microscopic examination and/or histopathology; and 3) bioassay of a suspect shrimp population with a sensitive indicator species followed by sampling and histopathology (Lightner et al., in press b).

Nonrandom samples of shrimp are selected in direct sampling procedure from culture tanks, ponds, or cages and examined directly for signs of BP or MBV in wet mounts, or they may be preserved in Davidson's AFA or 10% buffered formalin (Humason, 1967) for histological evaluation. The sensitivity of this procedure is limited, and it will only demonstrate shrimp with viral infections that are acute or subacute in a population with a high incidence rate. We have been able to diagnose IHHN, BP, MBV, and HPV with direct samples, but such samples have also produced false negative diagnoses on populations later shown by enhancement or bioassay diagnostic procedures to be positive for one of these virus diseases (Lightner et al., in press b).

A quarantined population in the enhancement procedure is reared under relatively crowded and stressful conditions. Postlarvae are best used for this test, which normally require 30 to 60 days. Random samples are taken at intervals throughout the test period, or nonrandom samples are selected as moribund animals are observed. Samples may be prepared for wet mount microscopic examination for BP and MBV, or preserved for histological evaluation. The enhancement procedure is far more sensitive than the direct sampling procedure for BP and MBV-caused diseases, and. for IHHN disease in *P. stylirostris* (Lightner et al., in press b). Paynter et al. (in press) have found that diagnosis of HPV in captive wild *P. esculentus* in Australia may also lend itself to the enhancement procedure. Enhancement is not a suitable procedure for demonstration of IHHNV in asymptomatic carriers. For example, enhancement will not readily demonstrate IHHN to be present in Subadult or adult *P. stylirostris* that are IHHN epizootic survivors, or in species such as

P. vannamei which are readily infected by the virus, but seldom show diagnosable infections (Lightner et al., 1983b).

Carriers of IHHNV may be detected by bioassay with sensitive "indicator" shrimp. Indicator shrimp in this procedure known as IHHNV-free (juvenile *P. stylirostris* of 0.05 to 4 g body weight) may be exposed to samples of suspect carrier shrimp by one or more of three methods: 1) injection with a cell-free filtrate prepared from a homogenate of suspect carrier shrimp (the indicator shrimp will show signs of IHHN disease within 5 to 15 days if the suspect shrimp were infected with IHHNV); 2) rearing in the same tank suspect carrier shrimp with indicator shrimp (the indicator shrimp will show signs of IHHN disease within 15 to 60 days); and 3) feeding chopped carcasses of suspect carrier shrimp to indicator shrimp (the indicator shrimp will show signs of IHHN within 15 to 60 days) (Lightner et al., 1983b, in press b).

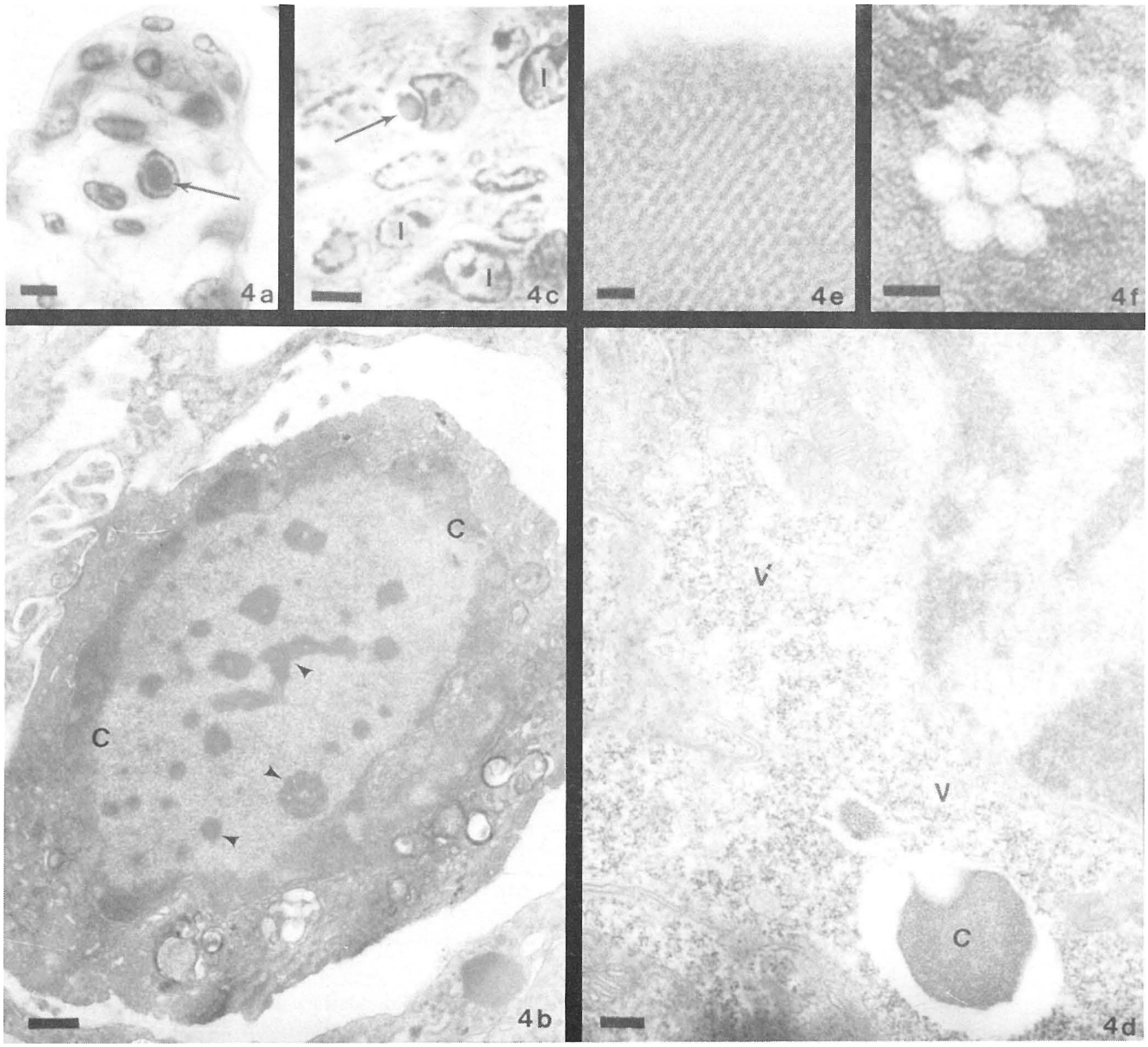


Fig. 4. IHHN: 4a) Histological section of a typical IHHN intranuclear eosinophilic inclusion body (I) in a gill epidermal cell of a juvenile *P. stylirostris,* ×1,100. Bar is 5 μm; 4b) TEM of an IHHN intranuclear inclusion body in a circulating hemocyte in the gills. Nuclear chromatin (C) has been displaced against the inner surface of the nuclear membrane, while the center of the nucleus has become filled with a proteinaceous granular (G) matrix that contains electron-dense spheres and strands (arrowheads), × 15,000. Bar is 0.5 μm; 4c) Histological section of gills showing cells with eosinophilic IHHN intranuclear inclusions (I) and a basophilic cytoplasmic inclusion body (which is an IHHN virus paracrystalline array) in a gill epidermal cell, × 1,520. Bar is 5μm; 4d) TEM of a gill epidermal cell with masses of IHHN virus (V) and a paracrystalline array of virions (C) in the cytoplasm. The nucleus (N) contains no virions, ×25,200. Bar is 250 nm; 4e) Higher magnification TEM of IHHN virions in a paracrystalline array, × 124,800. Bar is 50 nm; 4f) Negative-stained purified preparation of 20 to 22 nm diameter IHHN virus from particles cessium chloride density gradient centrifugation (2% PTA), ×410,000. Bar is 20 nm.

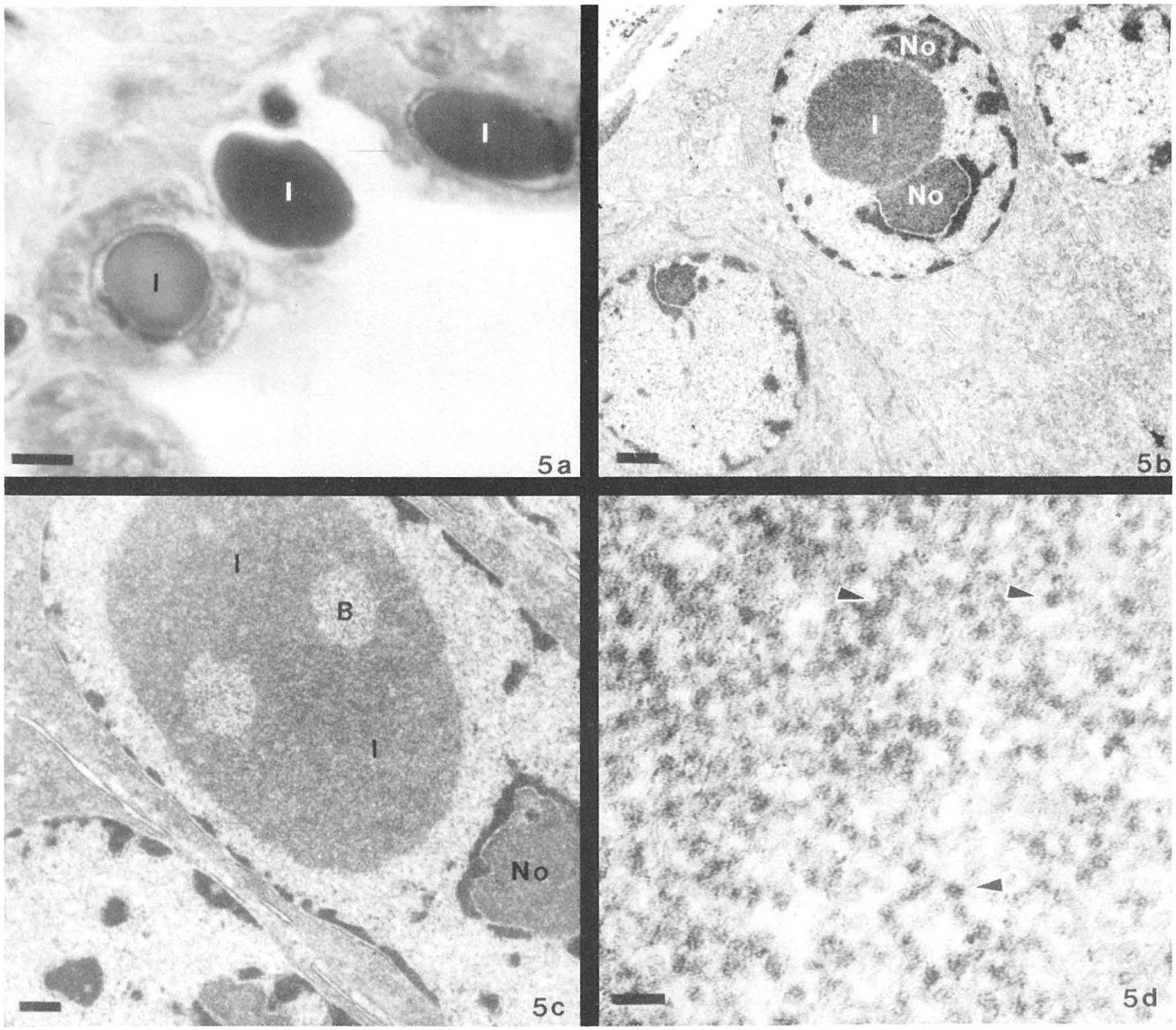


Fig. 5. Hepatopancreatic parvo-like virus (HPV): 5a) Histological section of a hepatopancreas tubule of *P. merguiensis* that is heavily infected with HPV. Dense basophilic HPV inclusion bodies (I) are present within markedly hypertrophied host cell nuclei, × 1,880. Bar is 5 μm 5b) TEM of an HPV-infected hepatopancreatocyte of *P. orientalis* that contains a developing intranuclear inclusion body (I). The inclusion body is composed of a granular virogenic stroma that is intimately associated with the host cell nucleoli (No), ×6,120. Bar is 1μm; 5c) TEM of a more advanced HPV inclusion body (I) which contains two intranuclear bodies (B) embedded in the virogenic stroma. The host cell nucleolus (No) has been displaced by the developing inclusion body, × 12,600. Bar is 0.5 μm; 5d) A high magnification of the virogenic stroma of 5c in which masses of HPV virions are present. Profiles of some HPV particles are clearly angular (arrowheads), × 147,000. Bar is 50 nm.

Actual diagnosis of infection by BP, MBV, BMN, HPV, and IHHNV is dependent on microscopic or histologic demonstration of the particular cytopathology that is unique to each disease. Gross signs and behavior are usually not sufficiently specific in shrimp with infection by these penaeid viruses to be used reliably in diagnosing these diseases.

Bacterial and fungal diseases

Bacteria. A number of bacteria have been implicated as causes of disease and mortality in cultured penaeids, especially in the larval, postlarval and juvenile stages (Johnson, 1978; Lightner, 1983). Bacterial infections in shrimp may take three general forms: erosions of the cuticle covering the general body surface, gills, and appendages (bacterial necrosis and shell disease), localized lesions within the body, and generalized septicemias. Recent reports on the occurrence of bacterial diseases in cultured penaeids in Kuwait (Tareen, 1982), and China (Meng and Yu, 1980, 1982a, 1982b, 1983) are similar to previously reviewed reports from other shrimp culture groups (Lightner, 1977, 1983). While bacterial diseases of a probable primary bacterial etiology have been

reported from penaeid shrimp (Nickelson and Vanderzant, 1971; Cook and Lofton, 1973), the majority are of a secondary etiology, occurring as a result of syndromes due to such things as ascorbic acid deficiency, toxins, wounds, extreme stress, etc. (Lightner, 1983). A number of reports in the literature support this observation. Many laboratory attempts have been made to complete Koch's postulates with bacterial isolates obtained from penaeids, and in each study a relatively massive inoculum had to be administered to overcome the natural defenses of the host and to produce disease and death in the experimental animals (Vanderzant et al., 1970; Lewis, 1973b; Lightner and Lewis, 1975; Corliss et al., 1977; Huang et al., 1981). One study showed that cell-free solutions of crude extracts of endotoxins and exotoxins of *Vibrio parahaemolyticus* and *V. alginolyticus* injected into *P. setiferus* produced significant mortalities with gross signs similar to those observed in actual bacterial infections (Leong and Hanrahan, 1980).

In every reported bacterial infection in penaeid shrimp reviewed up to 1983 (Lightner, 1983), motile, gram-negative, oxidase-positive, fermentative rods have been isolated from lesions or host hemolymph. Most isolates have been *Vibrio* spp., usually *V. alginolyticus, V. parahaemolyticus*, or *V. anguillarum*. Certain other gram-negative rods, including *Pseudomonas* spp., and *Aeromonas* spp. may occasionally be involved in bacterial disease syndromes in penaeid shrimp (Lightner, 1983). All of these genera and species have been reported to be among the normal microflora of penaeids (Vanderzant et al., 1970, 1971; Hood and Meyers, 1977; Yasuda and Kitao, 1980; Lewis et al., 1982). Although a variety of gram-positive cocci, including the etiological agent (*Aerococcus viridans*) that causes highly lethal Gaffkemia disease in *Homarus* lobsters, have been isolated from shrimp, none have been linked with disease in penaeids (Stewart and Rabin, 1970; Vanderzant et al., 1971; Vanderzant et al., 1972). Hence, it would appear that shrimp have only opportunistic pathogens that are part of their normal microflora. A possible exception to this was the discovery earlier this year of a gram-negative, acid-fast rod causing disease in adult *P. vannamei* (Lightner, unpub.). Shrimp infected with this microorganism were moribund when collected, but showed no externally apparent abnormalities. Histopathology, however, revealed that the acid-fast bacterium was present in very large numbers either encapsulated in melanized hemocyte nodules or in the tissues surrounding such granulomatous lesions in the host hepatopancreas, antennal gland, and mandibular organ (Fig. 6). The latter two organs were severely affected. Further studies on penaeid bacterial diseases should include tests for acid-fast microorganisms in the event that this pathogen has been overlooked in penaeids.

Several groups have reported effective therapy of these diseases using antibiotics such as Furanace, Furacin, Terramycin, Aureomycin, and Chloramphenicol, and antibacterial chemotherapeutics such as formalin, malachite green, and methylene blue (Aquacop, 1977; Tareen, 1982; Lightner, 1983). Vaccines against *Vibrio* sp. have been reported by Lewis and Lawrence (in press) to be potentially effective in preventing losses due to *Vibrio* spp. infections in aquarium and pond-reared *P. setiferus,* but the efficacious use of this vaccine in penaeids remains to be documented.

Fungi. Several species of fungi infect penaeids, and some are major pathogens of these animals. No new species of fungi parasitic to penaeids have been recognized since Lightner (1981, 1983) reviewed the subject, although several more reports have been published recently that expand the documented geographic and host range of *Lagenidium* sp., *Sirolpidium* sp., and *Fusarium solani* (Figs. 7, 8, 9). Members of these genera were reported to cause disease losses in cultured *P. semisulcatus* in Kuwait (Tareen, 1982), and in *P. orientalis* cultured in the Yellow Sea region of China. Large-scale hatchery losses of eggs and larvae to *Lagenidium* sp.

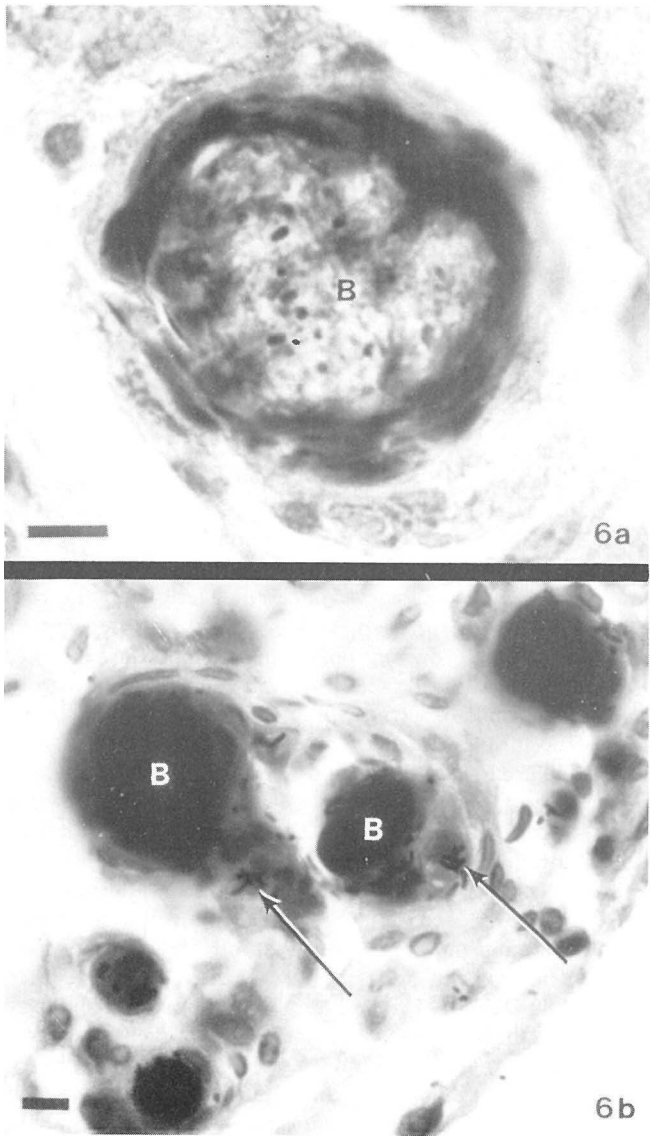


Fig. 6. Acid-fast bacteria: Histological section of the mandibular organ of an adult *P. vannamei.* Present in the section are melanized hemocytic nodules that contain masses of gram-positive rod-shaped bacteria (B), × 1,880. Bar is 5 μm; 6b) The masses of acid-fast bacteria (B) and a few isolated rods (arrows) are acid-fast positive, × 1,560. Bar is 5μm. (Stains: 6a, Brown and Brenn histologic gram stain and 6b, Ziehl-Neelsen.)

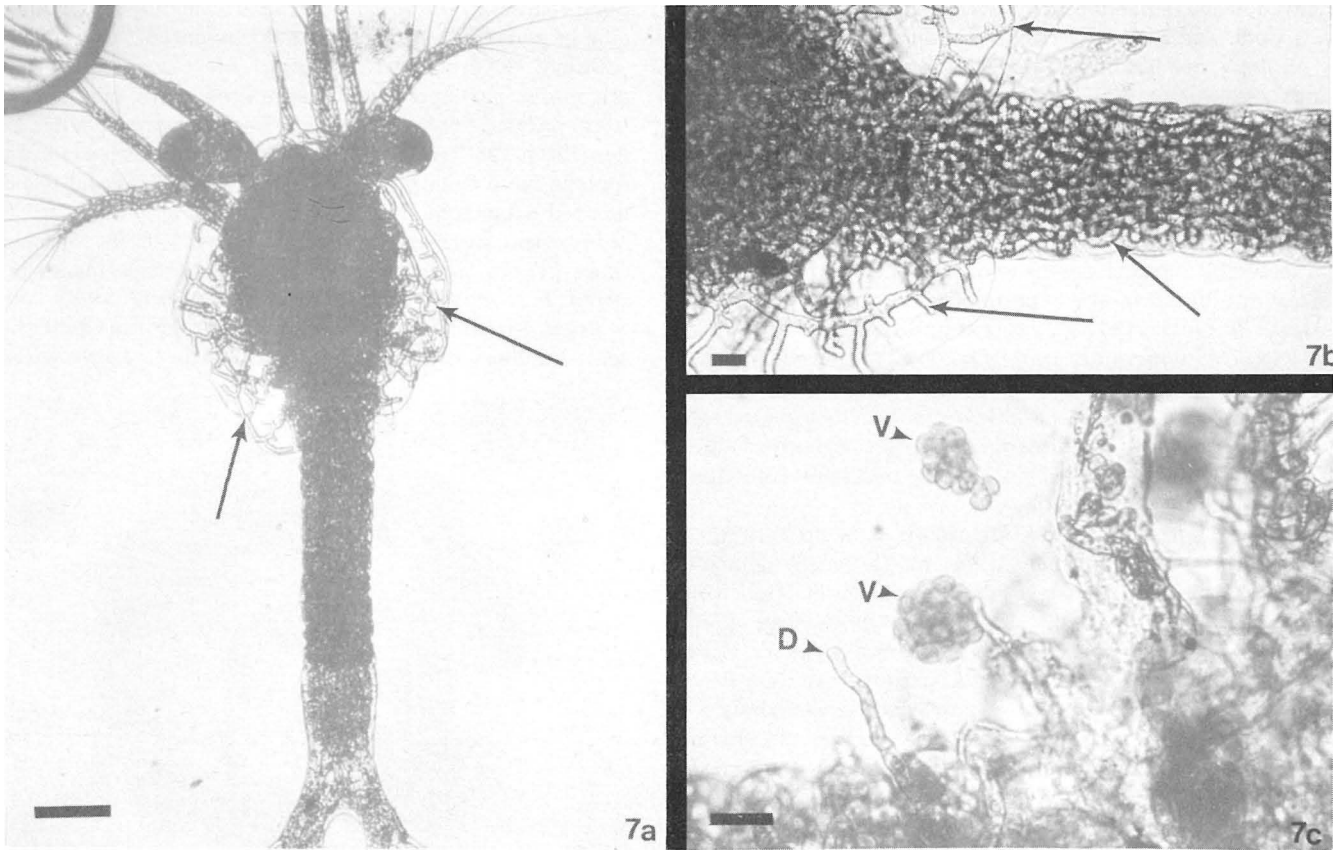


Fig. 7. *Lagenidium callinectes:* 7a and 7b) A larval *P. setiferus* with an advanced infection of *Lagenidium.* Hyphae (arrows) nearly fill the body of the larva; 7c) Discharge tubes (D) with terminal vesicles (V) that contain maturing zoospores of *Lagenidium.* (Magnifications: 7a, ×20. Bar is 0.5 mm; 7b, ×44. Bar is 100μm; 7c, × 78. Bar is 100μm.)

and *Sirolpidium* sp. were reported (Meng and Yu, 1980, 1982a), and *Fusarium* sp. was reported to infect juvenile *P. orientalis* in grow-out ponds in the same area of China (Meng and Yu, 1982b, 1983). As was the case in most of the bacterial species reported from cultured penaeid shrimp, the imperfect fungus *Fusarium* sp. (all isolates that have been identified are *F. solani)* and the phycomycetous fungi *Lagenidium* sp. and *Sirolpidium* sp. appear to be present in virtually all shrimp culture facilities throughout the world. This is not surprising because each of the fungi has a wide host range or can exist as a free-living saprophyte (Johnson and Sparrow, 1961; Moss and Smith, 1984). While no effective chemotherapeutants have been found for treatment of *F. solani* infections in penaeids (Hatai et al., 1974; Lightner, 1981, 1983; Tareen, 1982), a number of effective chemotherapeutants have been identified and tested against *Lagenidium* sp. (Bland et al., 1976; Lio-Po et al., 1982).

The histopathology (Bian and Egusa, 1981) and pathogenesis (Hose et al., 1984) of *F. solani* infections in penaeids have been recently reported. Penaeids respond to invasion by *F. solani* hyphae with an intense hemocytic response that includes hemocyte encapsulation, melanization, and the deposition of collagen fibers within a granulomatous lesion (Fig. 9) that surrounds and isolates the invading hyphae (Bian and Egusa, 1981). Studies of these lesions by TEM, however, have shown that, despite the intensity of host response, a large percentage of hemocyte-encapsulated *F. solani* hyphae remains viable within the granulomatous lesions (Fig. 9d; Lightner, 1981; Hose et al., 1984). Contributing to the pathogenesis of *F. solani*, in addition to its direct invasiveness and destructive effect on host tissues, are secondary bacterial infections and changes in the hemolymph content of the host. Hemolymph from severely *F. solani*-infected *P. californiensis* was hypoproteinemic, hemocytopenic, and frequently failed to coagulate (Hose et al., 1984).

Protozoan parasitic diseases

Microsporidians. Microsporidians (Protozoa, Microspora) cause a group of diseases in penaeids that are collectively called "cotton" or "milk shrimp disease." At least three genera of microsporidia, *Ameson* (=*Nosema*), *Agmasoma* (=*Thelohania*), and *Pleistophora*, are known to infect captive wild and cultured penaeids, especially in ponds or in enclosed natural bodies of water (Overstreet, 1982; Lightner, 1983). Tissues infected by these parasites include striated and smooth muscle, and the gonads. Infection prevalences in penaeid culture ponds have approached 10% (Couch, 1978). Severe infections in cultured penaeids may cause chronic disease mortality (Couch, 1978; Lightner, 1983), parasitic castration (Enriquez et al., 1980), as well as an unmarketable product.

Gregarines. Gregarines (Protozoa, Apicomplexa) are common inhabitants of the guts of wild and pond-reared penaeids (Johnson, 1978; Overstreet, 1978; Couch, 1983). Two genera, *Nematopsis* and *Cephalolobus,* are known in penaeids (Lightner, 1983). These organisms use a mollusk for completion of their life cycle and, hence, may be excluded from tank and raceway culture systems (Johnson, 1978). Even when present in such large numbers as to occlude the midgut or hindgut lumen (Fig. 12), gregarines appear not to cause significant disease in penaeids.

Noninfectious diseases

Diseases caused by epicommensals

Among the more serious diseases of cultured penaeids are those caused by noninfectious epicommensal organisms. These organisms are common and apparently ubiquitous in shrimp culture facilities. All life stages may be affected, but the most serious losses are encountered in juvenile and adult stages when the gills of the host become fouled (resulting in various forms of gill disease) by heavy infestations of epicommensal organisms such as filamentous bacteria, peritrich protozoans, and pinnate diatoms. Table 6 lists the more commonly observed and reported epicommensal organisms that alone, or with other epicommensals, cause "gill disease" and surface fouling in cultured penaeids. The more important diseases are discussed here.

Bacterial epicommensals. *Leucothrix mucor* (Fig. 10) is a very common ubiquitous estuarine marine bacterium, reported from every penaeid culturing area of the world (McKee and Lightner, 1982; Lightner, 1983). Consistent with this are recent reports of losses due to *L. mucor* in penaeids

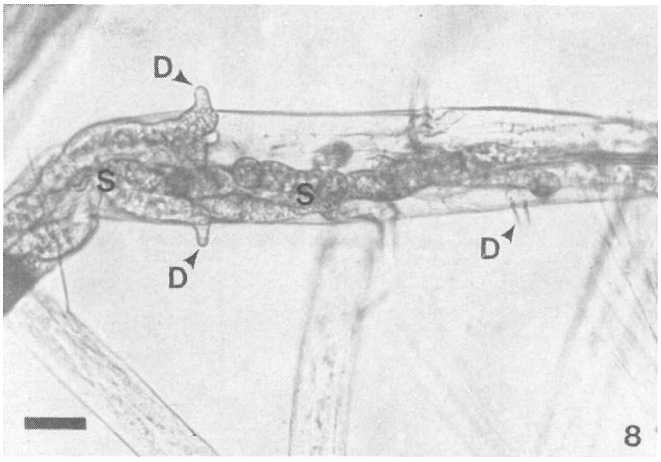
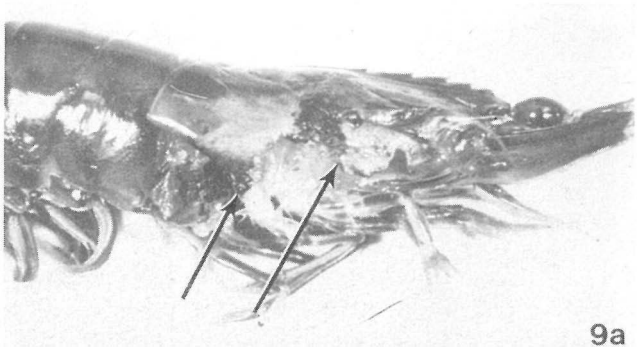


Fig. 8. *Sirolpidium* sp.: Wet mount of a larval *P. aztecus* infected with *Sirolpidium* sp. that shows sporangia (S) with short discharge tubes (D) that are developing from hyphae within an appendage, ×160. Bar is 50μm.



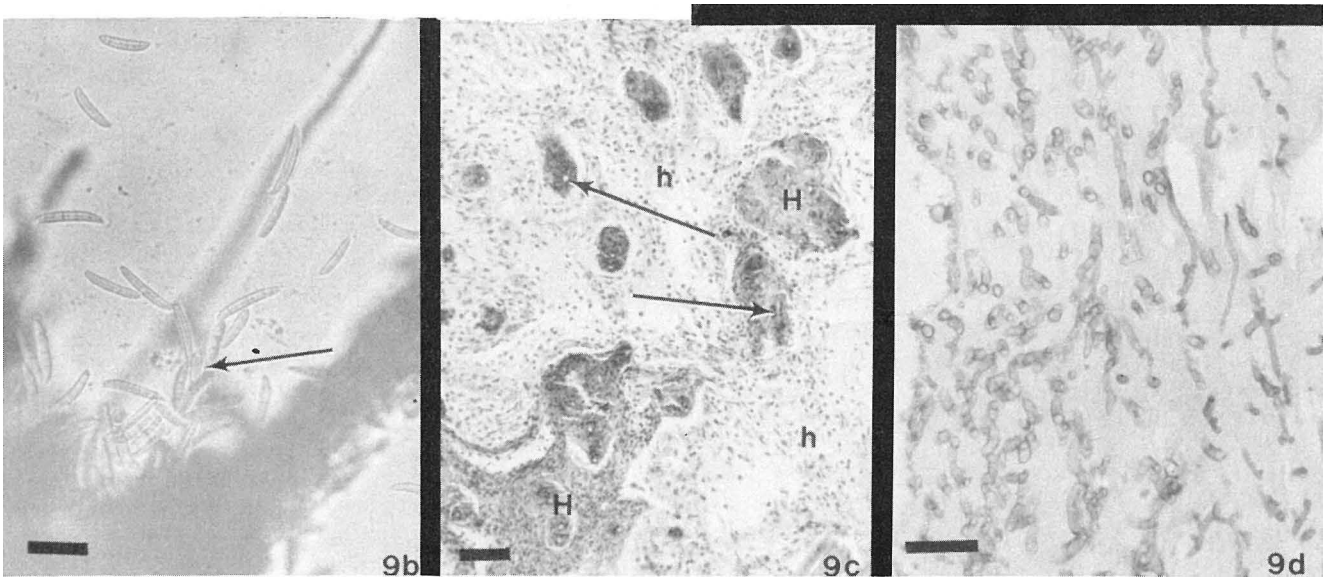


Fig. 9. *Fusarium solani:* 9a) *P. californiensis* with well-developed *Fusarium* lesions on the carapace and in the gills (arrows); 9b) Wet mount of conidiospores of *F. solani* from the gills of *P. californiensis.* Both canoe-shaped macroconidia and a microconidium (arrow) are present, ×400. Bar is 20μm; 9c) Histologic section of a *Fusarium* lesion in the body wall and muscle of a *P. californiensis.* Masses of necrotic melanized hemocytes (H) and unmelanized hemocytes (h) encapsulate *Fusarium* hyphae (arrows) in the lesion which is invading the adjacent muscle (M), ×132. Bar is 50μm; 9d) PAS-stained histological section of a *Fusarium* lesion showing the abundance of viable hyphae within a granulomatous lesion similar to that shown in 9c, ×400. Bar is 25 μm.

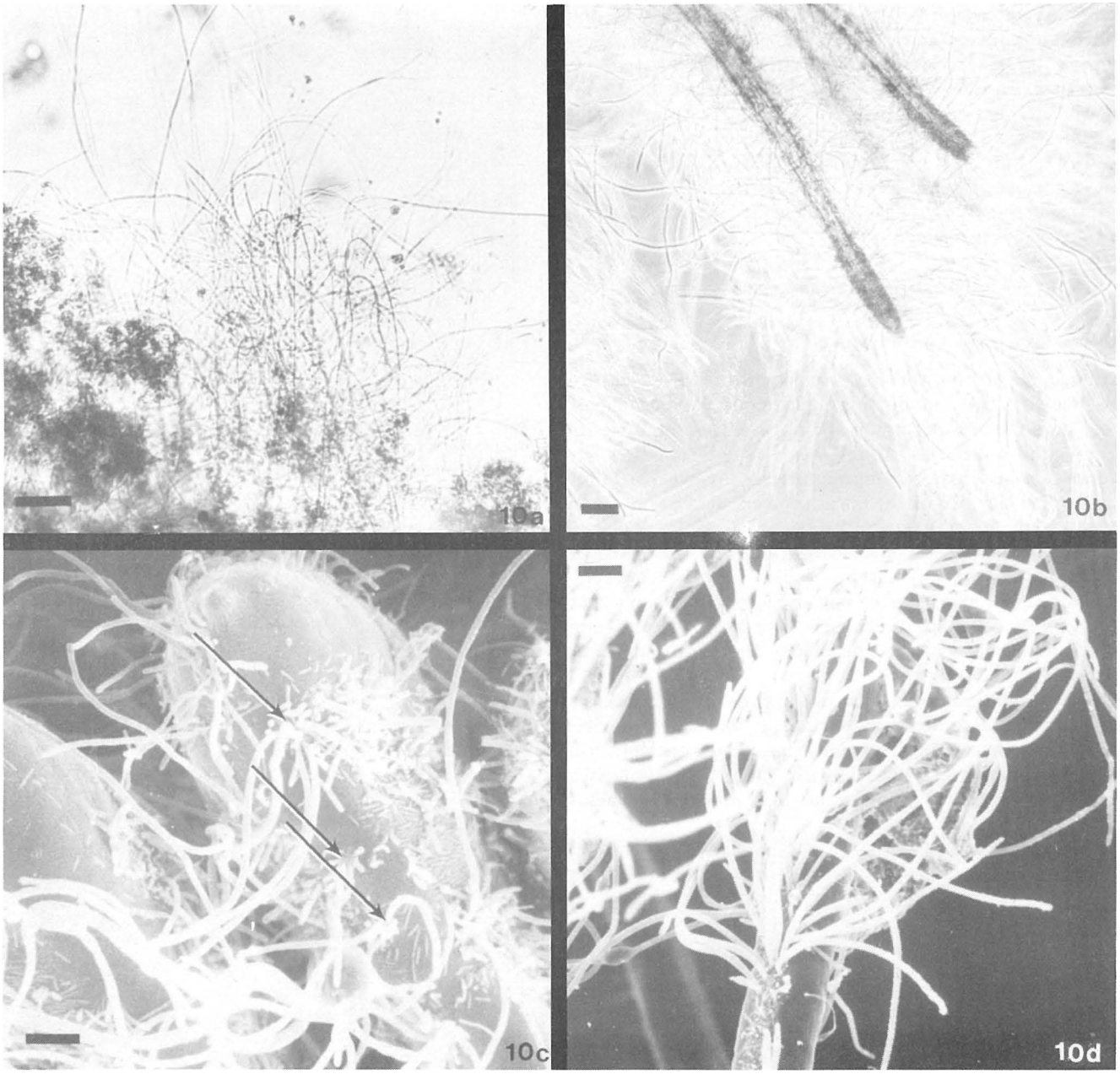


Fig. 10. *Leucothrix mucor:* 10a) Surface fouling of gill lamellae of *P. aztecus* by the filamentous bacterium *L. mucor,* ×180. Bar is 50μm; 10b) *L. mucor* on the tip of a gill mastigobranchia (functions to preen gills) of a *P. californiensis,* ×120. Bar is 50μm; 10c) SEM of *Leucothrix* filaments on gill lamellae of a *P. stylirostris.* Note that many of the filaments arise from a basal rosette (arrows), ×4,070. Bar is 2μm; 10d) SEM of *Leucothrix* filaments on the tip of a gill mastigobranchia of a *P. stylirostris,* ×1,110. Bar is 5μm.

cultured in Kuwait and China (Meng and Yu 1980, 1982b, 1983; Tareen 1982). *L. mucor* attaches to living and nonliving substrates, and in penaeid culture systems it readily attaches to the body surfaces of shrimp. In juvenile and older penaeids, *L. mucor* favors attachment to the gills and accessory gill structures (Fig. 10). Larval and postlarval penaeids may become so fouled by *L. mucor* filaments that respiration, feeding, locomotion, and molting may be seriously impaired, resulting in mortalities. *L. mucor* is noninvasive and it causes no demonstrable pathology to the surfaces to which it attaches (Lightner et al., 1975; Lightner, 1978a). Severity of disease due to *L. mucor* in shrimp is related to organic loading of the culture system, to its oxygen content, and to the added stress of molting. Mortalities due to *L. mucor* surface and gill infestations are due to hypoxia.

Several other species of bacteria have been implicated in bacterial gill disease and surface fouling diseases of cultured penaeids (Table 6). Included among the filamentous forms are *Thiothrix* sp., *Cytophaga* sp. and *Flexibacteria* sp. (Lightner, 1983). Unlike *L. mucor,* inflammation and melanization of the gills often accompanies high levels of infestation by certain of these filamentous bacteria (Lightner, 1978a).

Table 6. Epicommensal organisms observed or reported to cause disease in cultured penaeids.

Bacteria	Ciliates (Protozoa)	Blue-Green Algae
Leucothrix mucor	*Zoothamnium* spp.	*Spirulina subsalsa*
Thiothrix sp.	*Epistylis* spp.	*Schizothrix calcicola*
Flexibacter sp.	*Vorticella* sp.	Diatoms
Vibrio spp.	*Lagenophrys* sp.	*Amphora* sp.
Pseudomonas spp.	Apostome ciliate	*Nitzschia* sp.
Flavobacteria sp.	Suctoria (Protozoa)	*Achanthes* sp.
Aeromonas formicans	*Acineta* spp.	

Lewis et al. (1982) reported aggregation of hatchery-reared *P. stylirostris* larvae by surface fouling due to infestations of *Pseudomonas piscicida*, *Aeromonas formicans*, and *Flavobacteria* sp.

Protozoan epicommensals. A number of species of protozoa have been reported to cause surface fouling and/or gill disease in all life stages of cultured penaeids (Table 6; Overstreet, 1982; Couch, 1983; Lightner, 1983). The most commonly reported protozoans include the peritrich ciliates (Fig. 11) *Epistylis* spp., *Zoothamnium* spp., and *Vorticella* spp.; the loricate Ciliate *Lagenophrys* sp.; an undescribed apostome Ciliate; and the suctorian *Acineta* spp. (Couch, 1978, 1983; Overstreet, 1978, 1982; Meng and Yu, 1980, 1983; Lightner, 1983). As was the case with bacterial epicommensals, these protozoans, when abundant on the body surfaces, appendages, or gills, can cause difficulties to the host in locomotion, feeding, molting, and respiration (Fig. 11). Like *L. mucor*, most of the protozoans cause no appreciable internal damage to the host surfaces or gills. The exception to this is the unidentified apostome Ciliate, which caused melanized hemocytic lesions in the gills of *P. aztecus* (Lightner, 1975; Overstreet, 1978, 1982).

Algae. A number of species of blue-green algae and diatoms (Table 6) have been reported to be among the epicommensal organisms causing surface fouling and gill disease in cultured and captive penaeids (Lightner, 1983). *Amphora* sp. has even been observed growing internally in the gills of *P. setiferus* reared in a shallow, nonturbid, well-lighted tank (Overstreet and Safford, 1980).

Nutritional, toxic and environmental diseases

Nutritional diseases

Although a number of the nutritional requirements of cultured penaeids have been identified and such nutrients as the essential amino acids, cholesterol, linolei c acid, ß-carotene and potassium are needed in penaeid diets for optimum growth, survival and appearance (New, 1976; Kanazawa, 1984), only one nutritional diseas e syndrome of cultured penaeids has been described in detail. That disease, called black death or shrimp scurvy (Lightner et al., 1977, 1979) occurs in penaeids which are reared in culture systems lacking algae and receiving diets with insufficient ascorbic acid (Fig. 13). The disease has not been observed in shrimp cultured in systems where there is at least some algae. Shrimp with black death posses s melanized hemocytic lesions in the epithelial and supportive connective tissues of the general body cuticle, the foregut and hindgut, the eyestalks, and the gills. The lesions are most prominent in tissues with a high collagen content (Hunter et al., 1979). Addition of L-ascorbic acid to the shrimp's ration or rearing shrimp in the presence of algae effectively prevents black death disease (Lightner et al., 1979).

Toxic diseases

Hemocytic enteritis (HE): Blooms of certain filamentous blue-green algae, all belonging to the family Oscillatoriaceae,

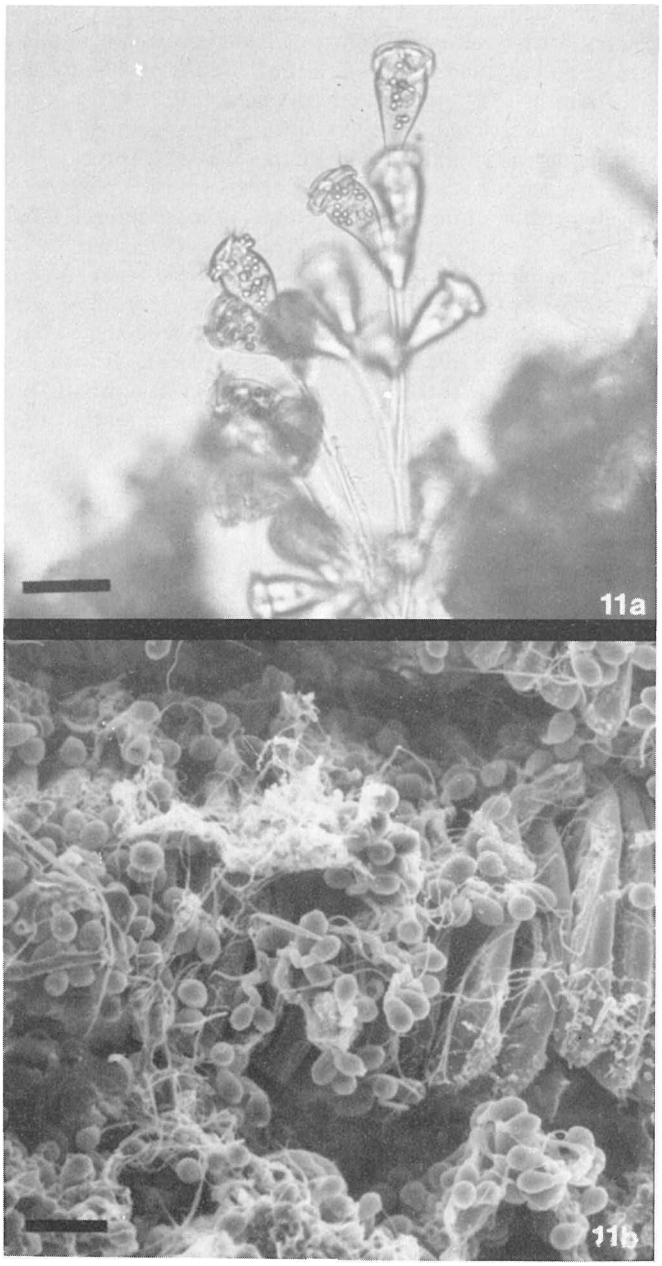


Fig. 11. *Zoothamnium* sp.: 11a) A colony of *Zoothamnium* from the gills of *P. californiensis*, ×115. Bar is 100μm; 11b) SEM of gills of *P. stylirostris* that are heavily fouled by *Zoothamnium*, × 220. Bar is 50 μm.

have been implicated as causing the disease syndrome HE in primarily young juvenile penaeids. The occurrence of HE seems to be ubiquitous, and examples of the disease exist from marine and freshwater shrimp aquaculture facilities in North America, Hawaii, Brazil, Philippines, and Israel (Table 7). One species of blue-green alga, shown experimentally to cause this syndrome, is *Schizothrix calcicola* (McKee, 1981). *S. calcicola* occurs in both fresh water and sea water, and has been reported to possess a potent endotoxin (Keleti et al., 1979). While HE is most commonly observed in early juvenile penaeids, it has been observed in Subadult penaeids as well.

The principal lesion of HE, which occurs as the result of algal endotoxin released in the gut from ingested algae, is a necrosis and marked hemocytic inflammation of the mucosal epithelium of the midgut and its caeca (Fig. 14; Lightner, 1978b), accompanied by necrosis and degeneration of the hepatopancreas (Lightner and Redman, 1984). The cause of death in shrimp with HE may be due to osmotic imbalances, poor absorption of nutrients, or to secondary bacterial infections. Species of *Vibrio,* usually *V. alginolyticus,* are the organisms most commonly isolated from the septic hemolymph of shrimp with HE (Lightner, 1983). Mortality rates in raceway-reared P. *stylirostris* with HE have reached 85% (Lightner, 1978b), but usually are less than 20%. Runting of shrimp affected with HE is a chronic effect in animals that survive the disease (Fig. 15) apparently due to midgut dysfunction and to the length of time required for the midgut mucosa to regenerate.

Dinoflagellate poisoning. Dinoflagellate blooms (red tides) have been circumstantially linked to serious mortalities of cultured penaeid shrimp in Mexico (Lightner et al., 1984), but a cause-and-effect relationship of mortality to the suspect species of dinoflagellates has not been experimentally demonstrated (Lightner, 1983). The occurrence of a toxicity syndrome called BSX, "Blue Shrimp Syndrome Unknown" in *P. californiensis* and *P. stylirostris* cultured in Mexico (Lightner, 1983) has been correlated with the occurrence of red tides. Shrimp with BSX die during molting or following handling stress, and in an affected population, a large percentage of the shrimp has been observed to develop "blunt heads" (Fig. 23). This condition was thought to develop from damage to the head appendages from the convulsive behavior pattern that occurs in this syndrome (Lightner, 1983). Dinoflagellate toxins are thought to be nontoxic to crustaceans (Sievers, 1969), but only short-term toxicity tests have been run on shrimp. However, during those tests, the few shrimp that molted also died. That observation and the circumstantial association of red tides and the BSX syndrome in Mexico indicate that the importance of red tide toxins to penaeids may be significant.

Table 7. Geographic locations and species of cultured shrimps and prawns in which hemocytic enteritis has been observed.

Species	Geographic location	Reference
Penaeus duorarum	Florida	Nimmo et al., 1977
P. stylirostris *P. vannamei,* and *P. californiensis*	Mexico	Lightner et al., 1978; Lightner, 1983
P. vannamei, *P. stylirostris,* and *P. japonicus*	Hawaii	Lightner (unpub.)
P. monodon	Philippines	Lightner (unpub.)
P. stylirostris	Israel	Lightner (unpub.)
Macrobrachium rosenbergii	Hawaii, Philippines and Brazil	Brock, 1983; Lightner (unpub.)

Aflatoxicosis and red disease. Aflatoxicosis and red disease are discussed together here because of the close similarity of their histopathology (Lightner et al., 1982; Lightner and Redman, in press b). However, the etiology of red disease is unknown, and while it may have a toxic cause, the possible role of an infectious agent in its etiology has not been completely explored. Both of these diseases have as their principal feature a necrosis of the hepatopancreas that is accompanied by marked intertubular hemocytic inflammation, tubule encapsulation, and melanization (Figs. 16, 17).

Aflatoxicosis. Necrosis and inflammation of the hepatopancreas, mandibular organ, and hematopoietic organs are the principal features of artificially induced aflatoxicosis (Fig. 16; Lightner et al., 1982). Although aflatoxicosis has not been proven to be an important disease of cultured penaeids, the mechanism for its being an important disease is in place. Penaeids reared in semi-intensive or intensive systems are fed artificial diets that may contain ingredients, which on occasion, can contain aflatoxin in sufficient amounts to result in aflatoxicosis (Araf a et al., 1979; Wiseman et al., 1982). Aflatoxin could also be produced "in situ" in penaeid feeds improperly stored under warm and humid conditions typical of penaeid culture regions (Wiseman et al., 1982).

The principal lesions of aflatoxicosis in penaeids (Lightner et al., 1982) occur in the hepatopancreas and the mandibular organ. In the hepatopancreas, acute and subacute aflatoxicosis is expressed as necrosis of the hepatopancreatic tubule epithelium that proceeds from the proximal portion of the tubules to the peripheral tubule tips (Fig. 16). A marked intertubular hemocytic inflammation followed by encapsulation and fibrosis of affected tubules follows in subacute and chronic aflatoxicosis, but does not develop in acute aflatoxicosis. The mandibular organ in aflatoxicosis displays a necrosis of the peripheral epithelial cells of cords within the gland that progresses proximally to the central vein (Fig. 16). Only a slight hemocytic inflammation accompanies the degenerative changes in the mandibular organ (Lightner et al., 1982).

Red disease. Red discoloration or red disease was first noted in Taiwan (Liao, 1977; Liao et al., 1977) in cultured *P. monodon.* The disease has also been observed in captive wild adult *P. monodon* and in juvenile and adult cultured *P. monodon* in the Philippines (J.F. LeBitoux and C. Emerson, pers. comm., 1982) and in pond-reared *P. stylirostris* in Hawaii (Lightner and Redman, in press b). Liao (1977) noted that red disease in some years in Taiwan was "quite serious" especially in cultured adult *P. monodon.* The hepatopancreas of normal decapod crustaceans contains a variety of carotenoid pigments, with most of the total body content of ß-carotene being stored in the hepatopancreas (Goodwin, 1960).

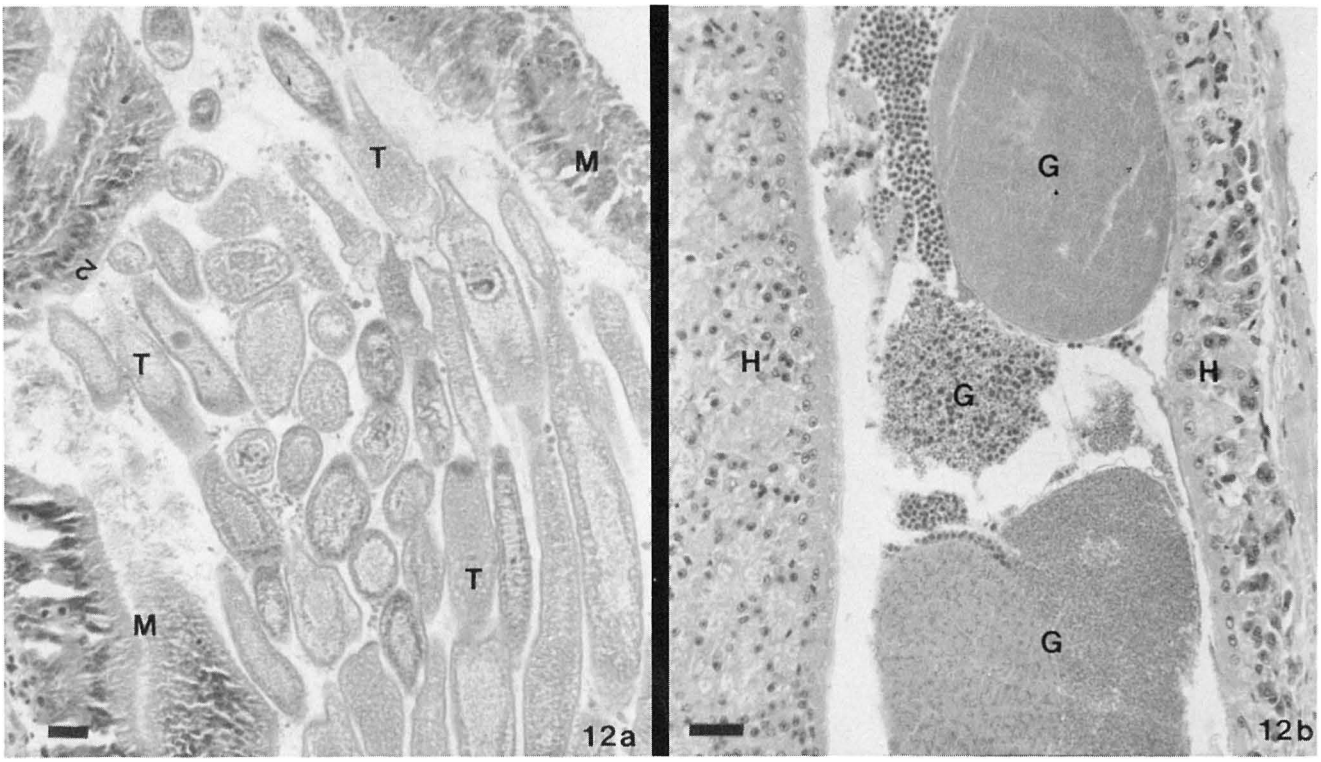


Fig. 12. Gregarines: 12a) Histological section of the anterior midgut (M) of a *P. monodon.* Numerous trophozoites (T) of a cephaline gregarine nearly fill the gut lumen, ×52. Bar is 100 μm; 12b) Section of the hindgut of the same *P. monodon* showing several gametocysts (G) in a crypt of the hindgut lumen (H), ×265. Bar is 25 μm.

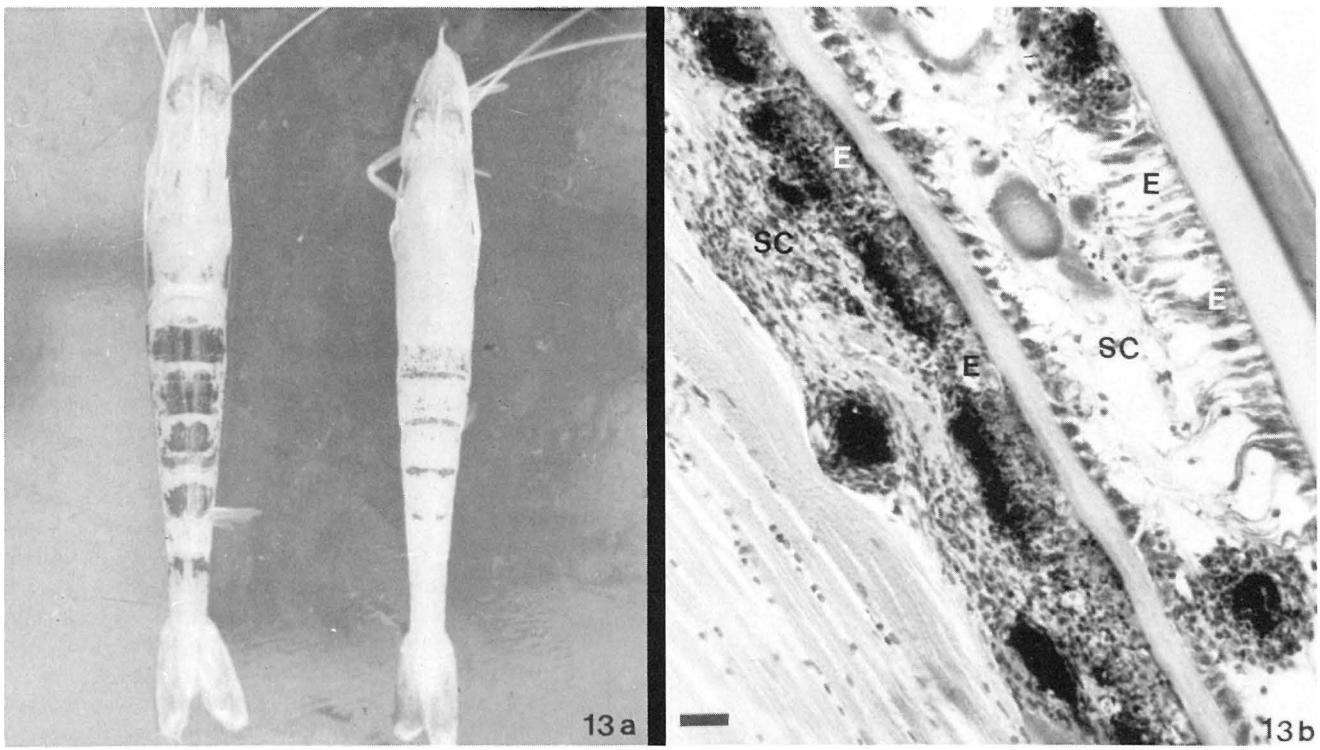


Fig. 13. Ascorbic acid deficiency syndrome ("black death disease"): 13a) Juvenile *P. californiensis* showing melanized subcuticular lesions that are typical of black death disease; 13b) Histological section through a cuticular lesion. Melanized hemocytic nodules and granulomas are present in the cuticular epidermis (E) and subcutis (SC) at this site where the cuticle of two abdominal segments overlap,×265. Bar is 25 μm.

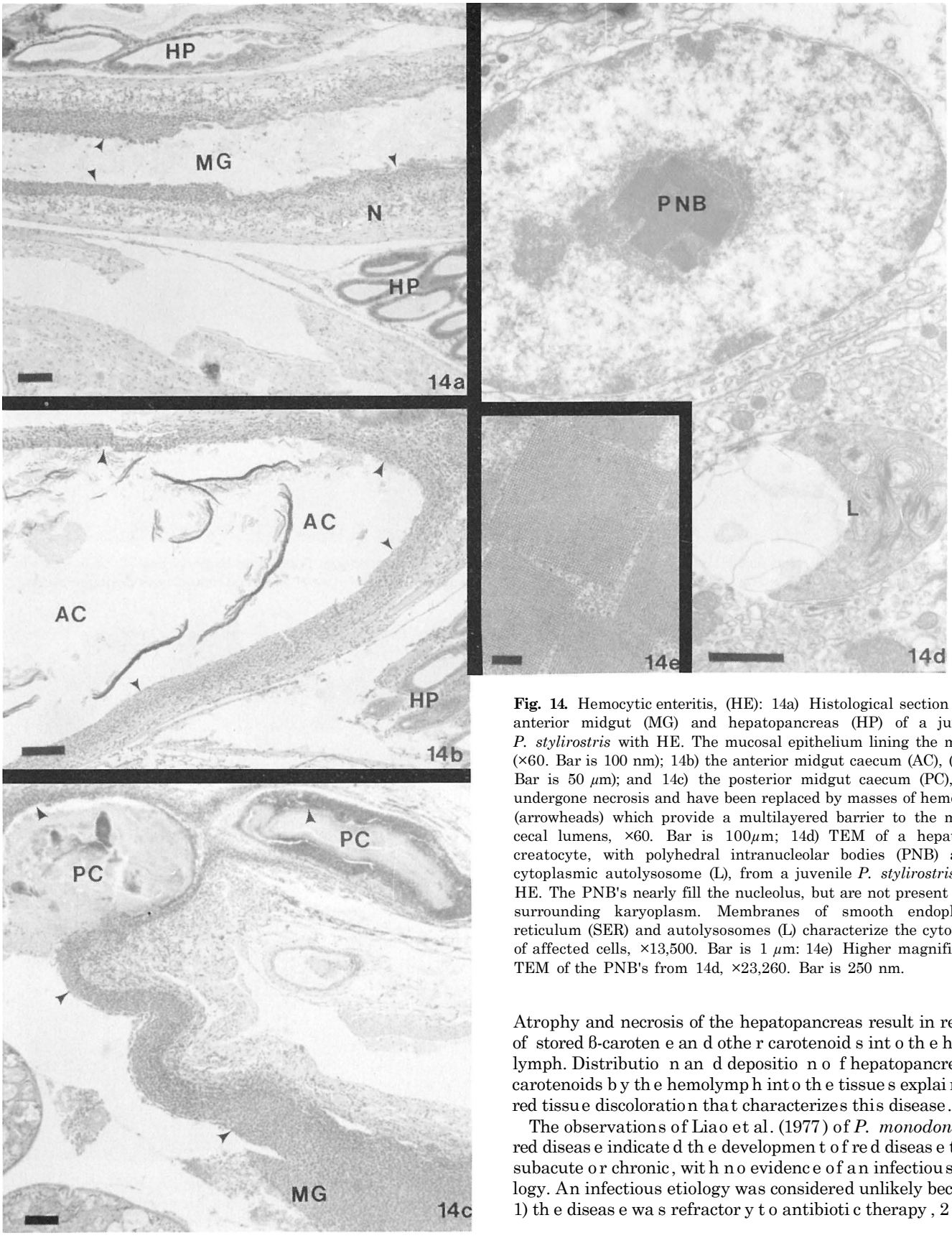


Fig. 14. Hemocytic enteritis, (HE): 14a) Histological section of the anterior midgut (MG) and hepatopancreas (HP) of a juvenile *P. stylirostris* with HE. The mucosal epithelium lining the midgut (×60. Bar is 100 nm); 14b) the anterior midgut caecum (AC), (×150. Bar is 50 μm); and 14c) the posterior midgut caecum (PC), have undergone necrosis and have been replaced by masses of hemocytes (arrowheads) which provide a multilayered barrier to the midgut cecal lumens, ×60. Bar is 100μm; 14d) TEM of a hepatopancreatocyte, with polyhedral intranucleolar bodies (PNB) and a cytoplasmic autolysosome (L), from a juvenile *P. stylirostris* with HE. The PNB's nearly fill the nucleolus, but are not present in the surrounding karyoplasm. Membranes of smooth endoplasmic reticulum (SER) and autolysosomes (L) characterize the cytoplasm of affected cells, ×13,500. Bar is 1 μm: 14e) Higher magnification TEM of the PNB's from 14d, ×23,260. Bar is 250 nm.

Atrophy and necrosis of the hepatopancreas result in release of stored ß-carotene and other carotenoids into the hemolymph. Distribution and deposition of hepatopancreatic carotenoids by the hemolymph into the tissues explain the red tissue discoloration that characterizes this disease.

The observations of Liao et al. (1977) of *P. monodon* with red disease indicated the development of red disease to be subacute or chronic, with no evidence of an infectious etiology. An infectious etiology was considered unlikely because: 1) the disease was refractory to antibiotic therapy, 2) the

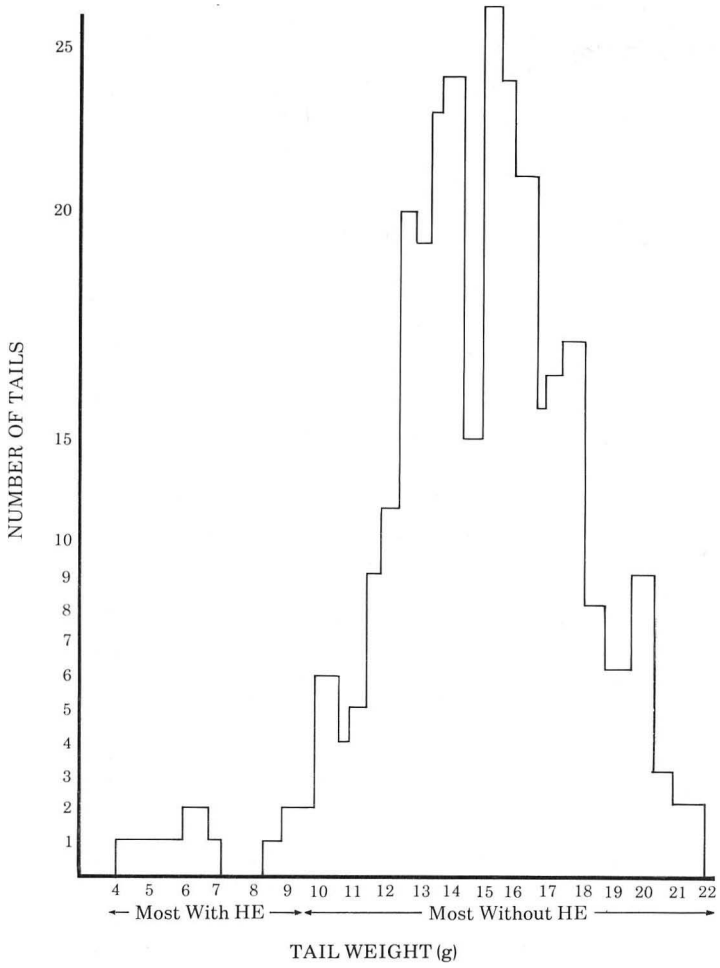
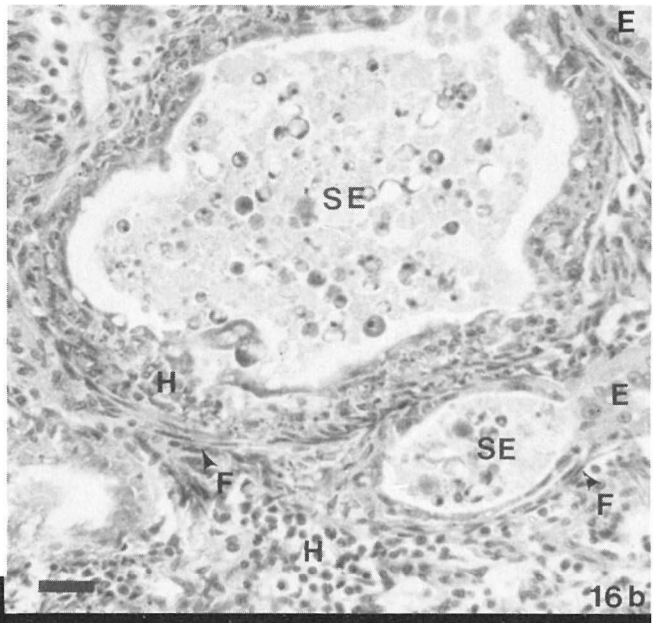
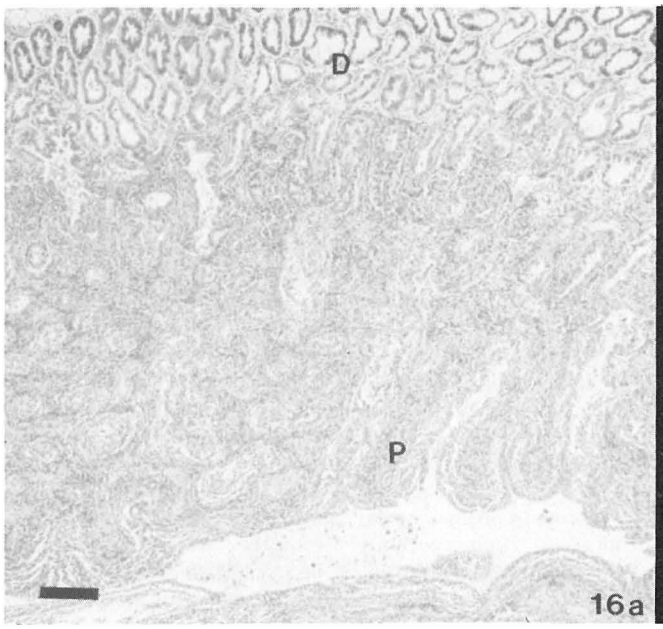
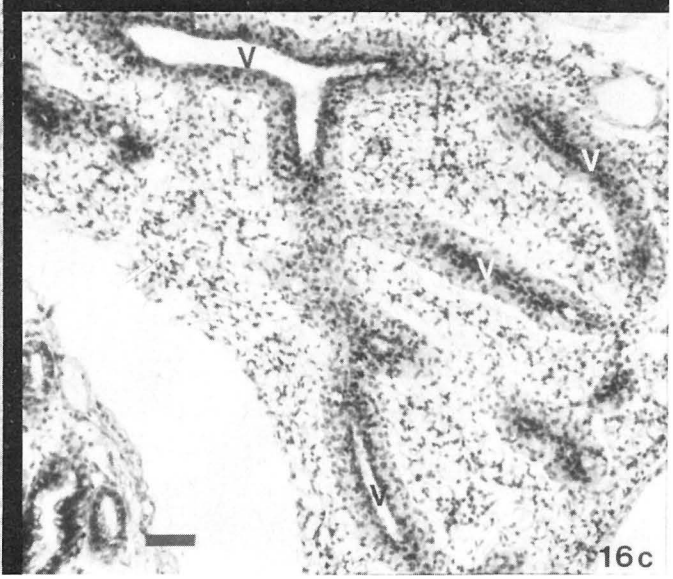


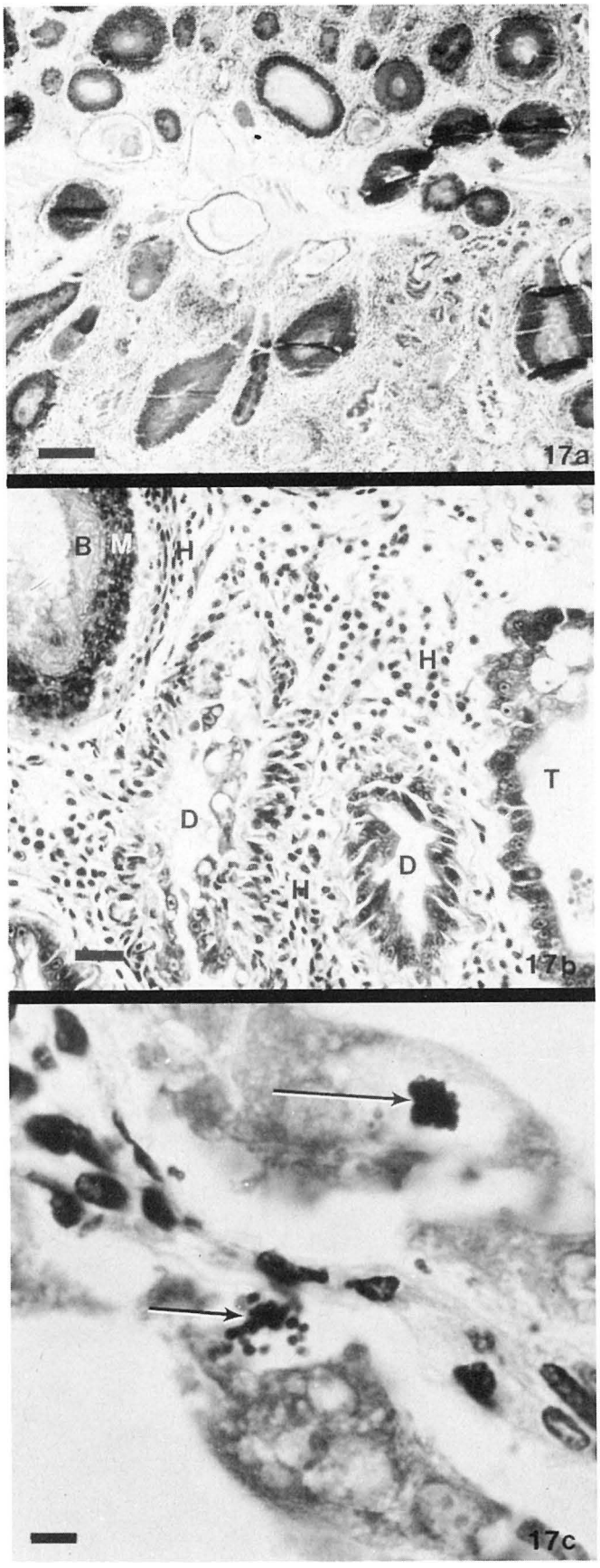
Fig. 15. Histogram of tail weight (in grams) of *P. stylirostris* from a population with chronic HE. The tendency for HE to reduce growth rate of affected shrimp to below that of the whole population is evident.

Fig. 16. Aflatoxicosis: 16a) Histological section of the hepatopancreas of a juvenile *P. stylirostris* with subacute experimentally induced aflatoxicosis. Degeneration and necrosis of the organ has proceeded distally (D, at top) from the proximal (P, at bottom) portion of the organ's tubules. The distal tubule tips are only slightly affected, while the medial and proximal portions of the tubules have been destroyed, ×50. Bar is 150 μm; 16b) Higher magnification of the medial portion of several hepatopancreatic tubules undergoing necrosis. Degeneration is proceeding from proximal (left) to distal (right). The tubule epithelium in the proximal region has been sloughed (SE) into the tubule lumen, while the more distal epithelium (E) remains attached. An intense intertubular inflammatory response consisting of hemocytes (H) and fibroblasts (F) is present surrounding the affected tubules, ×285. Bar is 25 μm; 16c) Histological section of the mandibular organ of a *P. stylirostris* with subacute aflatoxicosis. Normal epithelial cells surround the central vessels (V), but peripheral cells show extensive vacuolization, diminution of cytoplasm, and pyknotic nuclei, × 130. Bar is 50 μm.









disease was observed only in *P. monodon*, even when polycultured with *P. penicillatus* and *P. semisulcatus,* and 3) because attempts failed to transmit the disease to unaffected *P. monodon.* Liao et al. (1977) suggested a link between feeding rancid fish and red disease, because the disease was not observed when care was taken to insure that only fresh fish were fed. However, C. Emerson (pers. comm.) noted that red disease in the Philippines occurred in pond-reared and captive wild *P. monodon* fed exclusively artificial diets. Emerson indicated, however, that in his experience red disease was most common in manure-fertilized ponds with thick anaerobic detritus deposits.

Liao et al. (1977) described the sequential development of red disease in *P. monodon*: Affected shrimp passed through four stages, with the earliest detectable signs of the disease being a yellowish-green discoloration of the shrimp body. Otherwise shrimp so affected remained active and displayed normal behavior. During the next two to four days affected shrimp became reddish, with the normally white gills and the pleopods also becoming reddish. Finally after five to seven days, affected shrimp became distinctly red and totally lost their normal brown and tan pigment (banded) pattern. Shrimp in the final stages of the disease were lethargic, anorectic and showed a tendency to excessive surface fouling by epicommensal organisms. The amount of body fluid in the cephalothorax increased over normal shrimp and had a foul odor. The hepatopancreas was reported to be yellow or "pale."

Histological examination of *P. monodon* and *P. stylirostris* with red disease revealed a marked atrophy of the hepatopancreas and the presence of numerous melanized inflammatory lesions in the hepatopancreas, antennal gland, mandibular organ, gonads, midgut and gills (Lightner and Redman, in press). Hepatopancreatic inflammatory lesions were the most consistently observed lesion type (Fig. 17). Affected hepatopancreata were atrophied (reduced by as much as 50% of expected normal size), usually contained multiple hemocyte-encapsulated hepatopancreas tubules with necrotic or sloughed epithelial linings, and possessed a marked hemocytic infiltration in the intertubular spaces (Fig. 17). Brown and Brenn gram-staining of affected hepatopancreata

Fig. 17. Red disease: 17a) Histological section of the hepatopancreas of a juvenile *P. monodon* with red disease. Most hepatopancreatic tubules are heavily encapsulated with hemocytes, melanized and contain masses of necrotic tissue debris and bacteria. Only a few normally appearing hepatopancreatic tubules (T, in upper right) are present in this section, ×50. Bar is 150 μm 17b) A higher magnification photomicrograph of a portion of the same section shown in 17a. Several stages of hepatopancreatic tubule degeneration are shown. A nearly normal tubule (T), with its brush-bordered simple columnar lining epithelium, is separated by two degenerating tubules (D) from the remnants of another hemocyte-encapsulated (H) and melanized hemocyte-lined tubule (M) that has lost its lining epithelium and now contains a mass of tissue debris and bacteria (B), ×265. Bar is 25 μm; 17c) Gram-positive cocci are commonly present in the hepatopancreas of *P. monodon* with red disease. These cocci are seen either free in the lumen of the hepatopancreas tubules or in cytoplasmic vacuoles (arrows) of tubule epithelial cells (Brown and Brenn tissue gram stain), × 1,320. Bar is 5 μm.

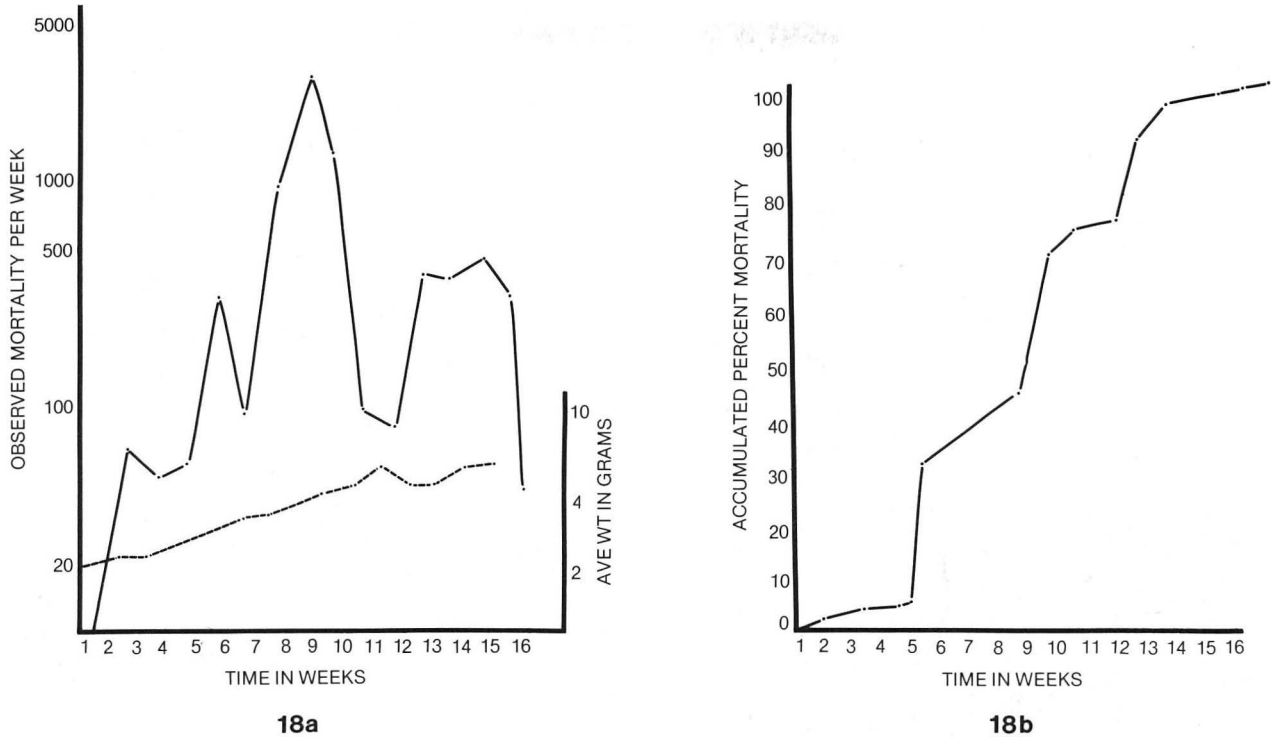


Fig. 18. Gut and nerve syndrome (GNS): 18a) Plots of mortality and growth rate in a population of raceway-cultured juvenile *P. japonicus* with GNS; 18b) Plot of accumulated percent mortality due to GNS in same population as shown in 18a.

of *P. monodon* and *P. stylirostris* showed the tubule lesions to contain masses of gram-negative rod-shaped bacteria and in *P. monodon* occasional prominent clusters of large (1.0 to 1.5 μm diameter) gram-positive cocci or short rods (Fig. 17c). Unlike the gram-negative rods that were always present in tissue debris in the lumen of hemocyte-encapsulated tubules, the gram-positive organisms in *P. monodon* were observed in clusters within cytoplasmic vacuoles of tubule epithelial cells, as well as in the lumen debris.

The significance of the relatively large numbers of gram-positive bacteria present in many of the *P. monodon* hepatopancreata with red disease is not known. Gram-positive bacteria do not typically make up a significant part of the normal microflora of penaeid shrimps and prawns (Vanderzant et al., 1970; Vanderzant et al., 1972; Lewis, 1973a; Yasuda and Kitao, 1980) or the known pathogens of penaeids (Lightner, 1983). The absence of these gram-positive bacteria in the Hawaii-reared *P. stylirostris* with red disease suggests either that they are not the etiological agent of red disease or that red disease may be a generalized syndrome, with more than one cause, resulting from a necrosis of the hepatopancreas and release of its content of carotenoid pigments into the hemolymph (Lightner and Redman, in press b).

Gut and nerve syndrome. This idiopathic proliferation condition affecting the midgut and ventral nerve cord has only been observed in populations of postlarval and juvenile *P. japonicus* reared in ponds, tanks, and raceways in Hawaii (Lightner et al., 1984). It has apparently not been observed in *P. japonicus* reared in Japan or elsewhere. The disease was named gut and nerve syndrome (GNS) to reflect its idiopathic nature and the principal organs affected. The severity and high prevalence of GNS in virtually all populations of cultured *P. japonicus* studied since 1980 in Hawaii had precluded the successful rearing of this species in Hawaii, particularly in high density culture (Fig. 18; Lightner et al., 1984). Although there is no evidence to support the hypothesis, GNS is hypothesized to be caused by a toxin, possibly an algal toxin, that is unique to Hawaii (Lightner et al., 1984). The principal lesions observed in *P. japonicus* with GNS are a hypertrophy of the anterior midgut mucosal epithelium basement membrane (BM) and a hyperplasia of the epineurium that covers the ventral nerve cord and segmental ganglia in the gnathothorax (Figs. 19, 20). There seemed to be a positive correlation between increased thickness of the BM and disease (i.e. poor growth, anorexia, extreme surface fouling, abdominal muscle necrosis, and opportunistic bacterial and fungal, usually *F. solani*, infections), and a possible relationship between ataxia, lethargy, and reduced escape response and the degree of hyperplasia of the epineurium (Lightner et al., 1984).

Black gill disease. A number of disease syndromes of cultured penaeids are accompanied by the presence of black (melanized) inflamed lesions in the gills (Fig. 21; Lightner, 1977; Lightner and Redman, 1977). In fact, black gills may accompany many of the syndromes described earlier in this review (Table 8), and are also frequently a sign of toxic syndromes caused by chemical irritants including certain heavy metals, oil, ammonia and nitrite, and ozone.

Gas-bubble disease. Gas-bubble disease has been reported to occur in penaeid shrimp as a result of supersaturation of

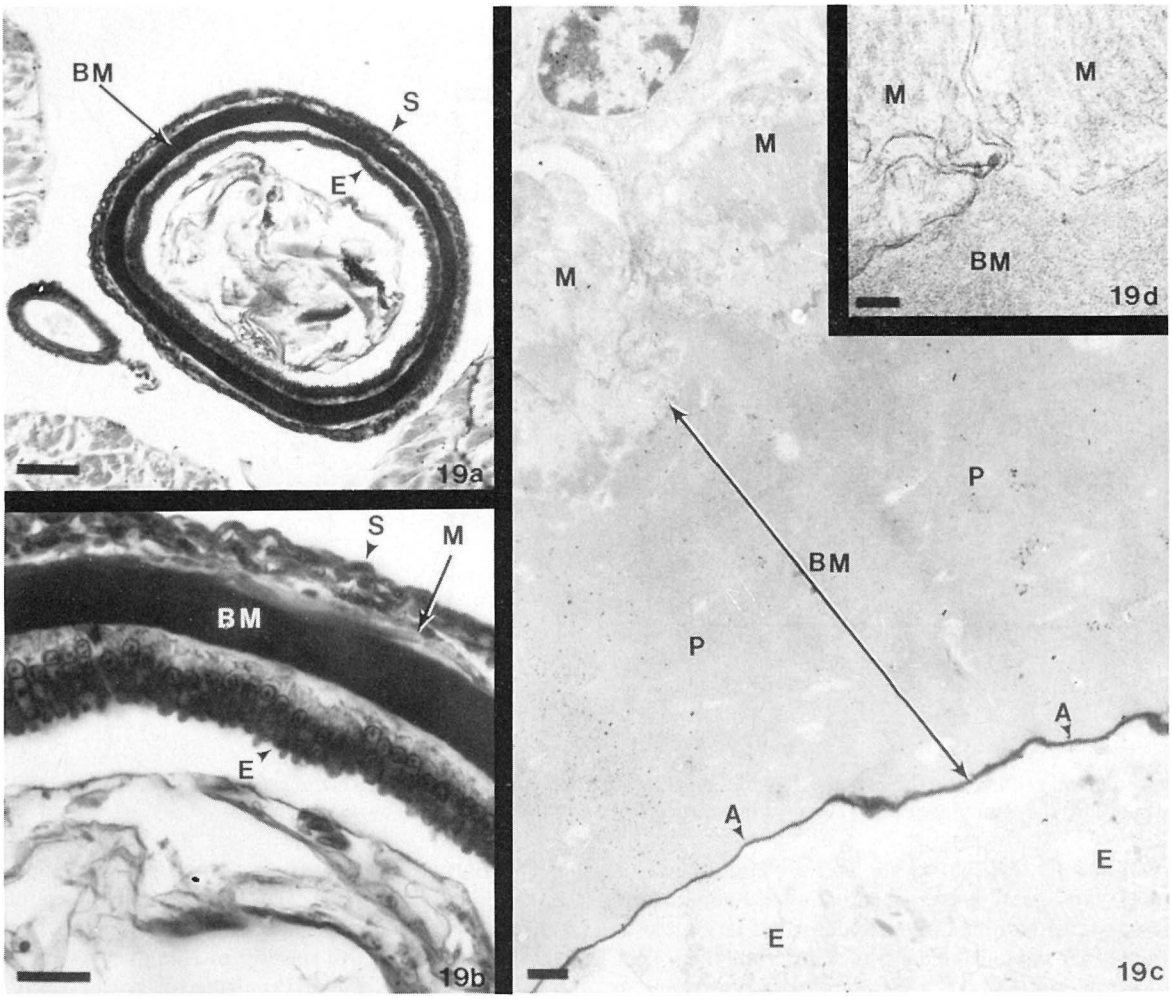


Fig. 19. Gut and nerve syndrome (GNS): 19a and 19b) Cross-section of the midgut from a *P. japonicus* with GNS. The mucosal epithelium (E) rests on a hypertrophied basement membrane (BM). The circular and longitudinal muscle layers (M) and the serosa (S) are normal in appearance (PAS staining) (19a, ×180. Bar is 50 μm; 19b, ×530. Bar is 20 μm); 19c) TEM of a hypertrophied basement membrane (BM). The mucosal epithelium (E) surface of the BM shows a slightly hypertrophied apical layer (A) that is more election dense than the greatly hypertrophied proximal layer (P), which lies adjacent to smooth muscle cells (M), ×6,000. Bar is 1 μm; 19d) A higher magnification TEM of the proximal portion of hypertrophied BM that shows it to be composed of fine fibrils embedded in a finely granular matrix, × 65,000. Bar is 100 nm.

Fig. 20. Gut and nerve syndrome (GNS): 20a) A sagittal section of the ventral nerve cord (N) and a segmental ganglion (G) in the gnathothorax of a juvenile *P. japonicus* with GNS. The epineurium (E) is composed of multiple repeating layers, rather than the normal single layers, ×86. Bar is 100 μm; 20b) A higher magnification of a multi-layered epineurium covering the ventral nerve cord is shown with seven repeating PAS-positive fibrous bands (F) that alternate with layers of granulocytes (G) that contain prominent PAS-negative granules, ×340. Bar is 25 μm; 20c) TEM of two fibrous layers (F) separated by a granulocytic layer (G). The nuclei of fibrocytes (N) are present in the fibrous layers, which are composed of bundles of collagen fibers arranged at oblique angles, × 3,300. Bar is 2 μm.

Fig. 21. Black gills: 21a) A juvenile *P. stylirostris* with black gills due to an intense hemocytic inflammatory response to damaged or necrotic gill tissues. Melanization of hemocytes and surrounding tissues results in the black color; 21b) Wet mount of a gill process from a juvenile *P. californiensis* with severe gill melanization, ×32. Bar is 250 μm.

Fig. 22. Gas-bubble disease: 22a) A juvenile *P. stylirostris* with gas-bubble disease. The gills of this shrimp appear white due to numerous gas bubbles within the gill lamellae; 22b and 22c) Wet mount of a gill process from a *P. stylirostris* with gas-bubble disease. At low magnification (22b, × 36. Bar is 250 μm), hemocoel rami in the gill process are outlined by gas emboli that, at a higher magnification (22c, X86. Bar is 100 μm), are shown to block all hemolymph circulation, thereby stopping respiration.

Fig. 23. Dinoflagellate toxicity syndrome: Juvenile *P. stylirostris* with gross signs of the disease syndrome BSX that has been circumstantially linked to red-tide toxins. Blunting of the head (of top two, bottom shrimp is normal) is due to erosion of the antennae, antennules, rostrum, antennal blades, and portions of the eyes.

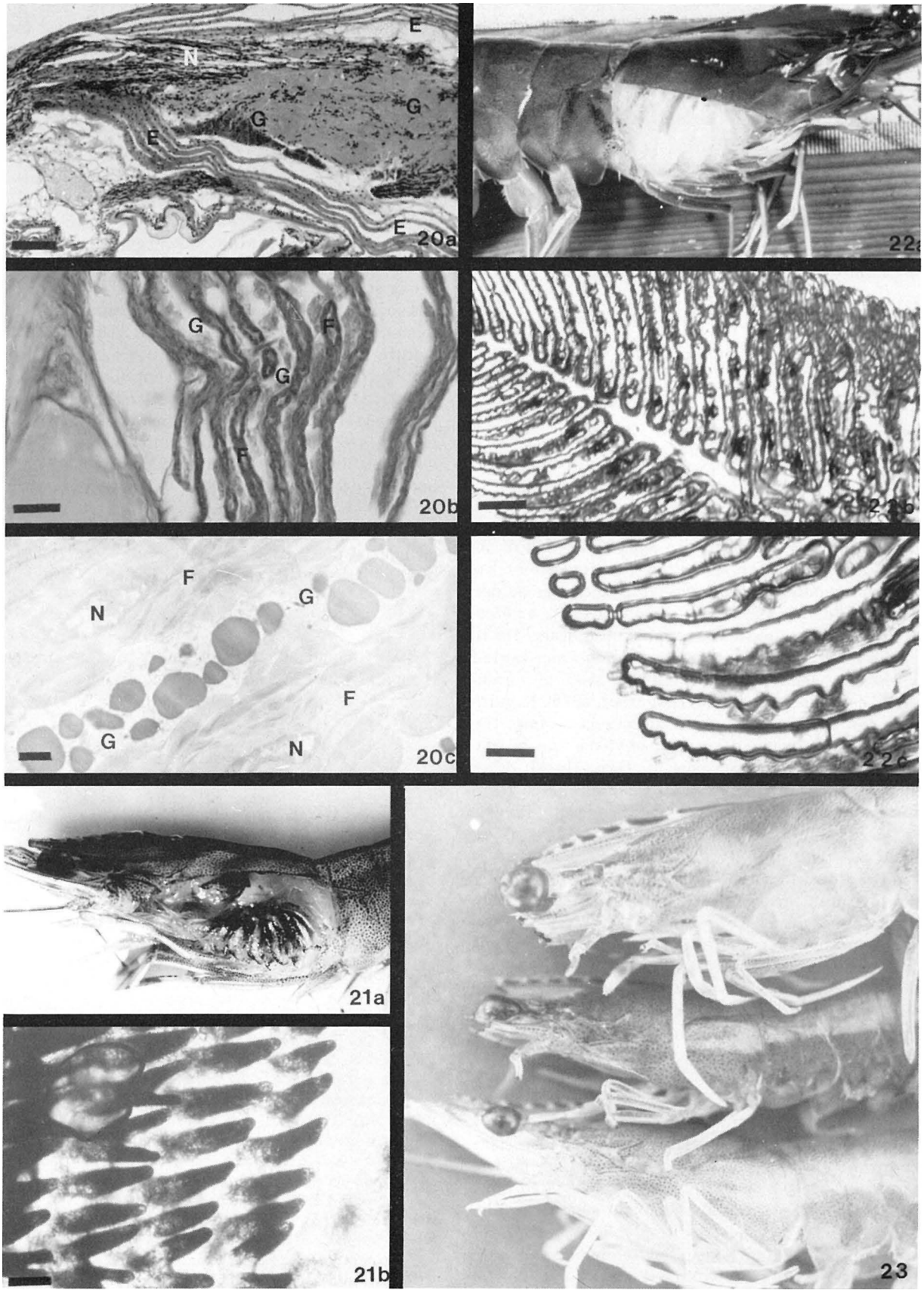

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Table 8. Biological and chemical agents reported to cause black gills in penaeid shrimp.

Agent	Reference
Virus	
IHHNV	Lightner et al. (in press)
Bacteria	
Flexibacter sp.	Lightner, 1978a
Cytophaga sp.	
Vibrio (Beneckea) spp.	Cook and Lofton, 1973; Cipriani et al., 1980
Fungi	
Fusarium solani	Egusa and Ueda, 1972
Protozoa	
Apostome Ciliate	Couch, 1978; Overstreet, 1978
Nutritional Deficiency	
Black Death (shrimp scurvy)	Lightner et al., 1979
Chemical	
Cadmium, copper	Couch, 1978
Potassium permanganate	Lightner, 1977
Ozone	Danald et al., 1979
Ammonia and nitrite	Lightner, 1983

atmospheric gases and oxygen (Lightner, 1983). Shrimp are similar to fish in their sensitivity to supersaturation of atmospheric gases. Although the level of nitrogen or atmospheric gas supersaturation required to cause gas-bubble disease in penaeids has not been formally studied, a threshold of about 118% saturation is assumed (Lightner, 1983). Oxygen-caused gas-bubble disease in penaeids was reported to occur when oxygen reached or exceeded 250% of normal saturation in seawater (Supplee and Lightner, 1976). Regardless of the gas causing gas-bubble disease in shrimp, the clinical signs are the same. The most obvious sign of gas-bubble disease is that shrimp with it, float. (In all other diseases, dead or dying shrimp sink.) Examination of fresh preparations of gills or whole tissue by microscopy reveals the presence of gas bubbles (Fig. 22).

Cramped tail. This occasionally observed condition of penaeid shrimp has been reported to occur in the summer months, when both air and water temperatures are high (Johnson, 1975b; Lightner, 1977; Liao et al., 1977; Meng and Yu, 1980). Penaeids with cramped tails (while still alive) have a dorsal flexure of the abdomen that cannot be straightened. The condition typically follows handling, although shrimp have been observed with cramped tails in undisturbed ponds (Johnson, 1975b). The cause of cramped tail is unknown, but its occurrence only during summer suggests that elevated water and air temperatures, the handling of shrimp in air that is warmer than the culture system water, and other stresses may contribute to the cause of the condition.

Muscle necrosis (spontaneous necrosis). Muscle necrosis is the name given to a condition in all penaeid species that is characterized by whitish opaque areas in the striated musculature, especially in the distal abdominal segments (Rigdon and Baxter, 1970). The condition follows periods of severe stress (from low oxygen, sudden temperature or salinity changes, severe gill fouling, etc.) (Lakshmi et al., 1978; Lightner, 1983). It is reversible in its initial stages, but it may be lethal if large areas are affected. "Tail rot" is the name given to the chronic and usually septic form of the disease when the distal portion of the abdomen (or appendages) becomes necrotic, turns red, and begins to slough.

Summary

There are five areas of research that should receive emphasis in the next several years in penaeid disease research: 1) Appropriately equipped laboratories in each of the major penaeid culture areas should identify and catalog those diseases occurring in wild populations and in culture facilities in their region; 2) Penaeid diagnostic laboratories should use or strive to develop for general use "standardized" diagnostic procedures whenever possible, especially for highly infectious agents such as the penaeid viruses; 3) Penaeid cell culture methods for primary cultures or cell lines must be developed to aid in the development of a much needed rapid, sensitive diagnostic test or tests for the penaeid viruses; 4) Improved methods of disease prevention, control, or chemotherapy are needed for many of the penaeid diseases now adversely affecting the penaeid culture industry; and 5) Approval is needed from those government regulatory agencies (such as the U.S. Food and Drug Administration and the U.S. Environmental Protection Agency) for drugs and chemicals used as pesticides and chemotherapeutics in penaeid culture that may pose a health risk to humans.

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Extensive and Semi-Intensive Culture of Prawn and Shrimp in the Philippines

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Abstract Various farming systems for prawn and shrimp are compared, with emphasis on the extensive and semi-intensive culture of tiger prawn *Penaeus monodon* and white shrimp *Penaeus indicus* in monoculture or in polyculture with milkfish (*Chanos chanos*). The bases of comparison include pond design characteristics, stocking density, food supply, water management, average production, technical, and other major input requirements. Common factors that may influence production for each system are also discussed.

It is observed that prawn and shrimp production has been mainly characterized by the extensive system. Of the 200,000 ha of brackishwater fishponds in the Philippines, about 25% (50,000 ha) are stocked with prawns and shrimps in monoculture or in polyculture with milkfish. Only a relatively small portion (less than 500 ha) of the area is utilized for semi-intensive culture. The dramatic increase in area utilization for extensive prawn production in recent years can be attributed to high market demand, increased hatchery-bred fry production, minimum technical requirements, and lower production cost and risks.

The trend towards intensification among existing large fishfarms is hampered by rising capital costs for fishpond improvement and increasing operational expense and risks. However, intensification is gaining some attention and progress in limited areas, primarily to maximize utilization and production to avoid high investment cost of land for expansion. Further development and progress in the industry will be dependent on such factors as market price, availability of fry and feed at reasonable cost, supply of trained technicians, technical problems, financial situation, and economic viability of the operation.

Introduction

Prawns and shrimps* are among the food items with high demand in Japan, U.S.A. and some European countries. Tan (1984) reported that Japan's imports of frozen prawn and shrimp in 1983 was 148,589 tons. The Philippine export of the same product for that year was only 4,321 tons or barely 2.9% of Japan's total imports.

U.S. consumption of tropical shrimp in 1983 was 216,400 tons, of which 155,180 tons were imported. In effect, the total market demand for frozen prawn and shrimp in U.S.A. and Japan alone is about 300,000 tons annually excluding the demand of Europe and other countries.

The potential for prawn and shrimp production in the Philippines has been very promising. The country has a warm tropical climate, ideal soil for culture, and unpolluted estuarine areas considered to be the natural habitats of these species. Also, a good portion of the vast existing brackishwater fishponds presently devoted to milkfish culture is suitable to the culture of various penaeid prawns and shrimps. Among the commercially important species now being cultured in the Philippines are the jumbo tiger prawn, *Penaeus monodon*; white shrimp, *P. indicus* and *P. merguiensis*; and the sand shrimp, *Metapenaeus ensis*.

*Prawns and shrimps in this paper refer to the jumbo tiger prawn *Penaeus monodon* and the white shrimps *P. indicus* and *P. merguiensis,* respectively.

Highlights of development

Prawn and shrimp farming in the Philippines has evolved from a traditional and crude polyculture method to an improved monoculture farming system. In earlier decades, farmers were largely dependent on the entry of wild fry into their ponds during spring tide. The fry brought inside the pond by tidal inflow were grown on natural food often together with milkfish. Since the occurrence of fry is seasonal and the quantity unpredictable, the production of prawn and shrimp during this period was unreliable.

To be assured of better production, farmers thought of intentionally stocking a certain number of fry in monoculture or polyculture with milkfish. Wild prawn and shrimp fry were then collected using various gears such as lures made of grass and twigs, filter net and fry raft, fry seine and scissors net depending on whether the collecting site is along the shore, mouths of rivers or estuaries, etc. (Motoh, 1981). Since information on pond culture of prawn was inadequate at the time, farming attempts often failed.

The increasing demand for prawn and shrimp in the international market in the early sixties triggered the interest of both the government and private sectors in developing the prawn industry. Upon gaining some information from printed materials and from fishery scientists and officials who have observed prawn culture activities in Taiwan and Japan, some farmers ventured seriously into prawn production. Most if not all ventures, however, did not prosper due to various problems such as inadequate and seasonal fry supply, lack of technical knowhow and skill, and the high rate of

mortality in ponds (Delmendo and Rabanal, 1956; Caces-Borja and Rasalan, 1968).

Breakthroughs in the mass production of penaeid fry under controlled conditions at the Mindanao State University Institute of Fisheries Research and Development, in Naawan, Misamis Oriental and SEAFDEC Aquaculture Department in Iloilo, in the late sixties and early seventies marked the take-off point in the development of the prawn and shrimp industry in the Philippines. The impact on industry was the venturing into prawn culture of more farmers because of greater assurance of fry supply.

With the proliferation of hatcheries all over the country in the late seventies and the development of nursery techniques (Apud, 1979), more fishponds were converted to, or constructed for, prawn culture. A privately-owned multimillion peso prawn culture complex was in fact established in Negros Occidental in 1979. A number of entrepreneurs followed and established different types of prawn culture facilities whose sizes varied according to level of investment.

In 1983, there were about 60 government and privately-owned hatcheries in the country with an estimated total production potential of 500 million fry annually (Primavera, 1984). This quantity can supply about 50,000 ha at a stocking density of 5,000/ha at two croppings/year. Even if only 40% (200 million fry) of estimated potential capacity is achieved, the hatcheries are still capable of supplying some 20,000 ha.

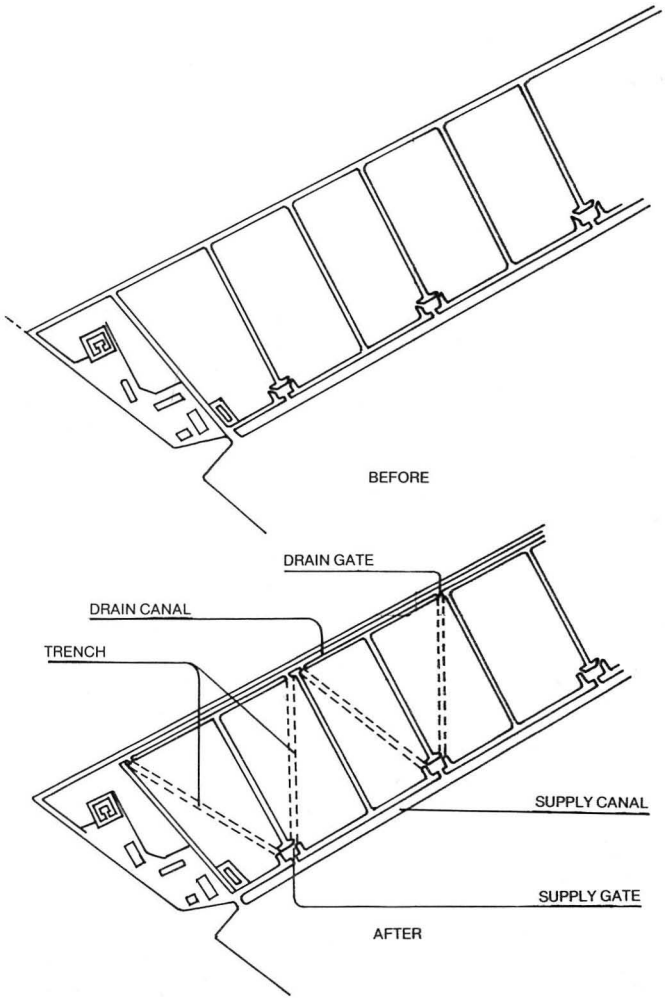

Fig. 1. Milkfish ponds renovated into semi-intensive prawn culture ponds at the Leganes Research Station, SEAFDEC Aquaculture Department (after Torres, 1983).

The rapid increase in fry supply as a result of continuous progress in hatchery operations has greatly increased the hectarage for prawn production during the last five years. To date, it is estimated that about 30,000 to 50,000 ha of the 200,000 ha of brackishwater ponds in the Philippines are devoted to prawn production utilizing various culture systems.

Classification of culture systems

Prawn and shrimp culture systems are classified into three, namely, extensive, semi-intensive, and intensive. The classification is based mainly on pond facilities, stocking density, food supply, water management, yield, technical knowhow and skill and other major inputs. While semi-intensive and intensive farming have gained some progress in recent years, the extensive system still remains the major practice possibly because of the relatively large landholdings (50-300 ha) per farmer. In order to shift to the semi-intensive or intensive system, large areas will require greater amount of inputs, risk, high-level technical knowhow, and supervision.

On the other hand, increasing acquisition and development costs per unit area has led farmers with small landholdings to go into intensive operation. Intensified farming virtually increases the yield per hectare thereby absorbing the relatively higher capital investment and risk. Further progress and development of any farming operation will largely depend on the supply and cost of fry, technical knowhow, quality and cost of feed, and economic viability of the operation. For purposes of this paper, discussion is confined to extensive and semi-intensive farming operations.

Basic considerations

Site suitability

The major environmental factors that influence prawn and shrimp production in extensive and semi-intensive operations include climatic conditions, source of water, and type of soil. Better production is observed in areas having short and not so pronounced dry season with moderate rainfall distributed almost throughout the year and having sufficient source of good water free from pollutants, with salinity of 10-20 ppt and pH above 7. Desirable types of soil for diking purposes are either clay loam, silty clay or silt loam. Sandy clay suits the creeping and burrowing habit of *P. monodon.* The favorable soil pH is between 7.0 to 8.3. It is desirable to have pond bottom elevation easily reached by ordinary high tides to enhance water replenishment and to easily maintain desirable water depth of 1 m. Accessibility of areas also facilitates supervision and transport of input materials and products. Support facilities such as electricity and an ice plant, if available, are beneficial.

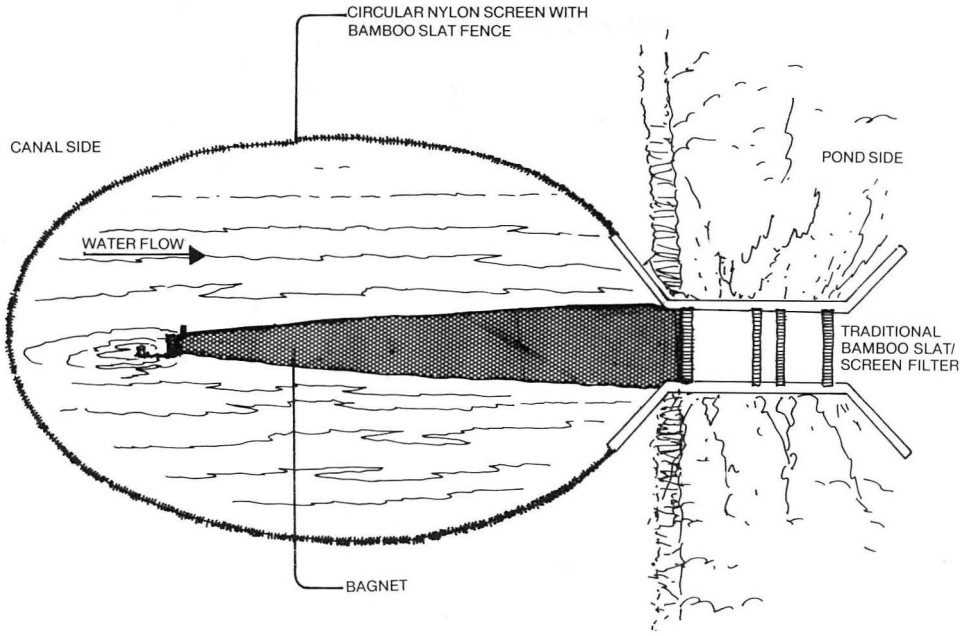

Fig. 2. Combined use of circular screen and bagnet to effectively control pests and predators.

Pond design characteristics

At present, most prawn farmers utilize ponds originally designed for milkfish culture. In extensive farming where prawn and shrimp are mainly dependent on natural food, minimal improvements are introduced depending on the existing conditions of the milkfish pond. In contrast, more improvements in terms of depth, gate and canal system are required for semi-intensive operations.

In extensive ponds, existing compartments range from 2 to 20 ha. Such large sizes lead to difficulties in water management, pest and predator control, and retrieval during harvest. Hence, pond sizes ranging from 1 to 5 ha are more appropriate for the extensive system. In semi-intensive ponds where the stock is provided with supplementary feeds in addition to natural food, more efficient water exchange is needed. Smaller pond areas ranging from 1 to 2 ha are ideal.

Ponds capable of holding water at least 80 cm deep are desirable for both extensive and semi-intensive operations. If this is not met, the yield is affected. Otherwise a bottom trench, 5-10 m wide and 0.5 m deep, is excavated along the dikes or across the pond to provide a deeper portion covering at least 25% of the total area. Both extensive and semi-intensive ponds require dikes that are structurally strong and high enough to provide free board of at least 30-40 cm for division dikes and 50-60 cm for secondary dikes.

A single gate and canal system to serve both water supply and drain requirements is adequate for ponds of not more than 3 ha in extensive operations. However, the single gate-canal system is inadequate for larger ponds. In semi-intensive ponds, supply gate and canal system is separate from the drain gate and canal (Fig. 1) to allow more efficient water exchange and to operate on a flow-through basis. The traditional screening facilities (bamboo screen) used for milkfish culture are not applicable. These are replaced by fine-mesh screen (0.2 mm mesh) installed singly either as bagnet or as a circular screen or a combination of both (Fig. 2).

Extensive and semi-intensive culture operations

Pond preparation

Pond preparation in the extensive and semi-intensive culture systems includes the following activities: drying of pond bottom, eradication of pests and predators, repair of pond facilities and propagation of natural food through pond fertilization and water management.

Drying the pond bottom can take a week or two. Undrainable portions of ponds such as water pools require pesticide application to eliminate unwanted species. Most insecticides commonly used contain chlorinated hydrocarbons which are non-biodegradable and may have some residual effects, leading to soil sterility and stunted growth in animals, and mortalities.

Some organic-based pesticides are safe and effective materials for pest and predator control. Rotenone powder preparation (5-8% rotenone) at a 5 ppm concentration or derris root at 20-40 kg/ha at 10 cm water depth can eliminate pests and finfishes. Tobacco dust or shavings are also effective at 200-400 kg/ha in eliminating pests, fishes and even snails. Nicotine and saponin, if available and cheap, are effective in eliminating predatory fishes at 10-15 kg/ha and 1 ppm, respectively.

A cheap and easily available material is lime, in combination with ammonium sulfate at 500-1,000 kg/ha and 100-200 kg/ha, respectively, or a ratio of 5:1. If the above materials are mixed, the ammonia released from ammonium sulfate becomes toxic when pH is raised above 9 because of lime. The pond may be flooded and stocked with fry immediately after application.

Other chemical compounds recommended for use are sodium hypochlorite (active chlorine 5%) which is available as a bleaching solution and calcium hypochlorite, a commercial powder with 75% active chlorine. Both compounds are effective at 5 ppm concentration.

The most commonly used fertilizer in the industry is chicken manure applied at 1-2 ton/ha. Pig and cattle manure, mud press and, to some extent, rice bran and rice straw are also utilized. The organic and inorganic fertilizer combination used depends largely on soil and water conditions as well as type of food. Normally, organic fertilizer application is followed by inorganic fertilization at 75-150 kg/ha of 16-20-0 and 25-50 kg/ha of urea (46% N). The propagation of *Ruppia maritima* requires 15 kg N/ha plus 15 kg P/ha applied every 2 weeks (P. Subosa, pers. comm.).

Stocking

Juveniles reared in a nursery pond or in a net enclosure (Fig. 3A, B) adjacent to or within the grow-out pond area are merely transferred or released without acclimation or without packing while tank-reared juveniles require acclimation to pond conditions. Failure to acclimate fry during stocking has been a common mistake committed by fishfarmers. In many cases, farmers do not even measure salinity and temperature of transport water and pond water. At present, prawn farmers may specify to hatchery or nursery sources their salinity preference based on condition of the pond prior to packing and transport of fry. This practice eliminates the need for salinity adjustment during stocking.

Stocking density is dependent on the culture system including food availability, water depth, and efficiency in water management. Fishfarmers engaged in extensive operations stock 2,000-6,000 *P. monodon* fry/ha or 20,000-30,000/ha in the case of *P. indicus*. When natural food is abundant, about 500-2,000 milkfish fry/ha are added. The presence of prawn or shrimp together with milkfish is favorable to both species. Results obtained from various polyculture studies of milkfish and prawn or milkfish, prawn and shrimp (Pudadera, 1980; Eldam and Primavera, 1981; Apud et al., 1983) confirmed several beneficial effects. Eldani and Primavera (1981) specifically pointed out that one of the important benefits of prawn in polyculture with milkfish is their control of the population of chironomid larvae. These can occur at very high density (40,000-50,000/m^2) and compete with the favored stock for food, oxygen and space. Gundermann and Popper (1977) reported the disappearance of *Chironomus* larvae in Fiji ponds several weeks after stocking with *P. merguiensis* and *P. indicus*.

Stocking densities in semi-intensive operations may vary from 20,000 to 50,000/ha for *P. monodon* and 50,000 to 100,000/ha for *P. indicus*. These density levels are based on industry experience and the results of various studies on the intensification of prawn grow-out at the SEAFDEC Aquaculture Department Leganes Research Station (Mochizuki, 1979; Apud et al., 1981; Norfolk et al., 1981). At these density levels, it is possible to obtain survival rates ranging from 70 to 80% for *P. monodon* and 60 to 70% for *P. indicus*. Growth however, is highly dependent on water management and depth as well as the quality of supplementary feed.

Rearing

Extensive farming of prawn and shrimp relies heavily on natural food grown in the pond. Supplementary feeds are provided only occasionally when natural food production is low and stocking density is higher than 5,000 *P. monodon*/ha or 20,000 *P. indicus*/ha. In contrast, densities ranging from 20,000-30,000 *P. monodon*/ha and 50,000-100,000 *P. indicus*/ha in semi-intensive culture require regular supplementary feeding in addition to natural foods.

The natural food growing in prawn and shrimp ponds varies according to pond condition and location. Extensive culture as practised in northern Panay, parts of Bataan, Bulacan, Pangasinan, Samar, Leyte and some areas in Mindanao depends to a great extent on aquatic plants. The two most important species are *Najas graminea* and *Ruppia maritima*. Both plants normally occur in lower salinity (10-20 ppt) areas. *R. maritima* has a crude protein content of 15% (Apud et al., 1983). Both grow well in water 50-100 cm deep. Prawns

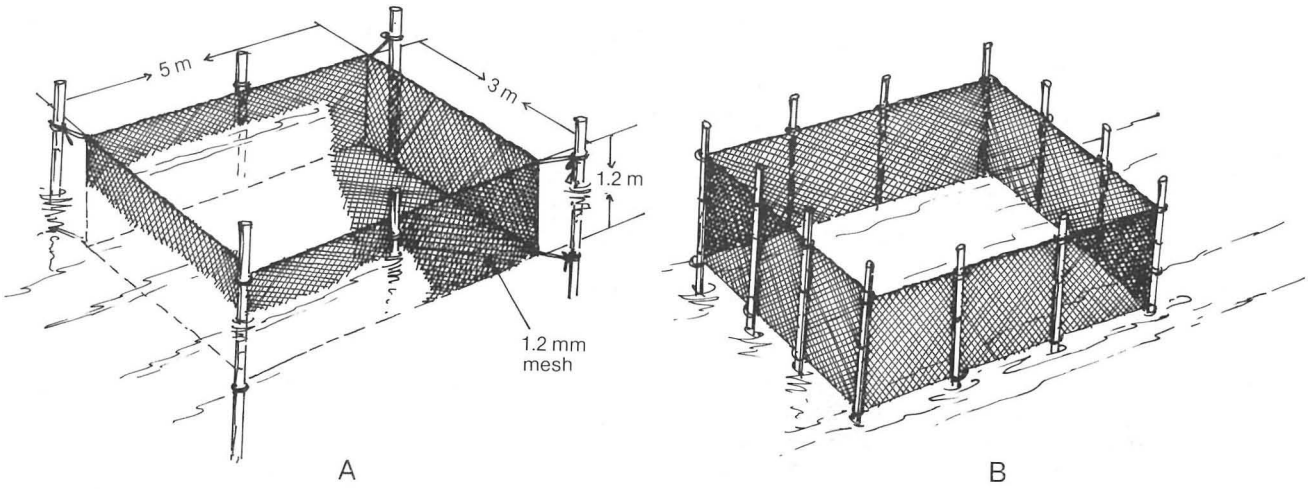

Fig. 3. *Hapa* prawn nurseries: A, *hapa* nursery in pond and B, net enclosure.

and shrimps graze on the soft parts of the plants, associated small animals (copepods, ostracods, insect larvae, nematodes, snails, etc.) and particularly on the decaying remains of the plants on the pond bottom (Primavera and Gacutan, 1984). The plants likewise provide shelter or substrate and improve water quality as silt and other particles are deposited on their leaves and stems.

Filamentous green algae such as *Chaetomorpha* constitute another natural food grown in ponds. *Chaetomorpha* grows in low salinity at water depth of 60 cm or more. It is also a refuge for various animals which are eaten by prawns and shrimps. The excessive growth of algae can cause harm by entangling the fry. This can be remedied by stocking milkfish at recommended polyculture rates. In some cases, ponds heavily loaded with these algae are drained completely by fishfarmers prior to stocking. Inorganic fertilizers are then broadcast directly into the mat of algae to soften the plants through plasmolysis.

Plankton, the microscopic plants and animals suspended in the water, form the base of the food chain. Deep ponds of low to medium salinity (10-30 ppt) are conducive to plankton growth.

Lablab, a microbenthic complex consisting of blue-green algae, diatoms, and other microscopic plants and animals, is considered a nutritious food for milkfish and even for prawns and shrimps. However, the environmental conditions under which it grows best (shallow water of 20-25 cm depth and higher salinity, 28 ppt and above) are not suited to prawn and shrimp. Also, the pond bottom easily deteriorates with excessive growth of lablab whose decomposition produces sulfides and other toxic gases and at the same time depletes oxygen on the pond bottom. Prawns and shrimps lose appetite at oxygen level of 3 ppm and below, hence lablab is not considered a good natural food for prawns unlike milkfish (Apud et al., 1983).

Although the stock in extensive ponds relies greatly on natural food, some farmers provide various kinds of supplementary feeds such as trash fish, mussel meat, toads, chicken entrails, cattle hide, snails, etc. In semi-intensive culture, processed feeds (formulated diet) and/or trash fish (Apud et al., 1981) are stored to provide adequate and ready supply of feeds in case unprocessed feeds are not available.

The amount of feeds and frequency of feeding are not yet well established. However, the daily recommended rates which decrease with time are 15-10% of estimated total biomass of prawns and shrimps for wet feeds and 10-4% for dry pellets. Forty percent of the feed is given in the morning and 60% in the evening. Feeds are placed in feeding trays and inspected a few hours after feeding to check whether the feeds are consumed or not.

There are relatively few cases of disease problems reported in extensive and semi-intensive operations. The most common complaint of fishfarmers is soft-shelling of prawns, a condition which inhibits molting and therefore results in retarded growth. Soft-shelled prawns are weak compared to those who undergo normal molting. Soft-shelling is attributed to possible factors like presence of microbes, nutritional deficiency and poor environmental conditions (C. Baticados, pers. comm.). This may also be caused by trace amounts of insecticides applied to adjoining agricultural areas. Proper water management and adequate food supply could prevent the occurrence of these problems.

Other diseases infrequently observed are the "black gill" disease caused by fungi or protozoa and a condition indicated by necrosis of appendages characterized by the browning of pleopods, pereiopods, telson and uropods at the earlier stages. This browning usually spreads progressively from the focus of infection towards the base of the appendages and finally leads to the erosion of some areas. According to Gacutan (1979), the etiology of this disease has not yet been determined; however, shell disease of this nature as in other penaeids can be caused by chitinoclastic bacteria such as *Beneckea*, *Vibrio* and *Pseudomonas* (Cook and Lofton, 1973). The progressive destruction of the exoskeleton provides areas for the entry of secondary infection which may cause death.

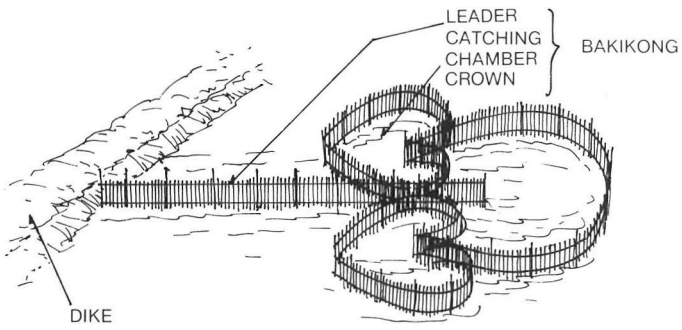

Fig. 4. Bamboo trap (*bakikong*) commonly used for partial harvesting.

Body cramp is another problem usually encountered during handling, transfer or harvesting during hot days. The body of a cramped prawn curves and becomes rigid, oftentimes leading to death. This may be avoided if prawns are handled or transferred during cool days. Fuzzy growth of algae on the exoskeleton is another disease. It may be caused by bacteria, protozoans or algae. These are associated with poor water quality and high organic matter content. Molting is inhibited and growth is retarded.

The occurrence of pests and predators cannot be totally avoided during the culture period. Most common are tilapia, gobies, small crabs, tarpon (*Megalops cyprinoides*), ten-pounder (*Elops hawaiiensis*), seabass (*Lates calcarifer*), etc. The elimination of predators during the culture period is a difficult problem encountered in the industry. So far, minimizing the population of tilapia is being done by the use of cast net. In the case of gobies, collection by feeding trays or traps are resorted to. Both measures may help at best but do not completely solve the problem.

Some fishfarmers have tried using selective pesticides such as rotenone or saponin to eradicate unwanted species during the culture period. However, supply of these products is scarce. The possibility of developing techniques for selective elimination with locally available derris root is promising. A bioassay of powdered derris root (Tumanda, 1980) indicated its selective effect. At 5-10 ppm, the powdered material kills tilapia, tarpon, ten-pounder, milkfish and other finfishes while leaving *P. monodon* unaffected.

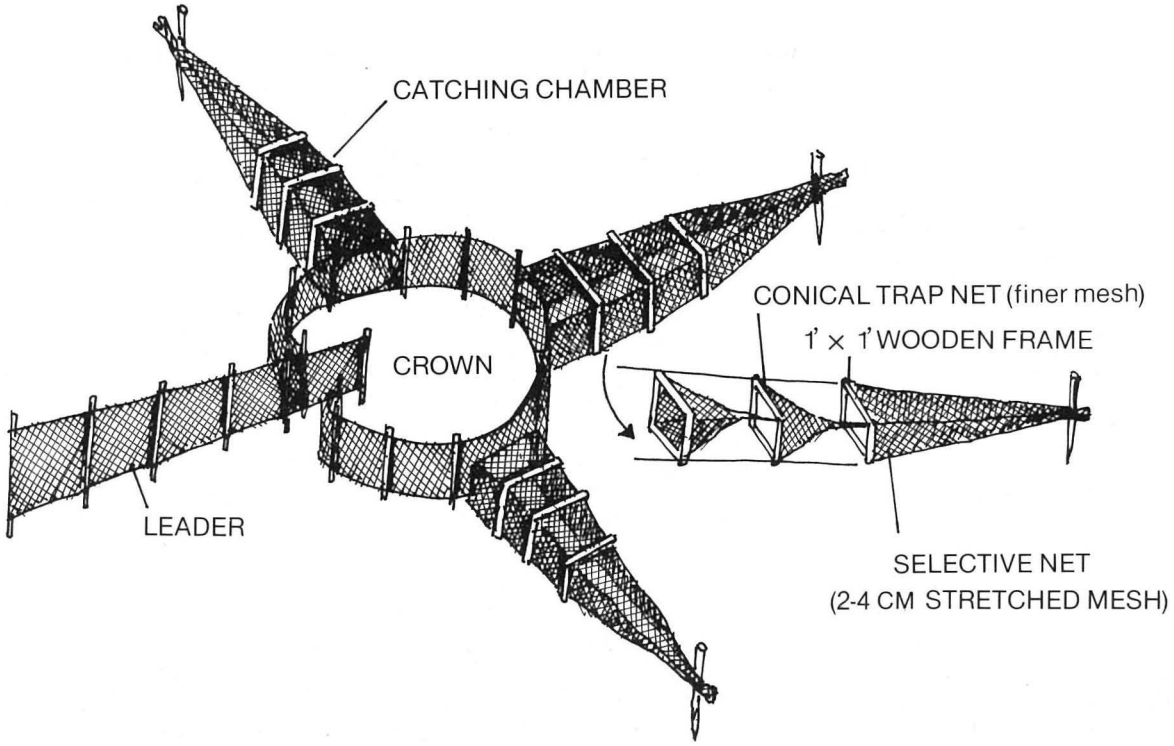

Fig. 5. Selective harvesting net collects only large prawns, undersized stock pass through the net (after Suemitsu, 1983 in Apud et al., 1983).

Harvesting and postharvest handling

In extensive and semi-intensive operations, most fish-farmers usually synchronize harvest with the spring tide during New Moon. It has been observed that prawns are more active during this time. Likewise, there is a greater percentage of hard-shelled shrimps two or three days after the peak of spring tide. If the timing is off, a greater percentage (20-50%) of harvest is soft-shelled. If soft-shelling is caused by normal molting, such can be avoided by inducing them to molt almost at the same time (V. Mancebo, pers. comm.). This is done by abruptly changing pond water four to five days before the scheduled harvest (during spring tide) preferably two days before peak of the highest tide. If the prawns are successfully induced to molt by brief exposure to stressful conditions such as sudden water change, only 5% may be soft-shelled, four to five days after such change.

Partial harvesting is undertaken when there is a wide range of sizes in ponds. Harvest gear popularly utilized for this purpose are bamboo traps (Fig. 4) and cast nets. The most effective gear recently introduced by the SEAFDEC Aquaculture Department is a pound net (Fig. 5) developed in Japan. This is a selective type of gear where smaller shrimps can easily pass through the net mesh used in this trap.

Farmers also attract prawns to traps by placing light over them in the evening. Cast net harvesting is made more effective by placing feed in certain areas where the net is cast. Partial harvest is convenient and can demand better prices for small batches of 20-100 kg per delivery to buyers. Partial harvesting is resorted to by some farmers in Bataan, Pampanga and Bulacan to meet the daily prawn and shrimp requirements of hotels and restaurants in Metro Manila. The advantage of this practice is that the total yield per hectare increases by about 20% (M. Suemitsu, pers. comm.) while the product gets consistently higher prices than when sold in the market at one time.

Total harvest is commonly done using a bagnet (Fig. 6) positioned so that it collects prawns that go with the current while draining the pond. As in partial harvesting, the prawns are initially stimulated to move by partial draining of the pond (30-70%) in the daytime a few hours before the incoming high tide after which the pond is flooded to maximum level during high tide.

In wide extensive ponds (10-20 ha), harvest by this method is oftentimes difficult especially when prawns are not so active. Considering the relatively large area, water manipulation is not effective in stimulating prawn movement. In many cases, the farmers resort to total draining or seining of trenches, and handpicking. While it takes much effort and time to pick up prawns from the pools and mud, prawns harvested this way easily deteriorate and therefore are not accorded the best price in the market. In semi-intensive ponds, the prawns can be easily stimulated to move. Thus harvest is more convenient, whether partial or total.

Another harvesting method that is practised by farmers in Bulacan and some other provinces is the use of a large suspension net (Fig. 7) installed at the drain portion of the gate. Its advantage over the bagnet is that prawns can be accumulated in the nets either by allowing them to swim against the current when flooding with tidal water or allowing them to go with the current when draining the pond. The large area

(50-60 m^2) of the net allows the fishfarmer to keep the harvested prawns or shrimps alive until a sufficient number is collected.

A recommended method of handling newly harvested prawns or shrimps is to transfer them from any harvesting gear into small bagnets in quantities not exceeding 10 kg. They are then washed thoroughly in the pond or in a tank after which the prawns inside the bags are immediately immersed in chilled freshwater (10°C) preferably while still alive. After 10 minutes or more in chilled water, the bags can be retrieved and the prawns are spread on the table or in baskets for classification.

Depending on the preference of the buyer, prawns, particularly *P. monodon*, are classified into different size groups, e.g., 6-18, 19-25, 26-40, and 41-45 pcs/kg. All prawns with sizes of at least 41 pcs/kg and those that are soft-shelled are bought at a much lower price or completely rejected. Another classification practised by buyers in Negros is 20 and below, 21-30, 31-40, and 41-50 pcs/kg. The last group plus the soft-shelled prawns are also rejected or bought at a much lower price. Prices fluctuate every now and then. White shrimp, e.g. *P. indicus* are usually classified into three categories, namely: large, 50-70 pcs/kg; medium, 80-100 pcs/kg; and small, 110 pcs and above/kg.

Problems and prospects

Problems

There are various problems confronting the industry today. A common problem is associated with marketing. Many fishfarmers complain about the classification and pricing pattern adopted by some exporters. It is alleged that there is a big disparity in pricing between first class prawns whose price is P120-150/kg, second class at only P90/kg and third class at P70/kg. The bulk of the processed products fall within the second and third classes.

Despite the proliferation of hatcheries, fry supply especially in Luzon is inadequate during some cropping periods. Lack of fry results in late and staggered stocking, thus adversely affecting production. Hatchery operators who own farms give priority to their own requirement before selling fry to others. Also, production in hatcheries is seasonal like wild fry supply so that prices also fluctuate according to demand.

Feed and feeding requirements have not yet been standardized. Many food sources and feeding practices have been tried but the results are as varied as the kind of feed and feeding scheme used. Likewise, the selling price of prawn has not kept up with the increase in imported and even local ingredients for processed feeds and cost of production.

There is a serious shortage of technical manpower in the industry. Big entrepreneurs usually employ the services of Taiwanese and Japanese technicians who are paid high rates. Local technicians who are as capable as foreign ones are employed by farmers who can hardly afford to offer better incentive. The major source of hatchery technology and technicians in the country is the SEAFDEC Aquaculture Department.

Another source of complaint are inconsistent yields caused by various technical problems. These include retarded growth and high mortality caused by any or a combination of several factors such as soft-shelling, diseases, nutritional deficiency, low pH, extremely high or low salinities, low dissolved oxygen, high H_2S and NH_3 levels, pollution, inadequate or inappropriate pond facilities (shallow ponds and defective screening), presence of pests and predators in large quantities, mishandling, lack of proper acclimation during stocking or transfer, and inefficient water management.

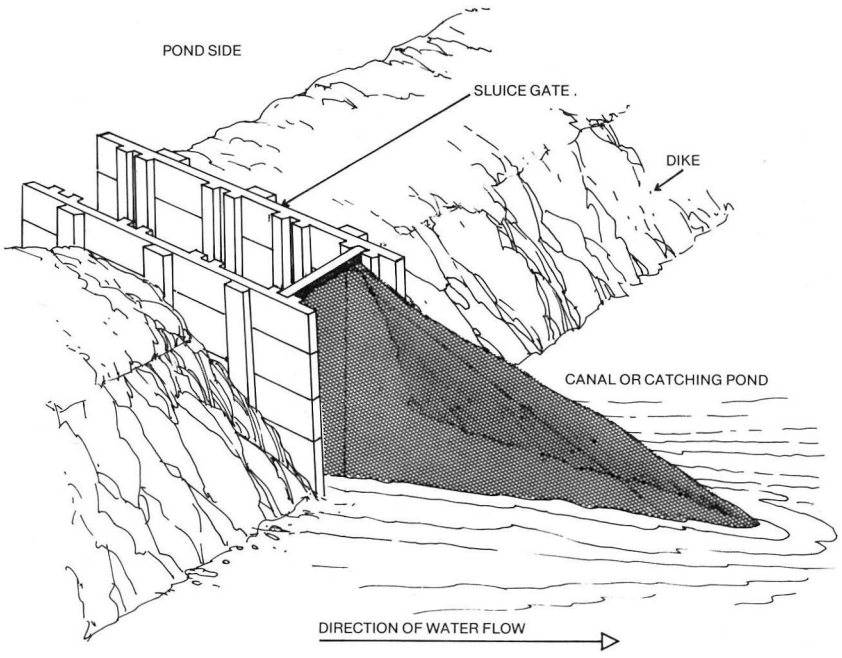

Fig. 6. Bagnet in operation.

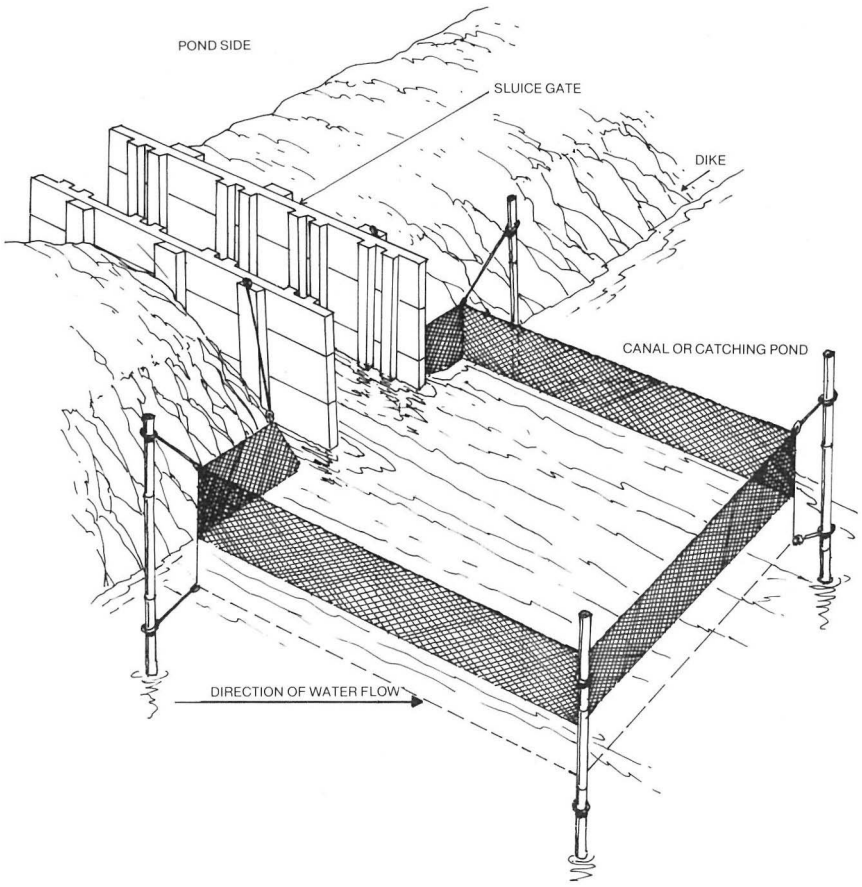

Fig. 7. Suspension net used for partial harvesting.

Prospects

There is a high market demand for frozen prawn and shrimp in the international market particularly in Japan, U.S.A. and Europe. It is evident that the potential for prawn and shrimp production in the Philippines is promising. The indigenous species, tiger prawns and white shrimps, have a bright prospect for intensified production. The Philippines has a warm climate, soil types and water quality all conducive to prawn and shrimp farming. A good portion of brackishwater ponds is also suitable for conversion into prawn and shrimp culture. The rapid progress and development of hatchery and nursery techniques will eventually solve the problem of inadequate fry supply, while the development of broodstock production and maturation techniques will solve inadequate spawner supply, a serious problem in hatcheries.

Conclusion and recommendations

Extensive farming is largely practised in many provinces of the country with consistent production in some areas. More expansion and improvements are expected within the next few years. Semi-intensive farming, on the other hand, is practised to a limited extent. Its further development will be dictated by the availability of fry at reasonable cost, supply of feed at lesser cost, availability of technical manpower, financial credit facilities, and cost of other inputs and improvements.

Market demand has not yet been saturated; however, there is a need to develop marketing strategies, methods of post-harvest handling, and transport of product to maintain high quality and command better price.

White shrimp farming has yet to be improved in order to achieve more profitable results. One aspect that should be studied is how to grow them bigger (15-25 g) in order to penetrate the international market. There is a high demand for white shrimps in the world market, and the market price is attractive. Local price for white shrimps is low, hence farmers are not as interested in its culture as compared with tiger prawn.

Although fry production has greatly increased due to the proliferation of hatcheries, fry supply is still inadequate to meet the increased demand resulting from expansion and improvements in pond culture. Thus, there is a need to produce fry all year round. Hatcheries should not be dependent on seasonal supply of spawners. Broodstock and maturation tanks should be maintained to meet spawner requirements.

The industry generally lacks supply of appropriate feeds, equipment, and other supplies. Both researchers and fish-farmers agree that food is one major limiting factor in the success of production. The kind of food and frequency of feeding, however, is not well established. To a large extent, feeding is looked upon by the industry as an added major input. The economics of feeding needs to be looked into and research on satisfactory local substitutes of imported ingredients should be continued.

There is a need to develop other support activities such as feed milling and storage, formulation and preparation of fertilizers, propagation of organic pesticides such as derris roots, and fabrication of blowers, paddlewheel, water pumps, different types of harvesting gear, and transport facilities.

The research, training and extension activities of various institutions involved in the development of prawn culture should be reviewed and restructured to suit the needs of industry.

The government should provide credit facilities at low interest rates and marketing incentive or protection so that producers will not be at the mercy of exporters. Strong fish-farmers' association or cooperatives are important in order to have collective bargaining power. Inputs can be acquired and marketing can be done through cooperatives for better profit.

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Intensive Culture and Feed Development in *Penaeus japonicus*

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Abstract The economic feasibility of shrimp culture with high productivity of over 10 ton/ha/crop is still under evaluation in some research institutes. However, there is one exception. In a limited area in Japan, there are 63 tanks that are actually in operation and are commercially productive. One of the trials to grow *Penaeus japonicus* is herewith introduced to represent the intensive culture of penaeid shrimp. Tank design, feeding, growth, survival, water management, cost analysis and disease are described. In addition, an illustration of successful semi-intensive culture in earthen ponds is shown to help explain how to intensify and stabilize production.

Introduction

It seems that there is no definition for the term "intensive culture." Previous papers use the word for convenience in contrast to the term "extensive culture." In 1976, Wickins classified shrimp culture into three categories, namely traditional, semi-intensive and intensive, depending on productivity, source of larvae and feed (Table 1). The economic feasibility of shrimp culture with a high productivity of over 10 ton/ha/crop categorized by Wickins is still under evaluation in many research institutes in some developed countries. An efficient closed system or flow-through system is still under consideration. In Japan, however, 63 round-shaped concrete tanks are actually in operation.

The two major projects of the Fisheries Research Station of Kagoshima since 1968 have aimed to develop an intensive culture system for *Penaeus japonicus* and to develop a special artificial diet for this system. The two projects resulted in experimental success two years before the oil crisis. Adopting this intensive system, three pilot farms were established, with the booming Japanese economy as background. The business sector was then eager to explore new fields, and tanks and related facilities could be constructed at a low cost. However, the ensuing oil crisis dramatically increased power costs three- to four-fold. Accordingly, these farms had difficulty in surviving during the days of serious stagflation.

Sometimes, this intensive system is called "Shigueno system" as a compliment, but it brings some mixed feelings. Before presenting this paper following Wickins' (1976) categorization, the writer wishes the reader to bear in mind that the system was planned and found successful for *P. japonicus* in Japan under an economic situation before the oil crisis. The writer would like to use this system as an example of the intensive culture of penaeid shrimp. A typical successful semi-intensive pond culture of shrimp in earthen ponds will also be described to show some effective measures for intensification of production.

Intensive culture in tanks

The above-mentioned system of culturing *P. japonicus* has been put into practice since a decade ago with the highest production far exceeding 10 ton/ha/crop. Table 2 shows a production record of Mitsui Shrimp Farm, Inc., one of four existing shrimp farms in the Kagoshima area that adopted this intensive culture system. In Kagoshima, there are 63 tanks of this kind totalling 6.3 ha. It is apparent that annual production well exceeds 20 ton/ha.

Table 1. Shrimp culture categorization (after Wickins, 1976).

Culture	Productivity	Postlarvae	Feed
Traditional	0-1 ton/ha/yr	Wild-caught, frequently with fish or a variety of prawn species.	Mainly on naturally produced food in the pond, enhanced by organic or inorganic fertilizers.
Semi-intensive	1-10 ton/ha/yr	Hatchery-reared postlarvae.	Controlled feeding with compounded feedstuffs, little reliance on natural production of food in the pond.
Intensive	10 ton/ha/yr	Hatchery-reared postlarvae.	Compounded diets.

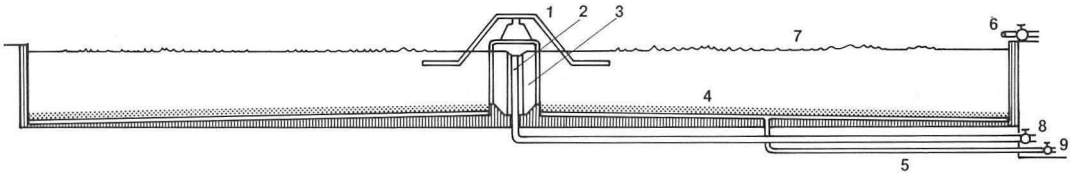

Fig. 1. Round tank (50 m diameter, 2.5 m deep) for intensive culture of *Penaeus japonicus,* side view. 1, water agitator; 2, outlet opening; 3, levelling pipe; 4, sand; 5, outlet pipe; 6, inlet pipe; 7, water level; 8, main outlet pipe; and 9, sand drain.

Figure 1 presents the side view of a round-shaped concrete tank built three years ago in the writer's laboratory. A false sand bottom 10 cm above the concrete bottom offers an aerobic bed for the shrimp. The agitator in the center creates a gentle circular movement of water which slowly carries unconsumed feed, cast shells, feces and detritus towards the center. Such undesirable material is swept away through the outlet opening at the center. Four inlet openings located on the peripheral wall jointly work to accelerate a circular movement of the tank water. The water mainly overflows through the outlet pipe standing at the center providing a flow-through system. The outlet valve (8 in Fig. 1) is fully open most of the time and the sand drain valve (9) slightly open to keep the sand bed aerobic and soft. This sytem is well capable of complete water change in 24 hours. As one of the leading shrimp food manufacturers, the company deemed it necessary to demonstrate the high quality of the feed it produces by culturing shrimp itself rather than through culture by other shrimp farmers.

On 29 May 1984, the tank accommodated about 200,000 postlarvae (P_{27}) weighing an average of 10 mg. The area of the tank is about 2,000 m^2. The population density at the beginning of this experiment was about 100/m^2. The shrimp were exclusively fed the compounded feed once every day after sunset. The amount of diet given every 10 days as well as the growth is presented in Fig. 2. The operator dives in the tank every morning to check for remaining food. This also gives a chance to observe the health and vigor of the shrimp and the condition of the sand bed. Care is taken to satisfy the shrimp but not to exceed its needs such that there is remain-

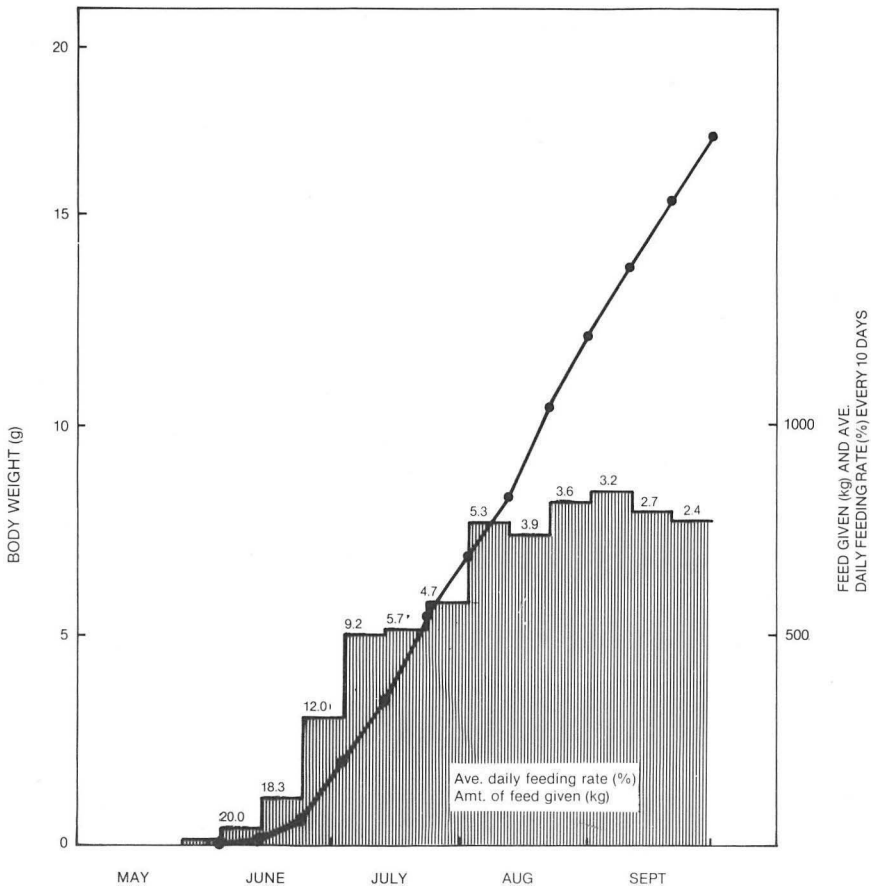

Fig. 2. Growth, amount of feed given and average % daily feeding rate (in figures) every 10 days in an intensive culture operation of *Penaeus japonicus* (1984).

ing food the next morning. The estimated population of the existing shrimp as of the middle of September revealed high survival of over 90%.

Seawater salinity is lowered with fresh water by about 2 to 5 ppt throughout the culture period. Physico-chemical parameters of the tank water monitored at 3 o'clock in the afternoon are depicted in Fig. 3. By the beginning of October 1984, the tank water was dark brown except when there were two typhoons and a week-long rainy days. The bad weather apparently made the water transparent and light in colour. Fig. 3 indicates the trend of increased transparency, total ammonia nitrogen, as well as reversed pH and dissolved oxygen in the water during these days. Through repeated experience, the writer believes that dark brown water is a sign of good environment for cultivating *P. japonicus* regardless of the size of shrimp and culture system. The brown colour is known to be affected mainly by varied species of propagated diatoms or micro-organisms which help to purify the water. Care is also taken not to allow algae to grow in the tank by scouring the bottom with chain links. This is done with a small boat such that the entire bottom is scoured at least once a week. The estimated high survival and rapid growth seem to indicate good results. Conversion ratio by this time is estimated to be about 2.1. The artificial diet should not only satisfy the nutritional requirements of the shrimp, but should also be well prepared so as not to pollute the environmental water.

Since 16 October 1984, partial harvest has been undertaken. The amount of marketed shrimp by the end of November was 1.1 tons. Total production is expected to be around 3 tons, which is equivalent to 15 ton/ha. Maximum feeding in one month in mid-summer amounted to 2,400 kg. This means a maximum feeding of 1.2 kg/m^2/month, about six times that of semi-intensive pond culture.

With regards to water quality, salinity was kept slightly lower than the sea water. Lower salinity is believed to be one of the favorable conditions for propagation of diatoms. The intake water is fairly influenced by the city effluent, thus vitamin B_{12}, iron, molybdenum, and some essential rare elements needed to grow diatoms are probably present in the water. Except for continued bad weather during the summer months, the bloom of diatoms kept the water dark brown and helped minimize total ammonia concentration. The calculated concentration of the toxic unionized ammonia has been kept below the safe level of 0.1 ppm (Wickins, 1976).

Through the culture period, the number of dead or moribund shrimp found gathered at the center every morning was 20 to 60. No *Vibrio* disease was observed. However, in November there was a slight increase in individuals with fungal infection among the dead shrimp observed. Fortunately, the infection did not affect the majority that were harvested. The harvest will be finished by the end of December without apparent disease.

A detailed cost analysis of the shrimp farms that have adopted such an intensive culture system is as follows: feed cost, 30%; staff wages, 17%; power cost, 12%; interest of

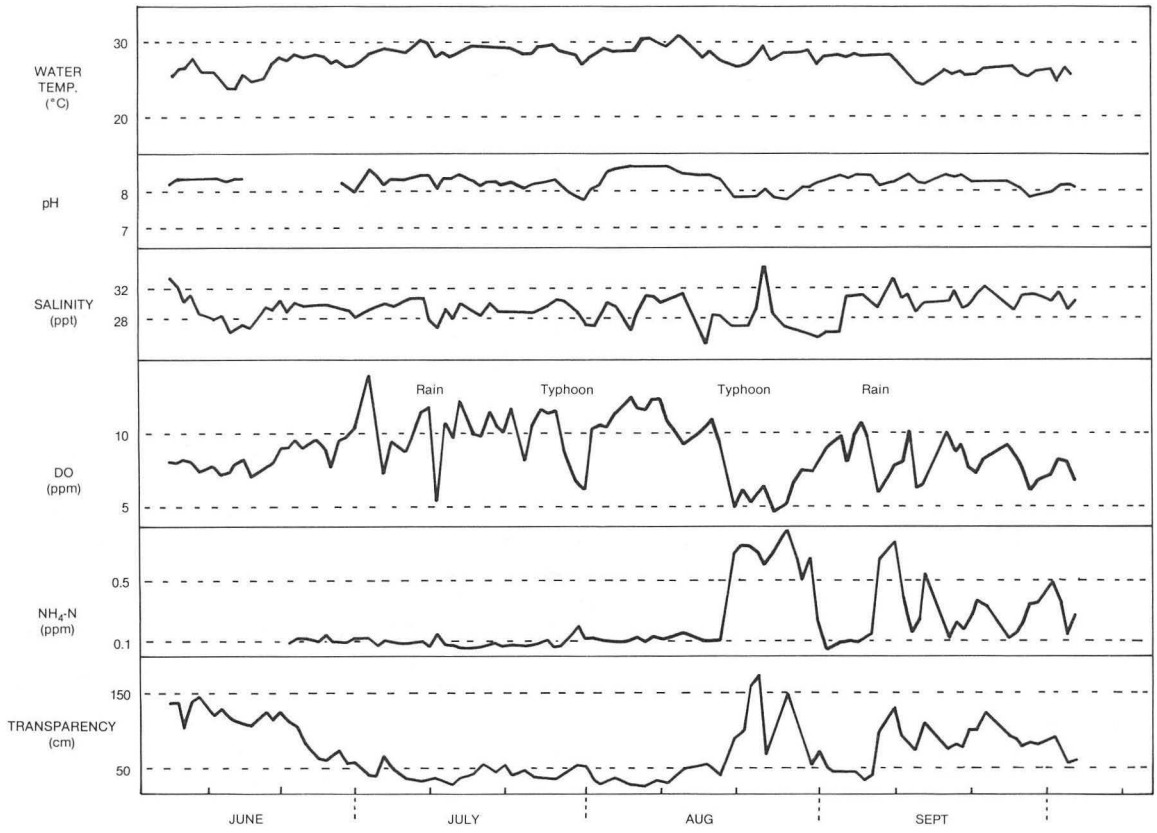

Fig. 3. Water quality (at 1500 hrs) in an intensive culture tank of *Penaeus japonicus* (1984).

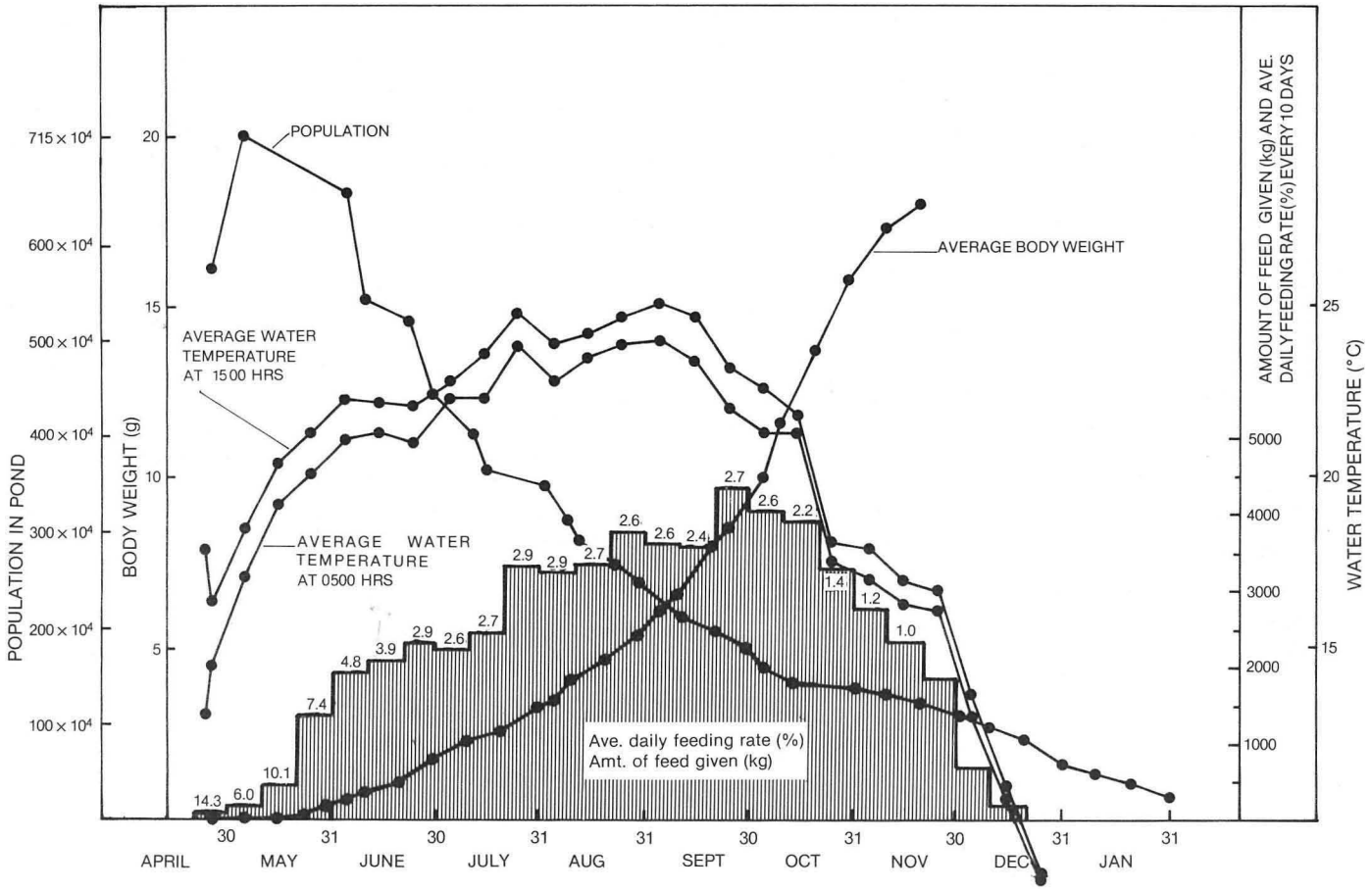

Fig. 4. Population, growth, water temperature, amount of food given, and average % daily feeding rate (in figures) every 10 days in a semi-intensive culture operation of *Penaeus japonicus* (1980). This operation was in a nursing and growing pond (pond 1, see text) of 5.09 ha with survival of 85.94%, gross production of 35,713.4 kg, net production of 35,584.7 kg and food conversion ratio of 1.61.

loan, 10%; market commission, 7%; depreciation fund, 7%; transportation fare, 6%; wasted materials, 3.6%; mending and insurance, 2%; labor wages, 1.3%; and miscellaneous expenditures, 4.1%. In recent years, one person can produce about 3 ton/year in this farm.

Semi-intensive culture in earthen ponds

Most cultured shrimp in the market are produced by the semi-intensive method. According to previous reports, the production of *P. monodon* in Taiwan, *P. japonicus* in Japan, *P. merguiensis* and some tropical species in some Asian countries, is largely by the semi-intensive method in earthen ponds. An example of commercial production of *P. japonicus* in Japan is shown in order to discuss ways of intensifying and stabilizing the productivity in this sytem. Results obtained in one of the successful shrimp farms in 1980 are illustrated in Figs. 4-7.

Table 2. Production record of *Penaeus japonicus* in Mitsui Shrimp Farm, Inc.

Year	Harvest (ton)	Area (ha)	Productivity (ton/ha/yr)	Food conversion rate
1979	41.4	1.50	27.6	2.7
1980	35.0	1.50	23.3	2.7
1981	34.6	1.65	20.9	2.8
1982	29.3	1.65	17.7	2.8

There are two patterns of growing shrimp in Japan. In the first pattern, the culture operation including marketing starts in April and is terminated by the end of the year. Shipping of shrimp is concentrated from September to December, hence cultured shrimp compete with wild shrimp for a good market price.

The second pattern is adopted by farms located in the southern part of Japan where the climate in winter is temperate enough for shrimp to grow. In this pattern, the culture operation starts in May and lasts until the next spring. Marketing is done in the cold season when shrimp fishing is not operational and the market is short of shrimp. It may be safe to say that the average market price for the latter is about 30% higher than for the former pattern.

One of the four ponds was first used to nurse the post-larvae to juveniles and then was continuously used as a growing pond (pond 1). The juveniles transferred from pond 1 into newly prepared growing ponds (2-4) were raised to adult size. The remainder of the juveniles in pond 1 were kept and grown to marketable size in the same pond. Figs. 4-7 present existing shrimp population, population density, total feed given every 10 days and growth curve of shrimp in each

pond. The postlarvae released from hatchery tanks into pond 1 were nursed to juveniles of around 0.6 g by the beginning of June and repeatedly transferred to growing ponds 2-4 by means of electric shockers. This was continued until October. A remarkable increase in growth of the transferred juveniles in the newly prepared growing ponds as compared with those that were retained in the nursery pond was noticed. The transfer operation ensures an accurate count of the number of existing shrimp. This is very important in determining the production schedule. Partial harvest for marketing usually starts in August. Partial harvest of small shrimp weighing 12-15 g was repeatedly done from one pond to another. It is well established that the repetition of the thinning procedure stimulates the growth of the remaining shrimp and ultimately maximizes total production. Partial harvest is followed by ordinary harvesting of adult shrimps usually by January of the next year. This shrimp farm ultimately recorded a total net production of 98 tons from 17 ha of ponds. This is equivalent to 5.79 ton/ha/year. The food conversion rate throughout the culture period for pond 1 was 1.61, whereas it varied from 2.02 to 2.64 in the three growing ponds. This is a result obtained in one of the typical successful shrimp farms in 1980.

Through the years, some technical knowledge has accumulated in order to maximize production of shrimp by the semi-intensive method. Most of these are also commonly considered in the intensive culture system.

1) Deepening of the pond. Deep ponds offer a more stable environment and therefore hold more shrimp. A depth of more than 2 m is recommended for *P. japonicus*.

2) Water agitation. To augment the productivity of the pond, agitators should be provided to destroy stratification of pond water. A 1.5 kw paddlewheel agitator for every 3,000 m^2 is recommended. The structure and use of agitator should allow efficient mixing of available oxygen in the water. An informative report is given by Busch and Goodman (1981).

3) Prevention of algal growth in the pond. Frequent and periodical scouring of the bottom area with a chain prevents algae from growing. For this purpose, some culturists use a specially devised tool which is pulled by a boat with ease.

4) Confirmation of number of juveniles after the nursery stage. Juveniles grown in the nursery ponds should be transferred to well prepared grow-out ponds. Number of juveniles should be confirmed during the transfer operation. This stepwise use of ponds will not only offer a well prepared

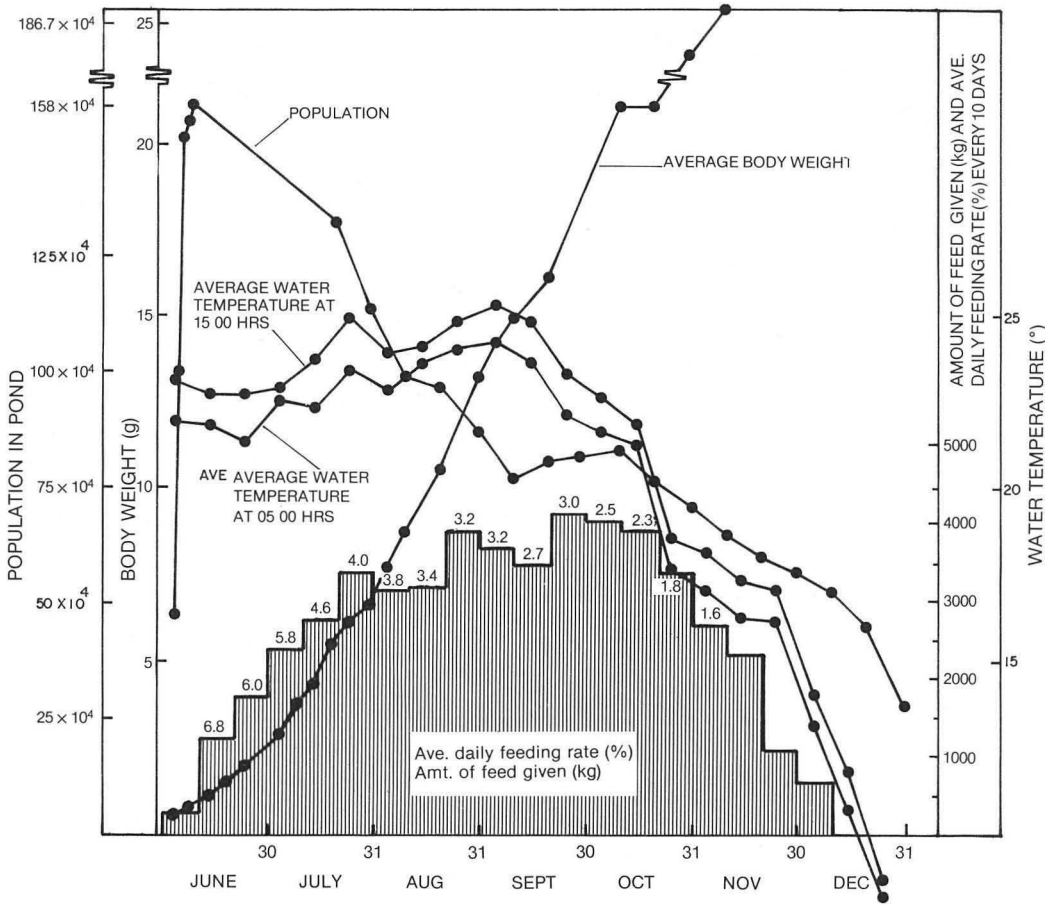

Fig. 5. Population, growth, water temperature, amount of food given, and average % daily feeding rate (in figures) every 10 days in a semi-intensive culture operation of *Penaeus japonicus* (1980). This operation was in a growing pond (pond 2) of 4.10 ha, survival of 88.56%, gross production of 28,425.8 kg, net production of 25,023.8 kg, and food conversion ratio of 2.08.

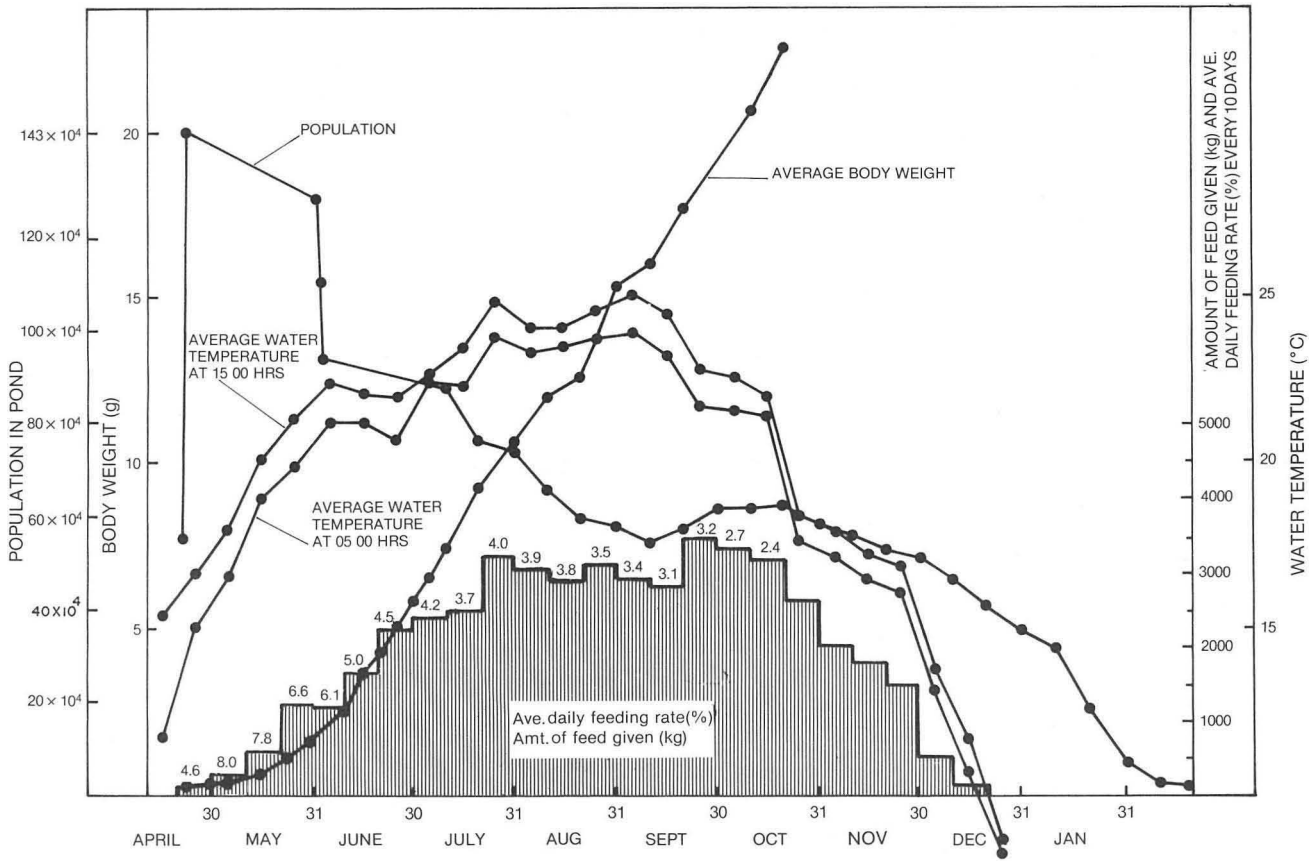

Fig. 6. Population, growth, water temperature, amount of food given, and average % daily feeding rate (in figures) every 10 days in a semi-intensive culture operation of *Penaeus japonicus* (1980). This operation was in a growing pond (pond 3) of 4.15 ha with survival of 90.24%, gross production of 29,405.9 kg, net production of 24,304.0 kg and food conversion ratio of 2.02.

and clean environment to the shrimp but also prevent predation by fish.

5) Partial harvest. Repeated partial harvest midway through the culture period eventually contributes to maximizing total production.

6) Low salinity. Past experience shows that a slightly lower salinity than sea water is suitable for growing shrimp. This is supported by the fact that wild shrimp migrate from the estuaries where salinity is a little low to offshore areas of higher salinity as they grow older. This is also confirmed by the study of osmoregulatory changes in the hemolymph of growing shrimp.

7) Brown water. Keeping the pond water brown reflects blooming of mixed diatoms as a key to penaeid shrimp culture in ponds. According to a recent report by Manabe et al. (1979), *Skeletonema costatum* grows better in diluted sea water containing sodium silicate, vitamin B_{12}, iron, and molybdenum. High temperature (30°C), low salinity (15 ppt) and moderate brightness (50,000 lux) jointly offer the best growing conditions for the diatoms.

Table 3. Results of analyses of some ingredients used in formulated diets for *Penaeus japonicus*.

Ingredient	Moisture (%)	Crude protein (%)	Total lipid (%)	Non-polar lipid (dry matter) (%)	Polar lipid (%)	EPA + DHA (in fatty acids) (%)
Squid meal	13.8	66.4	10.3	2.9	7.4	4.2
Cuttlefish meal	12.6	72.4	10.8	5.5	5.3	29.3
White fish meal	8.4	68.5	7.9	4.5	3.4	1.3
Shrimp head meal	11.6	30.7	5.2	2.2	3.0	19.4
Euphausia meal	8.6	45.8	4.6	1.4	3.2	27.4
Candida yeast	7.5	59.0	2.3	0.5	1.8	—
Soybean flour	6.4	34.9	22.8	20.3	2.5	0.1
Salmon testis meal	7.6	90.7	7.6	6.1	1.5	10.4
Pollack testis meal	4.2	—	16.6	5.1	11.5	36.8
Skipjack testis meal	11.3	87.2	—	—	—	—
Scallop viscera meal	11.8	52.3	39.9	15.8	24.1	9.9

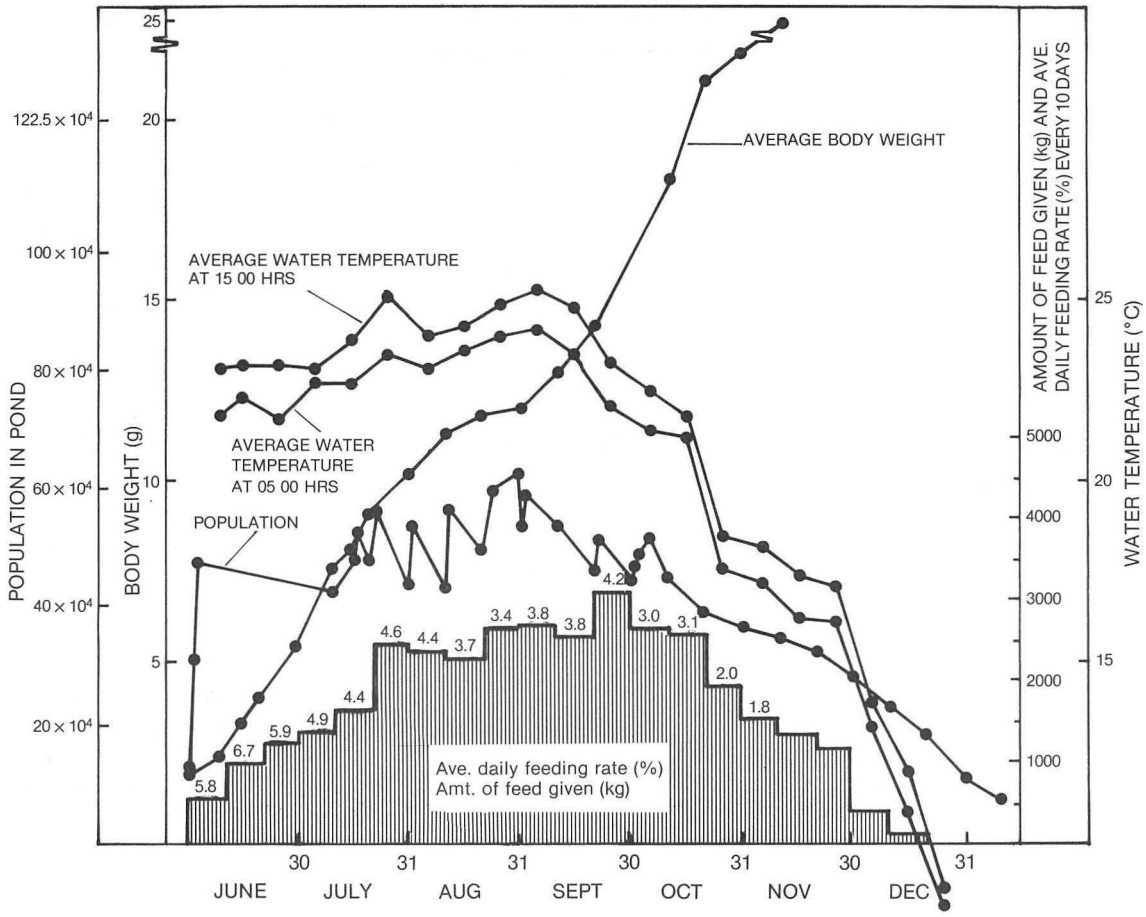

Fig. 7. Population, growth, water temperature, amount of food given and average % daily feeding rate (in figures) every 10 days in a semi-intensive culture operation of *Penaeus japonicus* (1980). This operation was in a growing pond (pond 4) of 3.68 ha, survival of 81.8%, gross production of 18,808.5 kg, net production of 13,493.5 kg and food conversion ratio of 2.64.

8) Use of electric shocker and crab trap in harvesting of shrimp. Electric shocker is ideal for use in the transfer operation of juveniles from nursery ponds to growing ponds. Recently, a kind of crab trap was found ideal for the selective harvesting of bigger and vigorous individuals.

9) Proper nutrition. There are many shrimp farms in the Kagoshima and Okinawa areas where compounded feeds are the only feed used. Proper use of reliable diets is gradually disseminated among the culturists. However, there are still many who use frozen trash fish, *Euphausia*, and *Mysis* whenever available and cheap. Repeated use of such materials is feared to cause thiamine and ascorbic acid deficiency especially during the hot season.

Feed development

In 1968, a study team was organized in the Kagoshima Fisheries Research Station to develop an artificial diet for *P. japonicus*. However, the members were stymied because there was no fundamental knowledge about the nutritional requirements of the shrimp. Since past experience confirms that the freshly preserved meat of squid is an excellent feed and is comparable to clam meat, the study was first directed towards the utilization of this food source. The swimming arms and fin of the common squid (*Ommastrephes sloani pacificus*) discarded in processing are made into a meal by boiling, drying and pulverizing. To improve protein quality,

Table 4. Results of analyses of four commercial feeds for *Penaeus japonicus*.

Compounded feed	Moisture (%)	Crude protein (%)	Total lipid (%)	Non-polar lipid (dry matter) (%)	Polar lipid (%)	EPA + DHA (in fatty acids) (%)
A	11.4	55.3	9.5	4.8	4.7	11.8
B	12.0	54.9	8.9	5.6	3.3	8.6
C	13.7	53.2	13.1	7.6	5.5	16.3
D	5.9	54.7	9.5	5.3	4.2	10.5

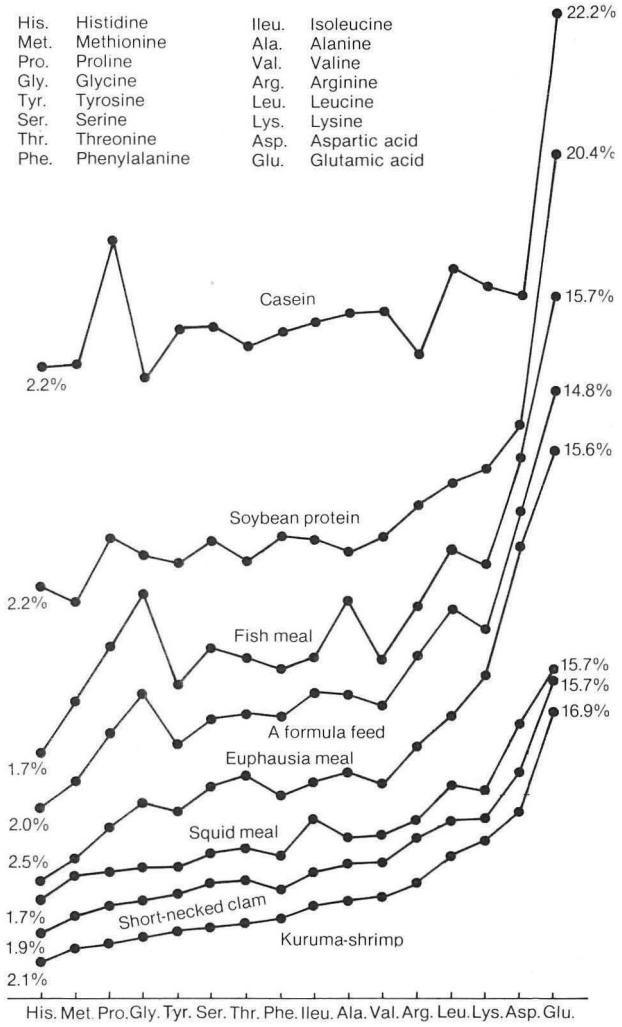

Fig. 8. Amino acid composition in eight kinds of materials and feeds relative to 16 amino acids.

the following ingredients are added to the squid meal: shrimp head meal, *Euphausia* meal, *Candida* yeast, fish meal, activated sludge, wheat gluten, soy bean flour, skipjack testis meal, salmon testis meal, scallop viscera meal, cuttlefish meal, etc. in proper proportions. The compounded feed mentioned above is enriched with vitamins, minerals, refined pollack liver oil, carotenoid pigments, antioxidants, etc. in proper concentration. The compounded material is moistened with 30% water and then expressed through a 2 mm die and cut into pellets of proper length. This is dried to less than 10% moisture. The product, 20 kg each, is packed together with a deoxidizing agent in a kraft paper bag lined with a laminated plastic film to prevent leakage of oxygen and to retard oxidation.

Reports of nutritional requirements of crustaceans are reviewed by New (1976) and Sandifer (1982). Close to 1,000 formulated diets containing different combinations of the components were tested on the shrimp for their effect on quality, growth and food value. Each nutrient and feed thus prepared was analyzed qualitatively for crude protein, polar and non-polar lipids, and fatty acids. Tables 3 and 4 present the results of the analyses of some ingredients and recent products by different manufacturers. In the search for new protein sources, local materials rich either in proteins containing basic amino acids or in polar lipids were examined.

Some important findings obtained in the repeated experiments of the test diets can be summarized as follows:

1) The increased intake of the diet with a high content of palatable items does not necessarily produce faster growth; rather, the proper amount of daily rations correlates most effectively with growth. The quantity of food eaten increased when food was lacking in some nutritive elements, while less food was eaten when the same nutrients were present in the diets in proper amounts, thus bringing about faster growth.

2) Young animals show higher efficiency than older animals for the same food. This suggests that total efficiency of the food being tested decreases as the rearing period is prolonged.

3) Amino acid analyses of many test feeds which were graded into four classes of feed efficiencies (below 60%, 60-80%, 80-90%, over 90%) indicate that feeds with efficiencies below 60% contain more acidic amino acids, whereas feeds with efficiencies over 60% show higher content of basic amino acids like lysine, histidine and arginine. The amino acid composition of feeds with higher efficiency approximates that of the shrimp. Furthermore, the short-necked clam, the most common feed given to shrimp, as well as squid meal, has an amino acid pattern similar to that of the shrimp as illustrated in Fig. 8.

4) The requirements of the shrimp for four essential fatty acids and phospholipids in the diet as recommended by A. Kanazawa and O. Deshimaru were taken into consideration in the formulation and compounding of the diets. This certainly contributed to the improvement of the food value of the diet.

Annual production of compounded shrimp food in Japan today totals about 2,200 tons, which is below the level of the Taiwan production of more than 10,000 tons for *P. monodon*. Due to the short period of development and various food values in the products made by different feed manufacturers, majority of shrimp farmers in Japan are not yet fully aware of the importance of using artificial diets. In the past 13 years, about 50% of the raw or frozen natural materials used as food has been gradually replaced with compounded feed. Among culturists, it is believed that the shift from natural foods to entirely compounded feeds will be realized in the next few years and only one or two manufacturers will survive the competition.

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Nutrition of Penaeid Prawns and Shrimps

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Abstract Since Hudinaga succeeded in the artificial hatching and subsequent culture of larvae of the prawn, *Penaeus japonicus,* techniques for rearing this prawn from hatching to commercial sizes have been improved in Japan and applied to other penaeid species in Asian and other countries. The nutritional requirements of *P. japonicus* juveniles started to be investigated about 15 years ago. As a result, this prawn is found to require proteins, lipids, carbohydrates, minerals, and vitamins for normal growth, indicating the deficiency disease, poor growth, and high mortality when reared with diets lacking some nutrients. On the basis of this knowledge, compounded artificial diets are used practically for commercial production of *P. japonicus* as substitutes for traditional live food such as the short-necked clam and mussel.

However, seed production of penaeids has depended on live food such as diatoms, *Chlorella* and *Artemia.* Mass culture of planktonic organisms not only requires much manual help and expensive equipment but also fluctuates with climatic conditions. Also, the nutritive value of planktonic organisms is occasionally variable and this makes the use of live food for mass culture restrictive. Therefore, the development of artificial diets for larval penaeids is one of the most important research areas in the field of penaeid culture. We have prepared microparticulate diets for larval penaeids for use both as substitutes for live food and for nutritional studies. In this presentation, I intend to deal with the overview of penaeid nutrition.

Introduction

Techniques for the artificial culture of crustaceans such as the prawn, *Penaeus japonicus*, the shrimp, *Macrobrachium rosenbergii*, and lobster, *Homarus americanus*, from hatching to commercial size have been established. However, some problems related to artificial diets and disease still remain. The nutritional requirements of *P. japonicus* have been manifested by the introduction of refined test diets by Kanazawa et al. (1970) and Deshimaru and Kuroki (1974a), and the prawn has been shown to necessitate adequate levels of proteins, lipids, carbohydrates, minerals and vitamins as do other aquatic animals. However, nutritional studies on other prawns and shrimps are few or fragmentary (Forster, 1976; New, 1976, 1980; Wickins, 1976; Hanson et al., 1977a, b; Ceccaldi, 1978; Kanazawa, 1980, 1982; Castell, 1982; Teshima, 1984).

This paper presents an overview of the nutritional requirements of penaeid prawns and shrimps.

Protein and amino acid requirements

Proteins are indispensable nutrients for growth and maintenance of life of all animals. Deshimaru and Yone (1978c) have pointed out that the prawn, *P. japonicus,* requires 52-57% protein for optimum growth and food efficiency. Kanazawa et al. (1981) have demonstrated that the shrimp, *Metapenaeus monoceros*, gave best growth with a diet containing 55% casein. Several groups of workers have reported the optimum protein levels in diets for *Penaeus indicus* (43%*:* Colvin, 1976), *Penaeus monodon* (46%: Lee, 1971; 40%: Aquacop, 1977; 40%: Khannapa, 1977; 35%: Bages and Sloane, 1981), *Penaeus aztecus* (23-31%: Shewbart et al., 1973; 40%: Venkataramiah et al., 1975), *Penaeus setiferus* (28-32%: Andrews et al., 1972), *Penaeus californiensis* (31%: Colvin and Brand, 1977), *Penaeus vannamei* (30%: Colvin and Brand, 1977), *Penaeus stylirostris* (35%: Colvin and Brand, 1977), and *Penaeus merguiensis* (50%: Aquacop, 1978; 34-42%: Sedgwick, 1979). Thus, the optimum protein levels in diets for prawns and shrimps are different among species. I assume that the diversity of optimum protein levels for crustaceans is likely to come from a variety of factors, namely, the discrepancy in food habits, ages of specimens, and protein sources used. In fact, Sick and Andrews (1973) have shown that soybean proteins are good protein sources for *Penaeus duorarum.* The content of essential amino acids (EAA) and balance of amino acids could be related to the nutritive value of proteins used (Kitabayashi et al., 1971b; Deshimaru and Shigueno, 1972; Deshimaru, 1982; Hew and Cuzon, 1982).

Kanazawa and Teshima (1981) have clarified by tracer techniques using radioactive acetate that *P. japonicus* requires 10 amino acids, i.e., arginine, methionine, valine, threonine, isoleucine, leucine, lysine, histidine, phenylalanine, and tryptophan, all of which are also EAA for various fish. The essential amino acids have also been demonstrated for other penaeids such as *P. monodon* (Coloso and Cruz, 1980) and *P. aztecus* (Shewbart et al., 1972). On the other hand, Deshimaru and Kuroki (1974c, 1975a, b) and Deshimaru (1982) showed that diets containing only amino acids instead of protein brought about a very poor growth and high mortality in feeding trials of *P. japonicus.*

Recently, the effects of dietary protein, lipid, and carbohydrate levels on the growth and survival of larvae of *P. japonicus* were examined by feeding trials using purified diet with carrageenan as a binder (Teshima and Kanazawa, 1984). As a result, the effects of protein levels on growth and sur-

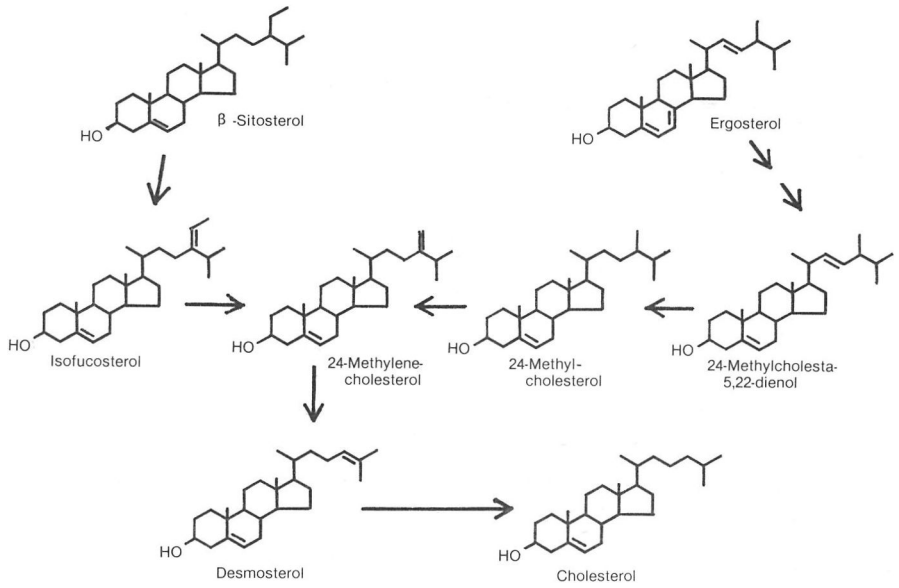

Fig. 1. Propose d mechanism for C-24 alkylation of C_{28} and C_{29} sterol s in crustaceans. C_{27} sterols : cholestero l an d desmosterol ; C_{28} sterols : ergosterol , 24-methylcholesta-5 , 22-dienol, 24-methylcholesterol , an d 24-methylenecholesterol ; C_{29} sterols : ß-sitostero l and isofucosterol.

vival of *P. japonicus* larva e varied with dietary carbohydrate levels but not with dietary lipid levels. The optimum protein levels fo r praw n larva e wer e estimate d t o b e aroun d 45% , 45-55%, an d 55 % o r mor e whe n th e diet s containe d 25% , 15%, an d 5 % level s of carbohydrate, respectively.

Cholesterol and other sterol requirements

Crustaceans requir e essentia l fatt y acid s (EFA) a s als o found fo r man y fis h species. However, th e uniqu e aspect of lipid nutritio n i n crustacean s i s tha t the y requir e dietar y sources of sterol fo r norma l growt h an d survival becaus e of the absenc e o f *de novo* sterol-synthesizin g abilit y fro m acetate an d mevalonat e (Teshim a an d Kanazawa , 1971 ; Teshima, 1982) . Feedin g experiments usin g artificia l diet s have shown that *P. japonicus* requires sterols for growth and survival, indicating an optimum level of 0.5% in diets (Kanazawa e t al. , 1971a ; Shud o e t al. , 1971) . Kanazaw a e t al . (1971b) hav e als o demonstrate d tha t *P. japonicus* coul d utilize t o som e exten t ergosterol , ß-sitosterol , an d stigmas - terol as a substitute for cholesterol. We presume that sterols other than cholesterol are utilized by *P. japonicus* after being converted to cholesterol in their bodies as proposed by Teshima and Kanazawa (1973) and Kanazaw a et al. (1976a) .

Table 1. Growth and survival of *Penaeus japonicus* larvae on purified diets with 0.5% level of each sterol.

Dietary sterol	Feeding period (day)	Survival rate (%)	Number of larvae			
			M_1	M_2	M_3	P_1
Sterol-free	9	30		29	1	
Cholesterol	9	74				74
7-cholestenol	9	37			30	7
22-dehydrocholesterol	9	60		19	41	
24-methylenecholesterol	9		19		41	
Ergosterol	9	68			6	56
24-methylcholesta-5,22-dienol	9	53			37	16
ß-sitosterol	9	55		27	28	
Stigmasterol	9	11		3	8	
Fucosterol	9	2	2			
Isofucosterol	9	61			37	24
Lanosterol	9	2	2			

Recently, we succeeded in rearing larval *P. japonicus* using refined diets (Jones et al., 1979a; Kanazawa et al., 1982; Teshima et al., 1982a) with best growth and survival using a diet containing 1.0% cholesterol (Teshima et al., 1982b). Furthermore, we demonstrated that the dietary value of sterols other than cholesterol is inferior to cholesterol, but 24-methylenecholesterol, 24-methylcholesta-5, 22-dienol, and isofucosterol had a high dietary value (Teshima et al., 1983) (Table 1). Based on the dietary value of various sterols examined, we suspect that the dealkylation of C_{28}- and C_{29}-sterols to cholesterol (C_{27}-sterol) proceeds via the following pathways: ß-sitosterol → isofucosterol → 24-methylecholesterol; ergosterol → 24-methylcholesta-5, 22-dienol → 24 methylcholest-5-enol → 24-methylenecholesterol; 24-methylenecholesterol → desmosterol → cholesterol (Fig. 1).

Essential fatty acid requirements

We have also shown the absence of *de novo* synthesis of linoleic (18:2ω6), linolenic (18:3ω3), icosapentaenoic (20:5ω3), and docosahexaenoic (22:6ω3) acids from acetate-^{14}C or palmitic acid-^{14}C in *P. japonicus* (Kanazawa and Teshima, 1977; Kanazawa et al., 1979b), in *P. monodon* (Kanazawa et al., 1979c), and in *P. merguiensis* (Kanazawa et al., 1979c) (Table 2). These data suggest that crustaceans

may require some of these fatty acids as essential nutrients. In fact, Kanazawa et al. (1977b, 1978, 1979d, 1979f) have shown by feeding experiments that juveniles of *P. japonicus* gave a higher weight gain with diets containing 18:2ω6, 18:3ω3, 20:5ω3, or 22:6ω3 than 18:1ω9, indicating the necessity of ω3-fatty acids, especially ω3-highly unsaturated fatty acids (HUFA). The optimum levels of 20:5ω3 and 22:6ω3 for *P. japonicus* juveniles were found to be about 1.0% in diets (Kanazawa et al., 1979a) (Fig. 2). Shewbart and Mies (1973) also revealed that growth of *P. aztecus* was improved by the addition of 18:3ω3 to the refined diet, and that optimum growth was attained with diets containing 1% 18:3ω3. Fenucci et al. (1981) found a quadratic correlation between the rate of growth and the percentage of 18:3ω3 in the diet of juvenile *P. stylirostris*. Jones et al. (1979b) and Teshima and Kanazawa (1984) pointed out the necessity of ω3-HUFA for growth and survival of the larval stages of *P. japonicus*.

Nutritive value of various lipids

Studies on EFA requirements for crustaceans have suggested that the nutritive value of lipids for prawns and shrimps is probably related to the types and content of EFA. High nutritive values of lipids rich in ω3-HUFA, such as pollack liver oil and shrimp head oil, have been demonstrated for *P. duorarum* (Sick and Andrews, 1973). Kanazawa et al. (1977a) have pointed out that superior dietary value was obtained with marine lipids containing ω3-HUFA such as pollack liver oil and short-necked clam oil, indicating that the inferior dietary value of soybean oil containing 18:3ω3 is possibly due to the shortage of ω3-HUFA such as 20:5ω3 and 22:6ω3. Guary et al. (1976a) also showed a high nutritive value of sardine oil and short-necked clam oil for *P. japonicus*. Aquacop (1978) reported that cod liver oil sustained growth and survival of *P. merguiensis* as the best source of lipid.

On the other hand, Deshimaru et al. (1979) have shown that a good lipid source for *P. japonicus* diets was a mixture of soybean oil-pollack liver oil (6% in diets; 1:3 or 1:1, w/w). Also, Colvin (1976b) has reported that a mixture of wheat germ oil and peanut oil was best for *P. indicus* among the vegetable oils examined.

As stated above, the types and content of EFA dominate the nutritive value of dietary lipids. However, other lipid components such as phospholipids (see section 5) and sterols should be considered in evaluating the dietary value of lipids for prawns and shrimps.

Effects of dietary phospholipids on growth and survival

Since short-necked clam oil had better growth-promoting effect for *P. japonicus* than pollack liver oil, we intended to clarify the compounds responsible for such an effect. Several lipid fractions were isolated from short-necked clam oil, and the growth-promoting effect was examined by adding 1% of each lipid fraction to a diet containing 7% pollack liver oil as lipid source. As a result, lecithin fraction had the highest effect, followed by the cephalin fraction (Kanazawa et al., 1979e).

Table 2. Proportional radioactivity in individual fatty acids constituting polar lipids isolated from *Penaeus monodon* and *Penaeus merguiensis* 24 hr after injection of acetate-1-^{14}C.

Fatty acid	% Distribution of radioactivity*	
	P. monodon	*P. merguiensis*
14:0	0.2	2.4
15:0	0.8	0.1
16:0	13.6	50.0
17:0	1.4	1.2
18:0	11.2	18.5
20:0	0.3	2.0
16:1	9.1	6.1
17:1	1.8	0.1
18:1ω9	37.3	10.2
20:1ω9	9.7	2.6
18:2ω6	0.1	0.3
20:2ω6	1.2	5.9
20:3ω6	1.1	0
20:4ω6 } 20:3ω3 }	7.8	0.1
22:5ω6	0.4	0
18:3ω3	0	0
20:4ω3	0.2	0
20:5ω3	0.5	0.1
22:5ω3	0.7	0.1
22:6ω3	1.1	0.2

*Fatty acids from polar lipid fractions were subjected to argentation TLC as methylesters, and then the methylesters of saturated, monoene, diene, triene, tetraene, pentaene, and hexaene fatty acids were subjected to preparative GLC on 10% DEGS followed by radioactive measurements of trapped samples.

Recently, Teshima et al. (1982b), by using microparticulate diets containing carrageenan as a binder, noticed that the inclusion of phospholipids in diets is indispensable to growth and survival of larval *P. japonicus*. When maintained on diets without supplemental lecithin, the larvae suffered 100% mortality before reaching the mysis stage. Hence, Kanazawa (1982, 1983) further examined the effects of various phospholipids on growth and survival of larval *P. japonicus*. Growth and survival of the prawn larvae were found to be improved by the addition of 1% soybean lecithin, bonito egg lecithin, and soybean phosphatidel inositol, whereas no beneficial effect on growth and survival was demonstrated with 1% dipalmitoylphosphatidylcholine, phosphatidylethanolamine (from bovine brain and bonito egg), phosphatidylserine (from bovine brain), sphingomyelin (from bovine brain), cytidine-5'-diphosphate choline, or taurocholic acid. These results suggest that the requisite for effective phospholipids is to possess choline or the inositol group besides unsaturated fatty acids as fatty acid moieties.

Little is known why dietary sources of phospholipids are effective in enhancing or sustaining growth and survival of larval and juvenile *P. japonicus*. I assume that dietary phospholipids may be required due to a specific requirement for some phospholipids for both the smooth transport of dietary lipids, particularly cholesterol, in the hemolymph and a slow rate of phospholipid biosynthesis.

Nutritive value of carbohydrates

The addition of large amounts (more than 10%) of glucose to diets generally reduces growth of prawns such as *P. aztecus* (Andrews et al., 1972), *P. duorarum* (Sick and Andrews, 1973), and *P. japonicus* (Deshimaru and Yone, 1978b; Abdel-Rahman et al., 1979). Abdel-Rahman et al. (1979) have shown that *P. japonicus* juveniles had a better weight gain on diets containing disaccharides such as sucrose, maltose and trehalose, and polysaccharides such as dextrin and starch, than on diets containing monosaccharides such as glucose, galactose and fructose. They thought that the reason why dietary di- and polysaccharides had a higher nutritive value than monosaccharides for *P. japonicus* is that dietary glucose is quickly absorbed from the stomach and released all at once into the hemolymph. Therefore, when large amounts of glucose were added to diets, blood glucose levels were elevated to abnormally high levels. Disaccharides and polysaccharides are not absorbed from the stomach, but are digested to glucose and trehalose in the midgut and hepatopancreas which are then released gradually into the hemolymph. Dietary disaccharides such as maltose are thus effectively utilized as an energy source. Aquacop (1978) suggested that a carbohydrate such as starch appears more suitable than glucose. Pascual et al. (1983) have also demonstrated that the addition of sucrose or dextrin as a carbohydrate source for *P. monodon* juveniles was better than other carbohydrates as shown in Table 3.

Table 3. Mean survival rate and weight gain of *Penaeus monodon* juveniles fed various carbohydrate-containing diets after 6 weeks of rearing. Numbers in parentheses represent initial stock.

Carbohydrate	% Survival		Ave. % weight gain	
Level (%)	10	40	10	40
Dextrin	(23) 36	(23) 23	24	34
Maltose	(23) 35	(23) 0	5	—
Sucrose	(23) 56	(22) 38	7	28
Molasses	(22) 0	(21) 0	—	—
Sago palm starch	(22) 42	(22) 0	7	—
Cornstarch	(23) 27	(22) 0	7	—
Cassava starch	(23) 0	(21) 0	—	—

There are conflicting results on the effect of supplemental glucosamine on growth and survival of *P. japonicus*. Kitabayashi et al. (1971a) have demonstrated that addition of 0.52% glucosamine to diets improved growth but that of chitin inhibited growth. On the other hand, Deshimaru and Kuroki (1974b) have pointed out that a dietary source of glucosamine is unnecessary for *P. japonicus* juveniles and it inhibits the growth-promoting effect of cholesterol. Thus, the role of dietary glucosamine is still not clear.

Mineral requirements

Prawns and shrimps may absorb some minerals from the water to some extent, but they may necessitate a dietary source of some minerals for growth because of repeated loss of certain minerals during molting. Deshimaru et al. (1978) and Deshimaru and Yone (1978a) have shown that *P. japonicus* take up calcium from sea water and does not require calcium, magnesium and iron. Kanazawa et al. (1984) have revealed that addition of calcium to diets could be necessary to maintain the ratio of calcium-phosphorus (1:1) in diets, although growth of *P. japonicus* on diets with and without calcium supplement is comparable. Kitabayashi et al. (1971a) have also pointed out the importance of the Ca/P ratio, indicating an optimum ratio of 1: 1 for *P. japonicus*. Huner and Colvin (1977) have shown Ca/P ratios of 2.2: 1 to be optimum for growth of juvenile shrimp, *P. californiensis*. Shewbart et al. (1973) considered that calcium, potassium, and sodium chloride are not necessary for *P. aztecus,* but phosphorus may be essential. The necessity of phosphorus has been manifested with *P. japonicus* (Kitabayashi et al., 1971a; Deshimaru et al., 1978a; Kanazawa et al., 1984). Deshimaru et al. (1978a), have reported that *P. japonicus* requires phosphorus (2.0%), potassium (1.0%), and trace metals (0.2%). Kanazawa et al. (1984) have shown that this species requires calcium (1.0%), phosphorus (1.0%), magnesium (0.3%), potassium (0.9%), and copper (0.6%) in dry diets. As mentioned above, there is some conflict on the published values for the requirement of prawns for calcium and magnesium. Since it is likely that the effect of calcium varies according to types of calcium salts used such as primary, secondary, and tertiary salts, the calcium requirement of prawns should be reevaluated by a more detailed experiment. The addition of iron (0.006%) and manganese (0.003%) inhibited growth of *P. japonicus* juveniles.

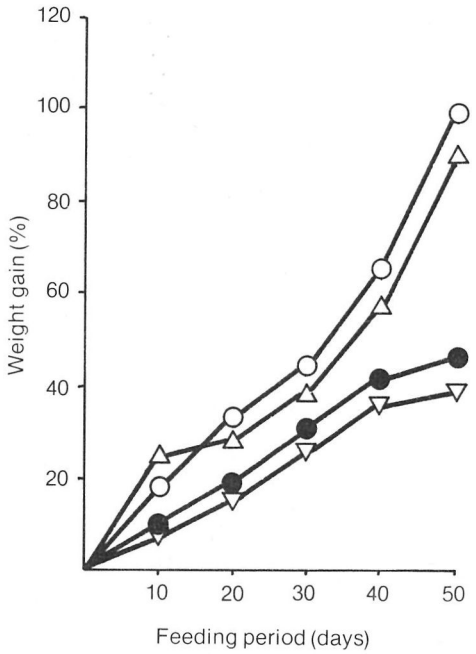

Fig. 2. Dietary requirements of *Penaeus japonicus* juveniles for icosapentaenoic acid.
▽ 5.0% 18:1ω9
● 4.5% 18:1ω9 + 0.5% 20:5ω3
○ 4.0% 18:1ω9 + 1.0% 20:5ω3
△ 3.0% 18:1ω9 + 2.0% 20:5ω3

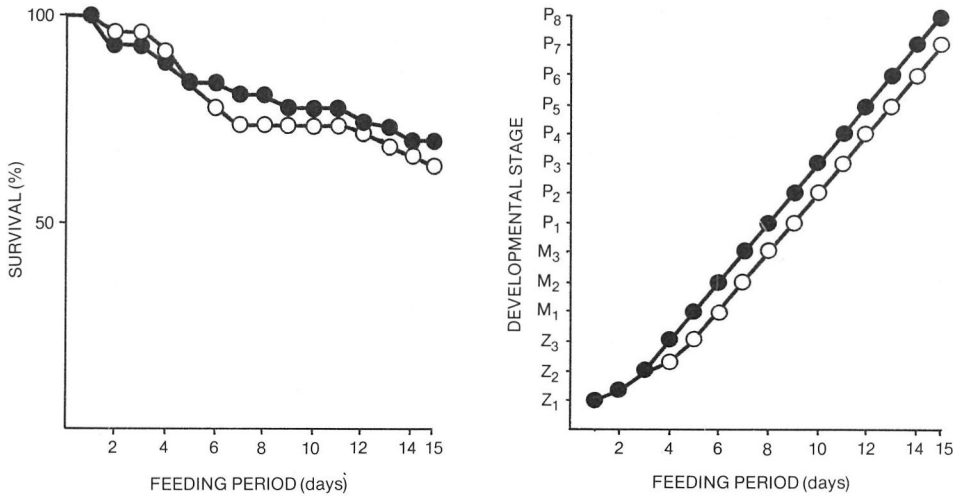

Fig. 3. Mass production of *Penaeus japonicus* larvae with microparticulate diet. ○*Chaetoceros* + *Artemia* + commercial diet; ● microparticulate diet.

Vitamin requirements

Several workers (Kanazawa et al., 1976b; Guary et al., 1976b; Deshimaru and Kuroki, 1976, 1979) have shown that *P. japonicus* juveniles require about 300-1,000 mg of ascorbic acid, 60 mg of choline, 200-400 mg of inositol, 6-12 mg of thiamine, and 12 mg of pyridoxine, per 100 g of diet, respectively. Lightner et al. (1977) have found that *P. californiensis* and *P. stylirostris* sometimes show an abnormal symptom, named "black death," with a characteristic blackening of the esophagus wall, cuticle, gastric wall, hind gut wall, and gills. "Black death" has been recognized as a symptom of ascorbic acid deficiency (Magarelli et al., 1979) with a dietary intake of 0.1% sufficient to prevent nutrition-related deaths among these shrimp (Lightner et al., 1979). It has been suggested that juvenile *P. californiensis* require dietary ascorbic acid to form adequate amounts of collagen from the unhydroxylated precursor, procollagen (Hunter et al., 1979). Also, depletion/repletion of ascorbic acid in whole body tissue was studied in *P. californiensis* and *P. stylirostris* (Magarelli and Colvin, 1978). On the other hand, Sedgwick (1980) has reported the requirements of *P. merguiensis* for vitamin and mineral supplements in diets based on freeze-dried *Mytilus edulis* meal.

Recently, Kanazawa et al. (unpublished data) also examined the requirements of larval *P. japonicus* for various vitamins by using microparticulate diets with carrageenan as a binder. As a result, the prawn larvae were found to require vitamin E, nicotinic acid, choline, pyridoxine, biotin, folic acid, ascorbic acid, cyanocobalamin, vitamin D, inositol, riboflavin, thiamine, and ß-carotene. The shortage of one of these vitamins resulted in the cessation or retardation of metamorphosis and in high mortality during larval development. Further studies have been done on the quantitative requirements of larval *P. japonicus* for several vitamins. The requirements for some vitamins such as ascorbic acid were apparently higher for *P. japonicus* larvae than for juveniles. It is conceivable, however, that some vitamins may have leached into the water before feeding. This means that the vitamin requirements of larval *P. japonicus* mentioned above should be regarded as "practical demand for rearing of the larvae."

Seed production with microparticulate diets

As mentioned above, the nutritional requirements of prawn larvae are studied by using microparticulate test diets. Recently, microparticulate diets were used as substitutes for live foods such as diatom and *Artemia* in seed production of *P. japonicus* (Villegas and Kanazawa, 1980; Kanazawa and Teshima, 1983; Kanazawa, 1985). From zoea 1 stage, the larval prawn reached postlarva 8 using only microparticulate diets. As a result, 21,000 postlarvae (survival rate of 70%) were produced in a 16-ton tank (Fig. 3).

Conclusion

The nutritional requirements of *P. japonicus* have been well investigated using purified or semi-purified diets. In this species, the requirements for proteins, lipids, carbohydrates, vitamins, and minerals have been manifested, and the accumulated knowledge has been useful in the commercial production of prawn diets. On the other hand, there is little information on the nutritional requirements of other prawns and shrimps. Further nutritional studies should be conducted on commercially important species to make formula feeds with a high dietary value. Another important subject is the manifestation of nutritional requirements in the larval stages of prawns and shrimps to achieve their successful mass production with artificial diets.

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Economics of Shrimp Culture in Asia

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Abstract There is a common belief that the demand for shrimp is so strong that the future of shrimp culture is very bright. However, there is a problem here. The Japanese market for shrimp has been expanding over the past 20 years, and the amount of imported shrimp has reached its ceiling. Since 1980, the amount imported has been 160,000 tons with some allowance. It will be rather difficult to exceed this level with the present price. It is very clear that if imports of shrimp rise above this level, inventory will rapidly increase and price will go down severely. Considering this situation, it is very important to reduce the cost of cultured shrimp because of severe competition in the market.

Various shrimp culture systems in Japan and Southeast Asia are described. They range from extensive to intensive systems. An analysis of their economics reveals some interesting facts. The downward trend of the rate of cost per kilogram in intensive culture is very slow compared to those in extensive and semi-intensive culture while the productivity is rising. This is because in intensive pond culture, the ratio of variable cost to total cost is rather high and variable cost does not change as the productivity rises. In the case of extensive pond culture, the ratio of fixed cost to total cost is rather high, so the decrease in fixed cost per kilogram is very high in accordance with the rise of productivity. Therefore, by simply increasing the productivity slightly, the extensive pond can cut its production cost significantly. If the price of shrimp in the market goes down, the intensive pond system will face extinction since it is difficult to cut production cost.

Cost forecast for cultured shrimp seems to indicate that extensive and semi-intensive methods will become dominant in the Asian region. Presently, productivity of these systems are low but can be greatly improved by using the "continuing method" and "circulating method" of pond management. The continuing method calls for stocking of different-sized shrimp which will be harvested on a staggered basis. The circulating method employs various sizes of compartments and the stock is moved from densely stocked small compartments to progressively larger grow-out ponds.

There has been a rapid expansion of tiger shrimp culture in Taiwan and Southeast Asia recently for the following reasons: (1) high growth rate; (2) high price and broad market; (3) development of technology for hatching and rearing of seedling; and (4) comparative ease with which technical help in culture is obtained from Taiwan and Japan. However, there is a significant demerit. It is not easy in some regions to obtain seedling due to their high price. The supply of seedling of tiger shrimp is absolutely insufficient because of the shortage of mature shrimp. On the other hand, it is easy to get white shrimp seedling at a low price in these regions. In addition to this, the growth rate of white shrimp is similar up to a body length of 12-13 cm in 80-90 days rearing. Cheap cost and a large supply of seedling will easily compensate for the small size. It is therefore important to expand white shrimp culture in Asia. The bright future of white shrimp due to its low production cost is presented in this paper with some data and calculations.

Demand and supply of shrimp

The total world population of wild shrimp from the sea has increased steadily from 439,000 tons in 1948 to 1.655 million tons in 1977, and has kept about the same production level since then. There is a common belief that due to over-exploitation of shrimp stocks, shrimp production from wild stocks will not increase much in the future. While there may of course be unexploited shrimp resources in the sea, additional shrimp catches from these sources will probably be more than offset by decreases in catches from over-exploited fishing grounds.

In addition, there is a widespread belief that the demand for shrimp is very strong and that it will continue to increase in the future. The basis for this idea is that the price of shrimp will rise due to the shortage of supply. Shrimp culture is expected to fill this gap in supply and demand. The rapid expansion in shrimp culture in Ecuador and Taiwan tends to support this belief.

There is much land suitable for shrimp culture in both tropical and subtropical Asia. Shrimp culture in this region has a long history as a co-product of milkfish culture. More recently, ponds previously specialized for milkfish culture have been converted to shrimp culture. This has resulted in the development of numerous new shrimp pond designs.

There is no problem in this industry's growth if the demand for shrimp is as strong as popular opinion has it. However, who can tell if this assumption is right? For example, take the situation of the Japanese shrimp market. Japan is an important importer of shrimp. Most of the shrimp exported to Japan comes from Asia.

Prior to examining the relationship between shrimp demand and supply in Japan it may be helpful to examine the relationship between supply and demand of cultured yellowtail (*Seriola quinqueradiata*) in Japan. The price as well as total production of cultured yellowtail increased from 1967 to 1975. Fig. 1 shows that the demand for cultured yellowtail

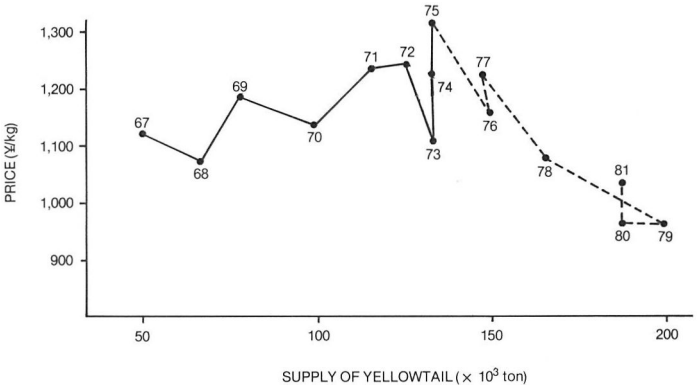

Fig. 1. Relationship between supply and price (deflated by prices in 1980) of cultured yellowtail in Japan. Source: Association of Marine Ranching.

was very strong during this period. However, after 1975, increased production resulted in decreases in price. Supply was greater than demand. Production decreases resulted as some culturists had to stop their operations. In addition, yellowtail culturists were asked to cut their production to a suitable level to stabilize the price of this cultured fish.

In the case of kuruma shrimp (*Penaeus japonicus*) culture in Japan, the relationship between supply and price is quite different (Fig. 2). There are three demand curves in the figures: first is from 1965 to 1972, second from 1973 to 1981 and third, after 1982. These three demand curves have been shifting towards the right. This suggests that the demand for kuruma shrimp is very strong. Thus, either the price will keep the same level despite a large production increase or culturists can expect the trend of higher price to continue in spite of production increases.

Total production of kuruma shrimp in Japan is about 2,000 tons. They are shipped to the market live. However, because of its extravagant price, kuruma shrimp is hardly consumed at home.

Since the Oil Crisis, especially the second one, the yearly

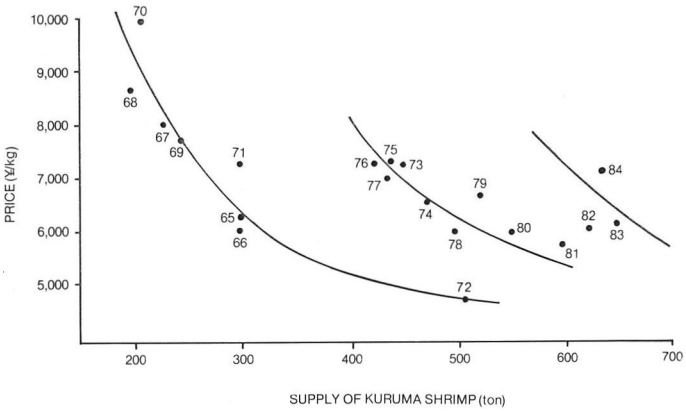

Fig. 2. Relationship between supply and price (deflated by prices in 1980) of cultured kuruma shrimp in Japan. Source: Tsukiji Central Fish Market, Tokyo.

increase in consumer's expenditure per capita in real terms has become stable averaging 2-3% and the value of the consumption became stable during the same time. The reason why the demand for cultured shrimp, a luxury food, has been increasing in this economically stagnant period is complex, and is beyond the scope of this review.

The situation as to the supply and demand of imported frozen shrimp is different. Total imports increased from 20,000 tons in 1965 to 164,000 tons in 1979. After that period they became stable at about 160,000-170,000 tons. On the other hand, the price of imported shrimp increased up to 1972 notwithstanding the increase of imports, but dropped considerably from 1973 to 1975 and since then has fluctuated severely (Fig. 3).

Figure 4 shows the monthly relationship between the amount of imports, price and inventory. It is very clear that since 1982, if imports increase, the amount of inventory will also increase and the price will decrease.

The inventory of imported frozen shrimp in the 1970's was under 20,000 tons and would hardly have influenced the price level. However, the inventory has reached a level of 50,000 tons recently. From 1980 to 1984 the amount of imports has been fairly stable, and only the inventory has increased yearly. This shows that it is becoming difficult to sell frozen shrimp in the Japanese market while keeping the same price level during import increases.

Consumption of imported shrimp is divided into two markets, one out-of-home and the other at-home. Out-of-home consumption seems to have reached its quantitative limit recently (Fig. 5). Thus, there may be little possibility of increasing consumption in quantity at the present price and, although at-home demand is strong, it is not expected to expand further due to the present high price compared to other foods. As Fig. 6 shows, the income elasticity of shrimp is very high compared to other animal protein foods. In Fig. 6, 1.0 in elasticity, for instance, means that if income goes up 10%, consumption of food will increase by 10% in value at home. However, quantity of home consumption has been fairly stable since 1980, so shrimp price must be lowered in order to enlarge its consumption in the present food market in Japan. The intake of animal protein per capita in Japan has reached its ceiling, so that an increase in consumption of one food will be at the expense of another. At present, the competition between animal protein foods is very severe. In these market conditions, price becomes very important in promoting shrimp against other foods. Considering the high price elasticity of shrimp at-home, consumption is sure to increase with a little drop of price.

In contrast to the stagnation of the Japanese market, the shrimp market in the U.S.A. has shown rapid expansion since 1982 (Fig. 7). There are two reasons for this: one is a drop in domestic shrimp production (catch fishery) and the other is the increase of exports from Ecuador and Mexico to the U.S.A.

The per capita intake of shrimp has been increasing recently, so exports to the U.S.A. can be expected to increase compared to that of Japan. However, one item to bear in mind is that the intake of fish in the U.S.A. increased in the latter half of the 1960's because of advertisement that fish is better

for health. The demand for fish, however, has become stagnant since 1977 due to their high prices. At present, the price of many fishes are higher than beef. On the other hand, the intake of chicken has continued to increase at its stable price. So even in the U.S.A., price competition in the animal protein market has been severe.

In Europe and other areas, the market for shrimp is expanding, but the size of these markets is still small. Despite the probable decrease in the production of shrimp from the sea, the total supply may increase owing to the worldwide development of shrimp culture.

The especially favourable economic situation in which the consumption and price increased simultaneously will disappear in the near future. There has been a seller's market for shrimp for so long that the "shrimp myth" has become ingrained in many people. The myth is that the price of shrimp will go up forever as if the demand is limitless. As a result, the recent severe fluctuations of price in Japan caused by the inbalance of supply and demand during periods of low price, has given rise to the wrong idea that these fluctuations are

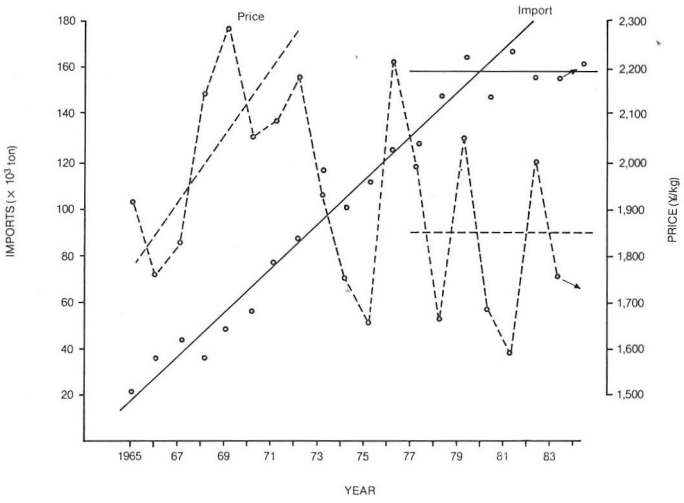

Fig. 3. Relationship between quantity of imported frozen shrimp and price (deflated by prices in 1980) in Japan. Source: Fisheries Agency of Japan.

caused by the intrigues of traders and intermediates in the distribution channels. In fact, this severe fluctuation shows that the market is beginning to saturate, when only a shift of supply will cause a severe drop in price. Considering the situation, in order to increase export to Japan and other markets, it is most important to cut the production cost, as the demand based on the present price is now nearing a stable state.

Natural productivity in pond culture

In aquaculture, especially in pond culture, the use of natural productivity is very important in minimizing production cost. The case of kuruma shrimp culture will be illustrated first.

There are three main production centers of kuruma shrimp culture in Japan. In each, the method of culture is different. This results from differences in the growing conditions of

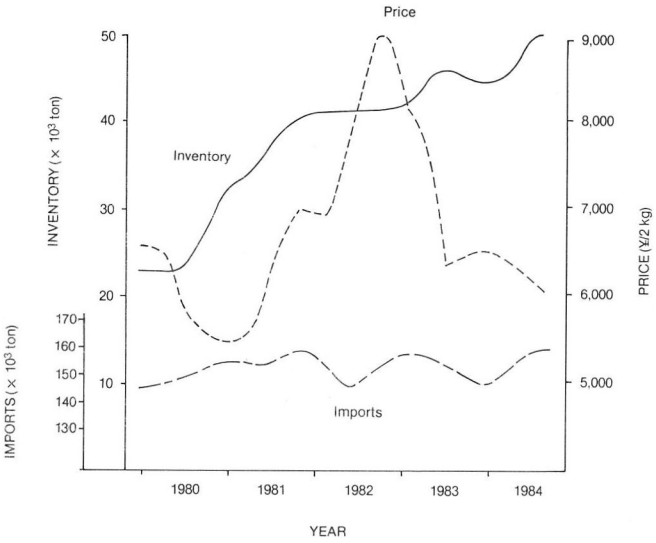

Fig. 4. Relationship between imports, inventory and price of imported shrimp (India white shrimp at 16-21 pcs/lb) in Japan. Source: Fisheries Agency in Japan.

shrimp and in economic differences between culture firms in each area. The ponds in the Seto Inland Sea area (type A, pool type on land) have been converted mainly from salt fields no longer in use (Fig. 8). The ponds in the Amakusa area (type B) are constructed in the sea with a concrete dike topped by standing wire-nets. The ponds in the Kagoshima area (type C) are of the circular type on land with water change by pumps.

Although each type of shrimp culture in Japan could be said to be intensive from a general point of view, types A and B are really semi-intensive by Japanese standards. Type C is intensive. The productivity of types A and B is roughly 400-700 g/m^2. Change of water is produced by tidal movement in types A and B, and rate of change is about 20-90%/day. On the other hand, water in type C is completely changed 3 or 4 times/day. With the large supply of oxygen,

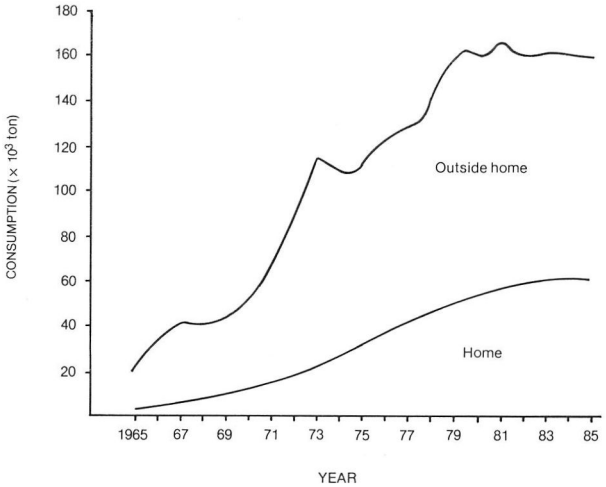

Fig. 5. Domestic consumption of imported shrimp in Japan. Source: Field survey.

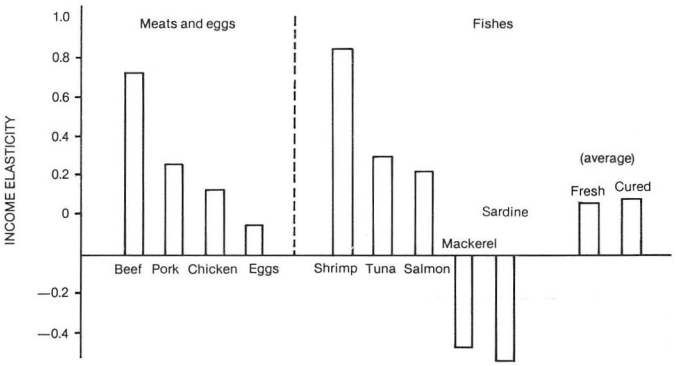

Fig. 6. Income elasticity of meats and fishes in Japan, 1981. Source: Statistics of home consumption by Japanese Central Government.

high density culture becomes possible. Moreover, with the development of special artificial feeds about 15 years ago, super-intensive culture has been realized.

Before the 1960's, there were many salt fields in the Seto Inland Sea area which were becoming underutilized due to technical innovations in the salt industry. Many of the culturists in the area were able to procure land at a comparatively cheap price. At present, land price is very high, so the construction of new type A ponds is not economical. The main characteristic of type A ponds is that culture technique is aimed at diatom production. Since diatoms do not grow well with either too much or too little water entering the pond, optimum growth is achieved by regulating the water change. In a pond with good diatom growth, the water colour is dark brown. Production of 40 g shrimp (2 pcs/m^2) without any supplementary feed is possible. This is because diatoms supply oxygen, and animal plankton and detritus (feed for shrimp) are produced naturally. In addition, luxuriant diatom growth may prevent the growth of harmful algae in the pond. Good production conditions for shrimp are thus maintained. For these reasons, the food conversion ratio from feed to shrimp is very low compared to the type C culture system (Table 1).

Type B pond is built along the shore. In the Amakusa area, tidal movement is wide (5-6 m). In the past, the construction cost of a pool type pond with a high concrete dike was prohibitive. Therefore, culturists make low concrete dikes and set iron piles on them with a wire-net spread between piles to contain the shrimp. At high and low tide the water flows freely in and out of the pond through the nets. The rate of water change is much higher than type A ponds, but regulation of water is difficult. The supply of oxygen to this pond is greater than to type A due to the large amount of inflowing water. However, diatom growth is not as good due to limited water control. The total supply of oxygen is about the same level as type A, so the productivity per square meter is also similar. As the amount of diatoms in this pond is low, the growth of natural feed is smaller than in type A. Accordingly, the conversion ratio is high in this pond and the production cost is high compared to type A.

In the Kagoshima area, it is not possible to build either type A or B ponds due to geographical features. In order to cope with high land prices and wages, high intensive and labour saving facilities had to be designed. All knowledge and techniques in aquaculture, not only in shrimp culture but also other cultures, were utilized in the design of type C ponds. The type C method leads to high production cost per kilogram compared to types A and B because of the high-priced feed and the high feed conversion ratio. In type C, the use of high quality feed makes high density culture possible, but the high rate of water change limits diatom growth. In addition, feed conversion is not good at a high density. Type C neglects natural productivity and is dependent on artificial feeds. This results in high production cost (Table 2).

It is a common belief that the high production cost of this type is due to the high cost of pond construction and other facilities, but this is not true. Even if the fixed cost per unit area is very high, the fixed cost per kilogram of shrimp is lower in type C than in types A and B due to higher productivity per square meter in type C. The high production cost mainly comes from the high conversion ratio and the high price of feed per unit and high electricity. These costs are a consequence of highly artificial techniques ignoring the benefit of natural productivity.

Thus as the use of natural productivity in aquaculture in temperate areas (Japan) is important, it is very clear that it is especially important in aquaculture in Asia. This is because the natural productivity of ponds in tropical and subtropical areas is higher than in temperate areas.

Table 1. Three types of kuruma shrimp culture in Japan.

	Type of pond	Dimension (ha)	Rate of water change (%/day)	Productivity (g/m^2)		Feed conversion ratio
				Present level	Target at present	
Type A						
I	Pool pond on	1-5	0.25	300-500	600-800	10-12
II	land	0.5-1	0.5	400-600	800-1,000	13-15
Type B	Pool pond in the sea	0.5-1	0.9	300-500	600-800	13-15
Type C	Circular pond on land	0.1	4.0	1,500-2,000	3,000-3,500	17-20

Source: Hirasawa, Y. and J. Walford. 1979. The economics of kuruma-ebi shrimp farming. Advances in Aquaculture, FAO. (With modifications by Y.H.)

Note: 1. Some firms are approaching the target productivities.
2. Conversion ratio is based on raw fish. One kg of artificial feed equals 6 kg of raw fish.

Before pursuing this theme, it is best to explain the reason for the existence of different types of culture methods in Japan. In general, a firm operating with a high production cost cannot stay in business in the long run. However, shrimps in ponds in the Seto Inland Sea cannot be overwintered because of low water temperature. Therefore, culturists in this area have to harvest and market shrimp at the end of the year when the price of shrimp is rather low (Fig. 9).

The water temperature in the Amakusa area is a little higher than in the Seto Inland Sea. Here, shrimp can survive the winter in a state of hibernation. Culturists are able to ship shrimps from January to March, having waited for the price recovery after shipments from the Seto Inland Sea. However, the physical strength of these shrimp is poor because the shrimp fast until the middle of March. In addition, shipment of live shrimp requires that shrimp hibernate again. This results in lower survival rates of shrimps transported during this period. Therefore, culturists in Amakusa complete most of their shipments between January and March.

The ponds in the Kagoshima area have a warmer water temperature than those in Amakusa due to the warm Kuroshio current that follows the coast. Thus, shrimp in type C ponds are healthy even in winter since they do not stop feeding. From April to May, the price of cultured shrimp is highest, because at this time of year there are no marketable shrimp from the Seto Inland Sea or Amakusa area and there are no live shrimp caught by fishing boats. The months of April and May are the best time for family outings, and demand for luxury foods becomes high. The supply of live shrimp from Kagoshima fills this market. The type C farms are able to concentrate all their shipment aimed at this period of extra-high price (Fig. 9).

Accordingly, type C ponds can co-exist with types A and B

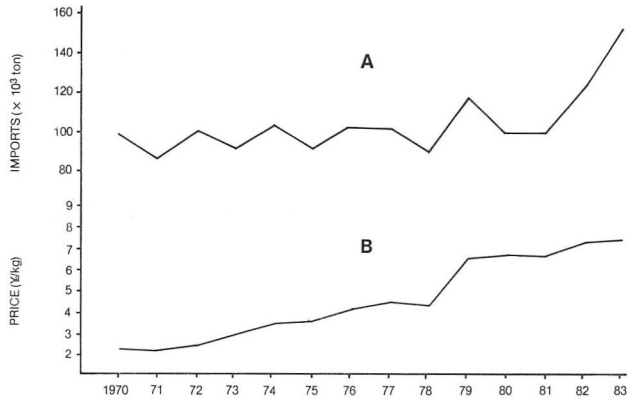

Fig. 7. Amount of imported shrimp (A) and price (B) in the U.S.A. Source: U.S.A. Fisheries Statistics by NMFS.

because they enjoy a higher sale price that offsets their higher costs. There is a trend toward constructing new culture ponds due to the high demand for live kuruma shrimp. However, there is no possibility of making ponds of types A or C, as land costs for the former are too high, and the latter is not efficient from an economic point of view. The new ponds which will be built hereafter may be a combination of types A and B. This new pond will have a lower land cost due to construction in the sea just like type B. However, it will have a high dike and will not use wire-netting. Complete control of water flow will result in high utilization of natural productivity as in type A. The construction cost of these new ponds, pool-type in the sea, is of course higher than that of type B, but the production cost per kilogram is lower than type B. There are many suitable places for the new ponds because they can be located in the sea along the shore.

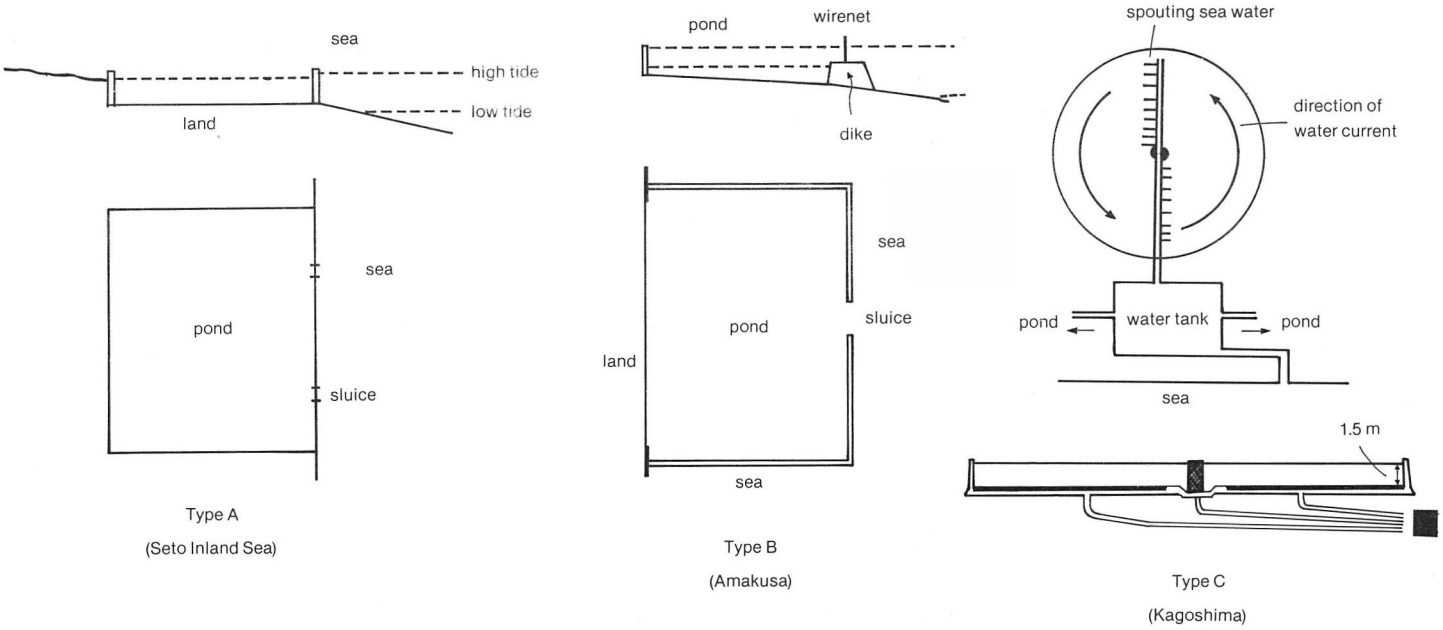

Fig. 8. Structure of different types of kuruma shrimp culture ponds in Japan.

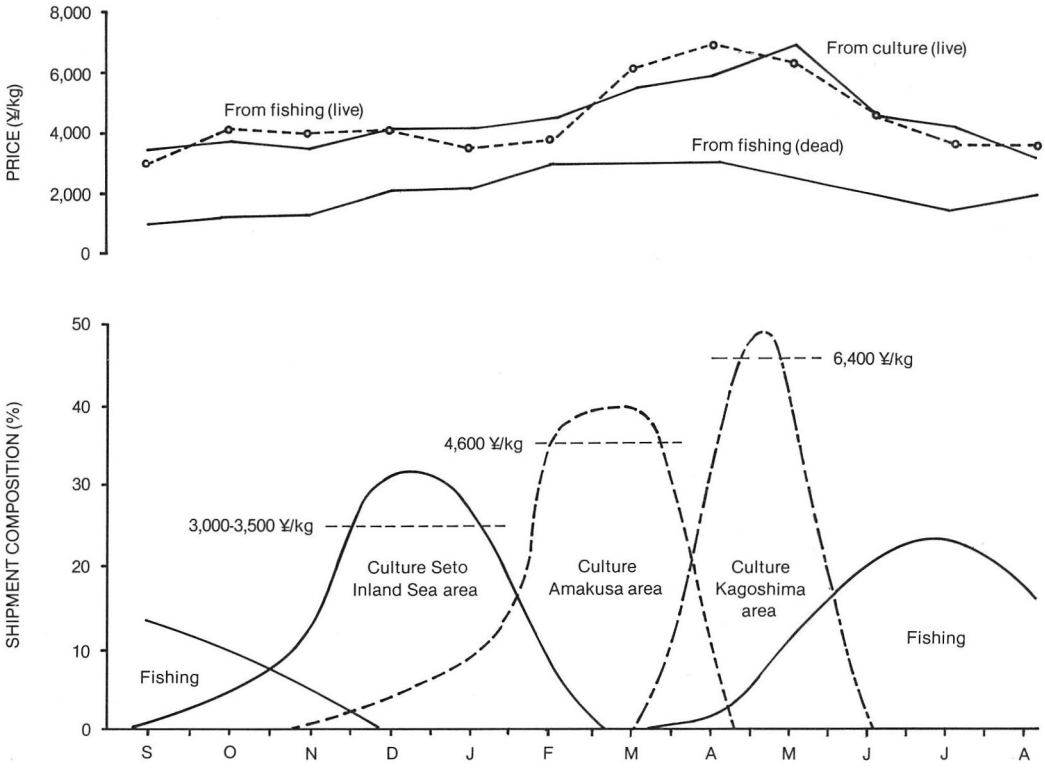

Fig. 9. Price of kuruma shrimp (¥/kg) and monthly composition of shipment versus total shipment per year (%) from a given area. Source: Hirasawa, Y. and J. Walford, 1979. The economics of kuruma-ebi shrimp farming. Advances in aquaculture, FAO.

Types of shrimp culture in Asia

Although there are many different methods of shrimp culture in Asia, they can be classified into the following (Fig. 10):

A. Trapping pond culture — extensive
B. Pond culture not specialized in any one species — extensive
   B-1. Milkfish pond
   B-2. Salt field pond
   B-3. Paddy field pond
   B-4. Pond in delta area
C. Pond culture specializing mainly in one species — semi-intensive
D. Pond culture specializing in only one species — intensive

Although there are many ways of defining culture methods as extensive or intensive, in this case, the following will be used:

Extensive — Water change, supply of seedling, and feeding are done naturally. Productivity is usually under 200kg/ha including fish.

Semi-intensive — Some human work is involved in the above operations.

Intensive — The above three operations are carried out by artificial means. Productivity is usually over 3,000 kg/ha.

Table 2. Typical example of cost per kilogram in kuruma shrimp culture in Japan, (from field survey).

	Type A	Type B	Type C
Selling price (¥)	6,000	6,500	7,000
Cost (¥)	4,500	5,000	5,600
feed	1,540	1,800	2,400
seedling	60	100	250
wages	1,000	1,000	500
shipment	410	420	450
repair	300	500	600
electricity	100	100	670
rent	50	10	10
depreciation	200	300	150
management and others	840	770	570
Productivity (g/m^2)	600	6000	3,000
Conversion ratio	12	14	18

A. Trapping pond culture — extensive

This pond makes use of natural topography and has a sluice gate which can be opened to allow nocturnal shrimp and seedlings into the pond during high tide. After one or two months, when many shrimps have accumulated and have grown a little in the pond, the sluice is again opened fully in the daytime during the lowest tide of the month and shrimp are caught through a trap net behind the sluice. The various species of shrimp and fish caught by this method are mostly of a small size. Many shrimp die and are damaged by the high water pressure and thus their market price is not very high. On the other hand, the operating cost is very small as little manpower is required, once the sluice and pond have been constructed. This method might be described not as aquaculture but as pond-fishing.

At present there are few farms of this type and it is difficult to obtain production data. The exact figures for one farm can be presented. The farm, operated by Dr. Kim C-M., existed two years ago in the southwest part of the Johor Bahru district of Malaysia and had a total of 32 ha of pond area. The average productivity was 167 kg/ha, but this becomes 250 kg/ha when the unused part of the pond is excluded (Tables 3-5). He has stopped his operation and his pond has now become semi-intensive.

B. Pond culture — extensive

B-1. Milkfish pond. This type of pond has a long history as by-product of milkfish culture in the Philippines, Indonesia, Taiwan, etc. The seedlings of shrimp together with milkfish fry enter into the pond through rough bamboo screens at particular times of the year. Although production of 100 kg/ha can be achieved, the productivity of this type of system is usually 50-60 kg/ha.

B-2. Salt field pond. Ponds of this type were made from old salt fields and are very numerous in the southern part of Bangkok, Thailand. The pond beds are flat and there are usually two sluices on opposite sides, an intake and an outflow. The force of outflowing water is not very strong, so shrimp can be caught live in cages at the sluice every day, young shrimp being returned to the pond again. As ponds of this type are generally well prepared for culture, the productivity is comparatively high (100-200 kg/ha). More recently, the practice of pumping water at the sluice has been tried. The productivity of these ponds increases two-fold due to a decrease in predators and their damaging effects. The main product of this type of pond is white shrimp, *Penaeus merguiensis,* in Thailand. Small shrimps produced naturally are often used as feed for larger ones.

B-3. Paddy field pond. After harvest, rice paddy fields are converted to shrimp ponds for the rainy season (November to May), along the southern part of the Indian coast. Sometimes, when culture goes very well, 400 kg/ha can be expected which gives a profit of over two times that of rice culture. However, due to predation the productivity is usually under 200 kg/ha.

B-4. Pond in delta area. This type of pond is constructed in flat delta areas where it is easy to build by construction of an earth dike. There have been many such ponds constructed recently in the estuary of the Ganges River in India due to the bright prospects for shrimp farming. Ponds of this type are rather small in size, but are well arranged for culture. Fig. 11 shows the pond areas in the estuary of the Pontevedra River near Roxas City, Panay Island, Philippines, since 1975. As a result of making ponds, wide areas of the estuary have disappeared. As ponds of this type are located in comparatively good sites, the productivity is fairly high compared to other types of extensive culture. Just as the merit of extensive farming is the ability to save costs and labor, the largest demerit is the difficulty of preventing damage by predators. Often a large population of predators is supported by the shrimp. If predators were prevented from entering the ponds, 400 kg/ha could be expected. Measures to prevent the entrance of predators into the pond are available. Moreover, when the ponds are well managed and are given sufficient fertilizer to grow food-plants before the stocking of seedlings, and the continuing or circulating method of pond use is applied, it may be possible to produce twice as many shrimp a year.

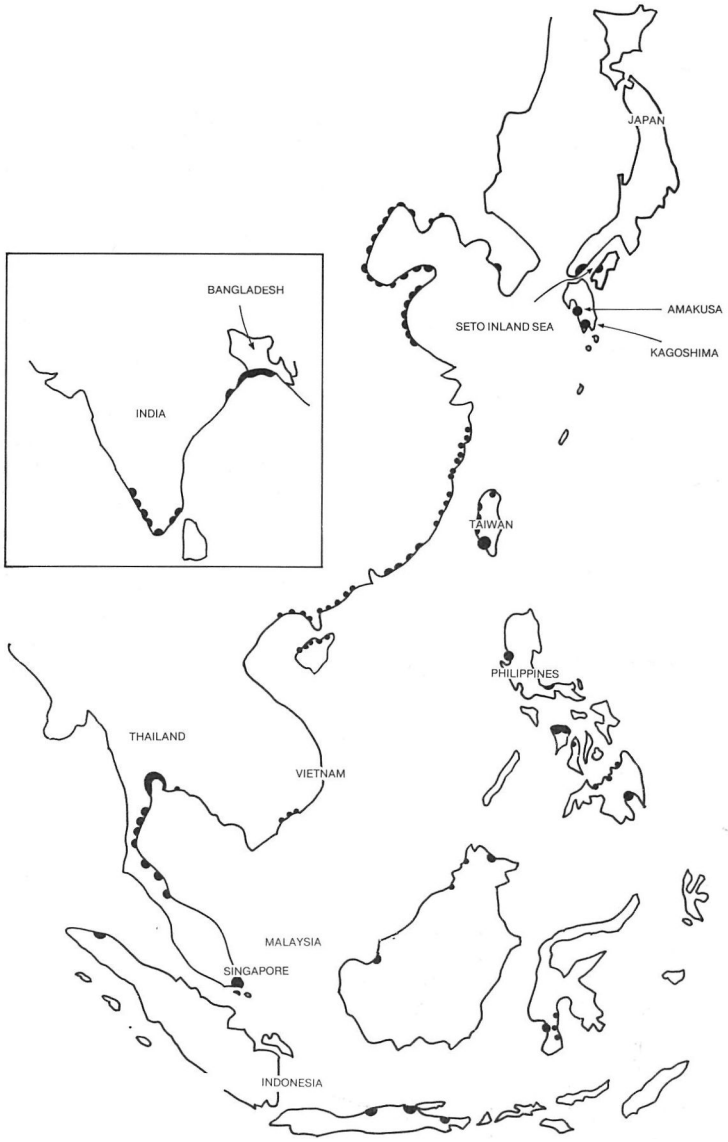

Fig. 10. Map of shrimp culture in Asia. Shaded areas denote location of farms.

Table 3. Production of Dr. Kim D-M's trapping pond, Johor Bahru, Malaysia.

	Quantity				Value			
	1980		1981		1980		1981	
	kg	%	kg	%	MS	%	M$	%
Total	4,527	100.0	5,375	100.0	34,855	100.0	41,923	100.0
Tiger shrimp	50	1.1	128	2.4	1,002	2.9	2,178	5.2
White shrimp	1,120	24.7	1.231	22.9	18,727	53.7	19,935	47.6
Medium-sized shrimp	332	7.3	328	6.1	3,189	9.2	3,183	7.6
Small-sized shrimp	1,311	29.0	1,549	28.8	7,801	22.4	11,015	26.3
Red shrimp	1,714	37.9	2,139	39.8	4,135	11.9	5,612	13.4

C. Pond culture — semi-intensive

A semi-intensive culture, as opposed to an extensive culture, is one in which the seedlings are bought from artisanal fishermen after being caught along the coast. They are put into the ponds where supplementary feed of trash fish is given. Semi-intensive ponds also require a sluice and ditch in order to manage a good rate of water change.

There are many types of semi-intensive culture, varying in the quantity of seedlings, the supply of feeds, and the degree of management of the ponds. Culture types B-1 to B-4 mentioned above may be shifted to semi-intensive culture while retaining basic characteristics. Because a small pond is more easily managed than a larger one, there is a common trend for the size of ponds to become smaller upon entering into the semi-intensive stage. While a pond may easily cover 10 ha when extensively farmed, it usually becomes 3-5 ha when converted to semi-intensive use (as in the Philippines).

In proceeding with the functionalization of the pond, one part becomes specialized as a nursery area. The purpose of the nursery pond is to increase both the survival and growth rates of seedlings by special care. Fingerlings of about 5 cm size become marketable after 3 months in tiger shrimp culture.

As already mentioned for extensive culture, eggs and seedlings of predators may enter the ponds. As their growth rate is faster than that of shrimp, predators will eat the shrimpy after 2-3 months rearing. The low productivity of extensive culture is mainly due to this problem. However, this can be improved by dividing ponds into appropriate sections. It is possible to prevent predators in the nursery pond. Fingerlings transferred from the nursery pond first to small growing ponds are fairly safe from small predators. When small predators become big enough to eat the small shrimp, the latter have to be shifted again to a second, comparatively larger growing pond. In this pond, medium- and large-sized shrimp can eat eggs and larvae of predators. Thus, it is very easy to prevent damage by predators by simply dividing ponds into suitable sizes and transferring shrimp from pond to pond.

In semi-intensive culture, if a pond is prepared and managed well, a productivity of 500-1,000 kg/crop is possible. In tropical and subtropical areas there are two seasons, the dry and rainy, of which the rainy season is suitable for culture in many places. If ponds make use of either continuing or circulating methods, it is possible to harvest three times in one culture season.

As farms become more semi-intensive, they tend to specialize in only one species of shrimp. At present, however, when shrimp are cultured with milkfish in semi-intensive ponds as in the Philippines, it is not to increase the production of the fish, but to prevent the over-growth of feed plants, such as lab-lab.

Table 4. White shrimp production (kg) in Dr. Kim's Farm, Johor Bahru, Malaysia.

Duration of harvest		Number of harvest						Total
		1	2	3	4	5	6	
Jan.	31-Feb. 3	18.9	38.1	29.7	24.0			110.7
Feb.	5-8	20.4	37.2	46.5	25.2			129.3
Mar.	3-6	29.1	27.3	19.8	19.8			96.0
Apr.	4-8	26.7	40.8	30.0	27.3	40.5		165.3
May	1-6	21.6	15.3	9.6	14.1	12.0		72.6
Jun.	2-8	28.5	27.9	18.9	12.6	7.8		95.7
Jul.	19-21	16.5	33.3	39.3	31.8			120.9
Aug.	1-4	69.6	56.7	22.8	37.2			186.3
Sep.	24-30	13.8	20.1	16.5	4.2	16.5	4.8	75.9
Oct.	25-29	11.4	10.8	5.7	6.3	14.1		48.3
Nov.	23-27	10.2	12.6	12.6	24.0	10.5		69.9
Dec.	23-27	9.6	13.2	12.0	15.9	9.6		60.3
Ave.		22.9	27.8	22.9	20.2	15.8	4.8	102.6

D. Pond culture — intensive

Intensive culture has much variety in its methods and the borderline with semi-intensive culture is not always clear. It is, however, possible to say that a culture is intensive if the change of water, amount of supplementary feeding, and stocking of seedlings are controlled by the operator. These three factors are regulated by the sophistication of techniques available.

The most basic of these three requirements is the change of water. The biomass that can be cultured within a given space is dependent on the dissolved oxygen concentration in water. The number of seedlings and the amount of feed are also dependent on the amount of oxygen available. The relationship is especially clear in pond culture. The continuing and circulating methods of pond use are both designed with the aim of using oxygen in the pond more efficiently.

The Kagoshima type C culture has a productivity of about 25-30 ton/ha despite the growth of shrimps almost stopping during winter. The highest productivity in the Asian area besides Japan is that achieved by culturists in Tungkang, Taiwan. An average production of 15 ton/ha has been achieved.

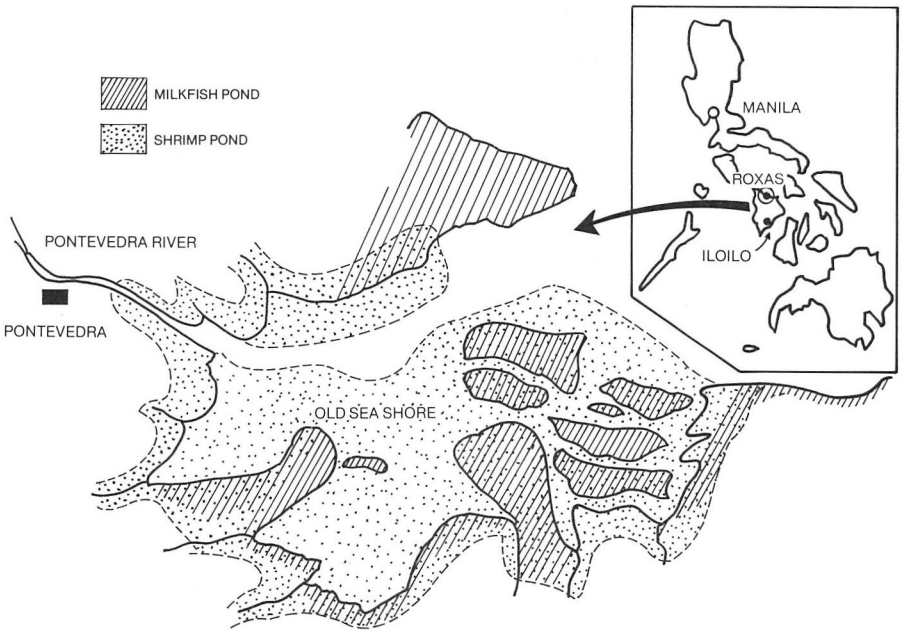

Fig. 11. Distribution of shrimp ponds in the Tinagong Dagat Inlet area near Roxas City, Panay Island, Philippines.

The key to reaching such a high level of productivity as in the Taiwan method is the ability to change water in a very short time (Fig. 12). It is necessary to change all the water in a pond within 2 to 3 hours. Sea water is pumped up directly though a pipe and fresh water is pumped from a well in order to lower the concentration of salt water artificially. Using this method of diluting sea water, it is easily possible to create the most suitable salinity for shrimp at any stage of growth. Salinity requirements change with size, especially in tiger shrimp (*P. monodon*).

Table 5. Cost and earning (MS) of Dr. Kim's Farm, Johor Bahru, Malaysia.

	1979	1980	1981
1. Revenue	20,962	36,809	43,485
shrimp	19,507	34,858	41,881
fish	1,245	1,444	467
others	210	506	1,137
2. Cost	15,086	26,990	26,308
pesticide	1,680	316	2,246
ice	103	—	—
feeds	357	—	—
transportation	87	—	13
wages	5,527	16,568	15,758
basic	2,745	10,470	11,650
fixed reserve	66	1,629	1,485
insurance		452	280
temporal	1,840	2,545	2,082
foods	876	1,472	261
others	517	1,887	875
general management	1,376	5,654	3,838
repair	3,330	—	—
tax	2,109	2,565	3,578
fixed asset	1,573	2,565	2,565
exports	536	—	1,013
3. Profit	5,876	9,819	17,177

The most critical time for tiger shrimp culture is the beginning of winter when water temperature falls abruptly. This can cause high mortality as tiger shrimp are particularly weak at low temperatures. At these times of emergency, the speed with which water can be changed is critical. Following an increase in the flow of warm subterranean water, shrimp recover their vitality.

As already shown in Fig. 10, there is a common trend to crowd ponds into specialized areas. In addition to fully utilizing a good environment for shrimp growth, it is often convenient for culturists to crowd together from a socio-economic point of view, especially in developing areas, because of the shortage of infrastructure, the necessity of obtaining seedlings and feeds, and the convenience in selling their products.

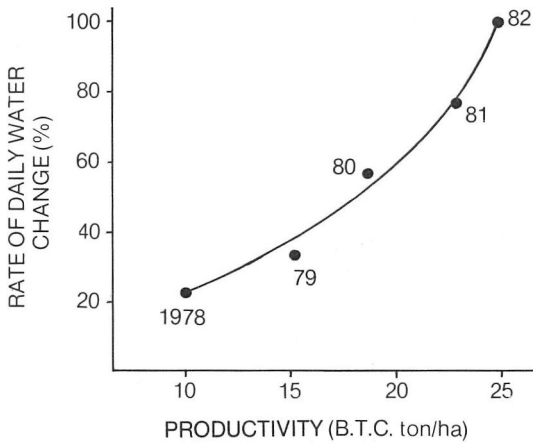

Fig. 12. Relationship between productivity and rate of water change in shrimp culture ponds in Taiwan using black tiger conversion (B.T.C.) method. Source: Pers. comm., M. Chu of Tungkang who holds the record for maximum production per hectare in Taiwan.

Table 6. Calculation of Black Tiger Conversion (B.T.C.).

	Production (kg) A	Price (¥/kg) B*	B.T.C. (¥/kg) A X B
Total	3,500		707
Tiger shrimp	100	1,800 (100%)	100
White shrimp			
Large	300	1,300(72.2%)	217
Medium	500	1,000(55.6%)	278
Other shrimps			
Medium	600	200 (11.1%)	67
Small	1,000	50(2.8%)	28
Fish	1,000	30(1.7%)	17

*Figures in parentheses (B) refer to price of commodity expressed as percent of price of tiger shrimp.

Problems faced in intensive culture include the excessive use of subterranean water that results in the phenomenon of ground water subsidence. Tungkang has experienced this. There is also a general trend to use much more medicine to prevent diseases. In the case of Japanese aquaculture, the use of antibiotic medicine is prohibited, but it is rather difficult to stop usage completely. In addition, there are many cases where sea water and sea beds have been contaminated by leftover feeds and the excrement of cultured fish. There are increasing numbers of previously cultured sea areas no longer suitable for culture in Japan.

Productivity and cost study using the B.T.C. method

Between shrimp culturists in Taiwan and Japan, there is not much difference either in productivity or technical level. However, in Asia there are greater differences. The Asian area is so broad that the existence of many types of culture systems and many kinds of cultured shrimps is inevitable. Moreover, differences in farm scale can be very great even in one area. Many areas have a pyramidal type of succession from small to large farms, so that it is difficult to set a standard scale or average size of farm. At present, there are limited economic statistics on shrimp culture in all Asian countries except Thailand, so that the comparative analysis of productivity, cost, and earning between different culture methods is very difficult. Also there are many kinds of shrimps cultured in various countries. Black tiger shrimp, *P. monodon*, is the main species of one country while white shrimp, *P. merguiensis* or *P. indicus*, may be that of another.

This situation makes it difficult to clarify by economic analysis general trends in shrimp culture in the countries in Asia. To cope with the difficulty, the Black Tiger Conversion (B.T.C.) method is introduced.

Table 6 shows a model of calculating B.T.C. from the production of cultured shrimps and fishes using price per weight. The method can be applied to shrimp culture because the price of cultured shrimps is decided mainly by the international market. A common international producer price throughout the world even in different areas and countries is thus possible. In other cultured species, the domestic market is usually larger than the export one so that the price of the cultured product is decided by the demand and supply relationship in the country. In these situations it is not possible to do comparative analysis on production and cost. Fortunately, shrimp culture is one of the cases suitable for analysis on a worldwide scale. In the following figures and tables, the B.T.C. method is used for rough calculation. It is very difficult to obtain exact data as to the prices and quantities of each species in a limited time, so it is used here only to show a basic idea of the B.T.C. method and its usefulness for more refined analysis in the future.

Table 7 shows results of the B.T.C. method using examples from different types of shrimp culture in Asia. These examples were obtained from field survey, so the number of samples is very limited. In the table, the production figure does not include the small-sized shrimps and trash fishes which become feed for large shrimp or are given to workers as an allowance in kind. Examples of kuruma shrimp culture are excluded from the table, because live kuruma shrimps

Table 7. Comparison of productivity and costs for typical example of each type of culture (based on field survey in 1981, 1982, 1983). Figures for South India and Ganges are from reports of experts and trading companies in Japan.

	Intensive	Semi-intensive		Extensive			
	Tungkang	Pontevedra (1)	Pontevedra (2)	South Bangkok	South India	Ganges	Johor Bahru
Production (kg/ha)	15,000	1,065	520	500	240	315	250
Tiger shrimp	15,000	525	310	—	10	5	6
White shrimp	—	—	—	300	80	160	57
Small-sized shrimp	—	—	10	200	150	150	187
Milkfish	—	540	200	—	—	—	—
Others	—	—	—	—	—	—	—
B.T.C. production	15,000	580	340	280	110	155	115
B.T.C. price (¥/kg)	1,800	1,950	1,950	1,900	1,630	1,710	1,530
B.T.C. cost (¥/kg)	1,620	1,258	1,320	900	1,100	1,000	1,140
Fixed cost	450	650	760	600	990	880	940
Variable cost	1,170	608	560	300	110	120	200
Seedling	230	260	200	—	—	—	—
Feed	730	184	160	—	—	—	—
Others	210	164	200	300	110	120	200

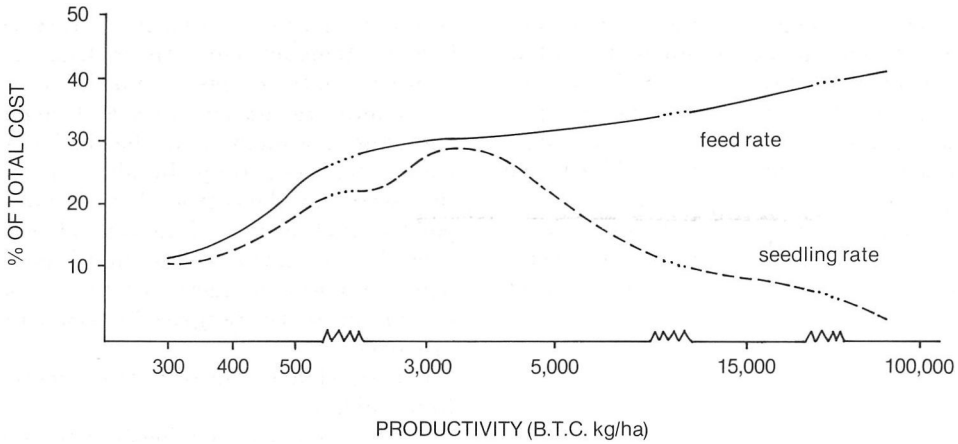

Fig. 13. Relationship between proportion of feed cost and seedling cost (as per cent of total cost) and productivity (B.T.C. method) in Asia. Source: Field survey in Tungkang, Taiwan.

have a special domestic market in Japan and imported quantities from outside are few. The price of this shrimp is decided by the domestic production situation. The producer price of B.T.C. is from 1,800-2,000 ¥/kg excluding the examples from India and Malaysia. The price is comparatively low in the case of India due to low wages and inconvenient transport, and in the case of Malaysia due to the large number of shrimp damaged or killed by high water pressure during harvest making up a large part of the total production.

In Asia, it is common for culturists to sell their products to merchants by the pond side, so that the price of shrimp is the producer's price. There is a comparatively wide range of production costs reflecting different economic situations and types of culture in each country. Generally, the production cost of extensive culture is less than that of semi-intensive and intensive culture in proportion to the degree of intensity.

This phenomenon, seen in Japan too, is a general feature of all shrimp culture except for extensive culture ponds having very low productivity. The production cost is highest in Taiwan and lowest in South Bangkok. The ponds in the South Bangkok area are so well prepared that the natural productivity is high enough to produce many small low quality shrimps and *Acetes* spp. which make good feed for white shrimp. In addition, small white shrimp are returned to the ponds, so that the productivity is high compared to other extensive culture systems.

The examples of semi-intensive culture in Table 7 were selected from the Pontevedra area, near Roxas City, Panay Island in the Philippines. This area has more semi-intensive ponds than other countries and the production cost is roughly halfway between that of extensive and intensive.

When the production cost is divided into two parts, fixed cost and variable cost, it happens that in proceeding from extensive to intensive culture, the fixed cost tends to fall. The fixed cost per hectare in the intensive culture is much higher compared to extensive, but the fixed cost per kilogram is lower because of high productivity. As the fixed cost is composed of depreciation, interest, fixed wages, etc., the rate of decrease is very distinct in proportion to the increase in productivity.

On the other hand, the variable cost per kilogram becomes higher when proceeding from extensive to intensive culture. Thus, the high level of variable cost keeps the production cost per kilogram high in step with the order of intensity. In the manufacturing industry, the variable cost per unit product may have only small differences even if the productivity is different between factories. In factories having a high efficiency, the production cost per unit product becomes low in proportion to the decrease in fixed cost and the variable cost per unit will remain at the same level.

The big differences in the variable cost of shrimp culture come mainly from the cost of seedlings and feeds. The seedling cost in kuruma shrimp culture in Japan is very low compared to other areas, because it is easy to get enough mature shrimp from the sea, and recently many culturists have built their own hatcheries to supply seedlings whenever they are needed. On the other hand, the seedling cost per kilogram in semi-intensive culture in Asia is very high, because mature tiger shrimp are few and hatchery technology has not yet reached a high level, except for Taiwan (Fig. 13).

The large differences in the feed cost are preeminent, and the feeding cost will increase at a higher rate than the

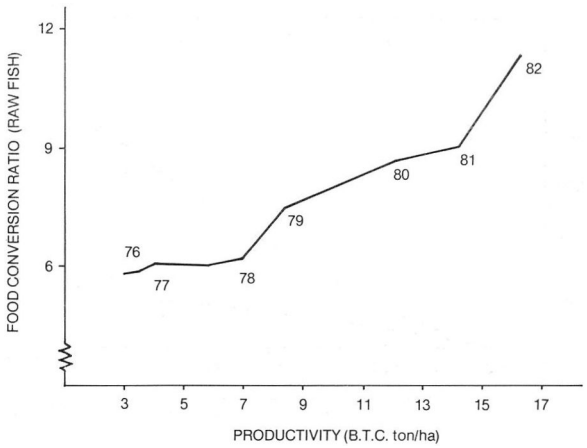

Fig. 14. Relationship between food conversion ratio and productivity (B.T.C. method) in Taiwan. Source: Field survey in Tungkang, Taiwan.

decrease in fixed cost. Intensive culturists must turn to more feed to compensate for the loss in natural productivity. Fig. 14 shows this relationship. In Taiwan shrimp culture from 1978 to 1982, the feed conversion ratio became higher in proportion to the increase in productivity. This is tied to high feeding cost. In addition to this, a high quality and high priced feed is needed in super-intensive culture. As already shown in Tables 2 and 6, kuruma shrimp culture is no exception.

In Table 7, the other main costs included in variable cost are temporary workers wages, shipments, repairs, electricity, etc. Besides semi-intensive culture, the extensive culture in South Bangkok shows the highest variable cost compared to other countries. This is because culturists there put much effort into preparation, such as levelling the pond bottom and digging a ditch along the earthen dike to make a nice habitat for the shrimp. In addition, they remove the mud that settles on the bottom. If they did not do this work, the pond would become a silted wild field within 2-3 years. Moreover, they use electricity to control the flow of water into the pond. It might be more accurate to say that the culture method in South Bangkok is between extensive and semi-intensive.

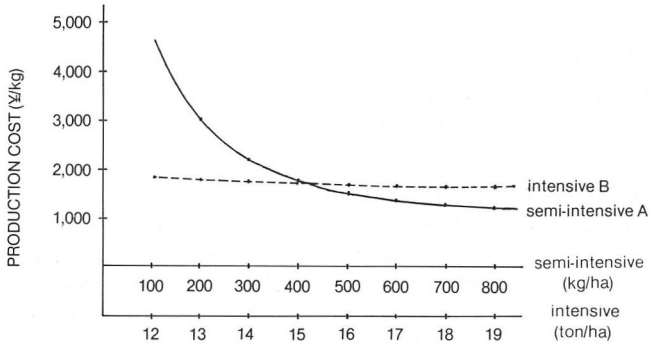

Fig. 15. Production cost versus productivity in semi-intensive (A, Pontevedra) and intensive (B, Tungkang) shrimp culture.

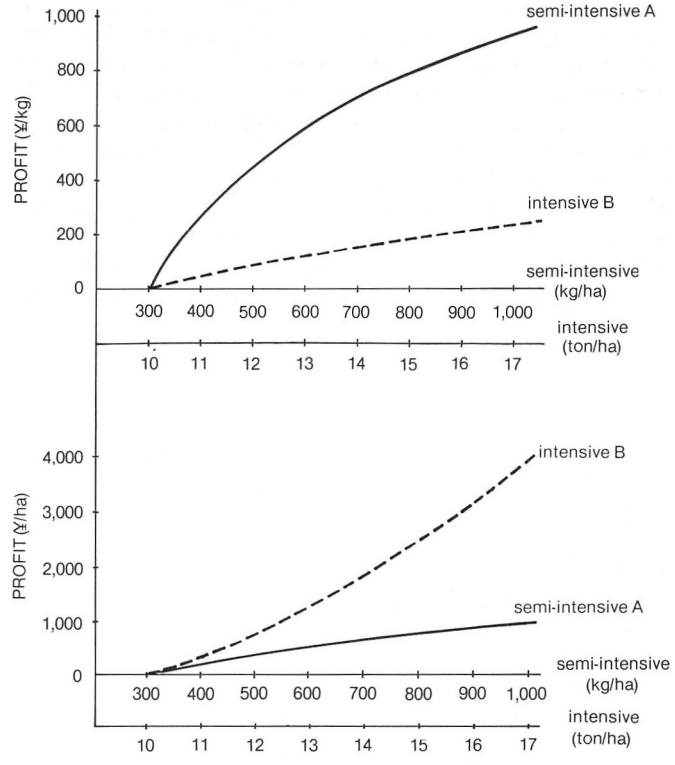

Fig. 16. Profit per kilogram and per hectare at different productivity levels (B.T.C. method).

It is possible to ascertain two important economic trends from Table 7.

1. The fixed cost per hectare is very high in intensive culture, but fixed cost per kilogram is very small compared to semi-intensive and extensive culture.

2. The percentage of variable cost out of total cost per kilogram is very high in intensive culture. This is due to the high cost of feed and seedling.

In Table 7, the productivities of extensive culture are all above 100 kg/ha. Usually, however, productivity of these ponds are under 100 kg/ha. The cost per kilogram in the extensive system having a productivity of 50-60 kg/ha is higher than that of the intensive systems presently used in shrimp culture.

Although a general trend of the economics of shrimp culture may become clear by this rough comparative study of each country and culture method, it is very difficult to say exactly what are true production costs. There are many problems in general comparisons such as what items to include in production cost, how to estimate the proper cost for each item, how to calculate depreciation, interest, and the evaluation of family labor, etc. In Asia, the condition of lease, land price, and interests often vary individually, so it is not easy to determine standard costs for each item.

Despite these difficulties, the cost per kilogram for each culture system can be compared with different levels of productivity. Fig. 15 shows the change in cost that may result from change in productivity using examples of Pontevedra as a semi-intensive case A and Tungkang as an intensive case B from Table 7.

Production cost per kilogram in this calculation is based on a productivity of 580 kg/ha in semi-intensive case A and 15 ton/kg in intensive case B. It is assumed that the variable cost does not change per kilogram and that the fixed cost per kilogram changes in direct proportion to the productivity change. The production cost per kilogram of A and B both decrease with increased productivity, but the rate of decrease is higher in B than A. In this calculation, production cost per kilogram of A at the productivity of 400 kg/ha becomes equal to B at the productivity of 15 ton/ha. To make the comparison clear, the two horizontal lines in Fig. 15 representing the productivity levels of A and B meet at the production cost of ¥1,600/kg.

The reason type B has a gentle cost curve compared to type A is due to its high percentage of variable cost in the total cost per kilogram. This means the percentage of fixed cost per kilogram is low, so that a decrease in this part does

not heavily influence the whole production cost per kilogram when the productivity increases. Theoretically, production cost per kilogram will eventually approach variable cost per kilogram if productivity is increased to infinity.

It is possible to raise the productivity of A from the level of 400 kg/ha to 1,000 kg/ha in the near future. On the other hand, it would be rather difficult to push up the present level of 15-20 ton/ha in B, because it has already attained a high productivity.

The range in productivity of semi-intensive culture in the Philippines is about 300-500 kg/ha and that of intensive culture in Taiwan is about 15-20 ton/ha. Due to the steep downward cost curve in semi-intensive culture, the production cost per kilogram of over 500 kg/ha in semi-intensive culture cannot be equalled even if the productivity of intensive culture were to increase. On the other hand, at present there are many culturists in Taiwan whose productivity level is over 15 ton/ha, so that semi-intensive culturists having under 400 kg/ha productivity cannot survive in the future when the total production of cultured shrimp from intensive culture continues to increase. From the field survey conducted in 1981-82, productivity in the Pontevedra area (Panay Island, Philippines) is under 200 B.T.C. kg/ha for extensive and 300-400 kg/ha for semi-intensive culture. There are few farms having over 400 kg/ha B.T.C. in that area said to be the most advanced shrimp culture area in the Philippines.

While it is almost certain that the production cost line of extensive culture will be positioned to the lower left part of the semi-intensive line when its productivity is beyond 100 kg/ha, the present level of extensive culture having under 100 kg/ha productivity will be higher than that of intensive culture. These low productivity ponds cannot survive when production from intensive and semi-intensive culture increases.

Costs per kilogram for intensive culture are now lower than those for a large number of the existing semi-intensive and extensive culturists. However, as Fig. 15 indicates, this situation may easily reverse when the productivities of the latter increase a little.

It is assumed in this calculation that the variable cost per kilogram does not change as the productivity level changes. This, however, is not always the case. For example, feed cost will increase following the increase in productivity. As is supported by Fig. 14 and Tables 1 and 2, an increase in the productivity per hectare of high intensive culture is followed by an increase in the food conversion rate. Experience with yellowtail culture in Japan can be used as an example here. The food conversion ratio about 5 years ago was 7-8 and fish grew to about 1 kg during 8 months rearing. Now the conversion is 8-9, and fish only grow to 800 g in the same rearing period. It is said that the reason for this slower growth is due to the deterioration of the sea bottom caused by left-over feeds.

In the case of shrimp culture, good bottom condition in ponds can be maintained if construction allows total water drainage and drying subsequent to the removal of accumulated slime. However, in high density culture, it is difficult to prevent the increase in the feed conversion ratio. On the other hand, in semi-intensive and extensive culture it is possible to grow adequate feed plants provided that ponds are properly fertilized after the pond bed is completely dried. In these ponds the growth of natural food is rather good, and an increase in seedling number up to a certain point will not cause an increase in the food conversion ratio.

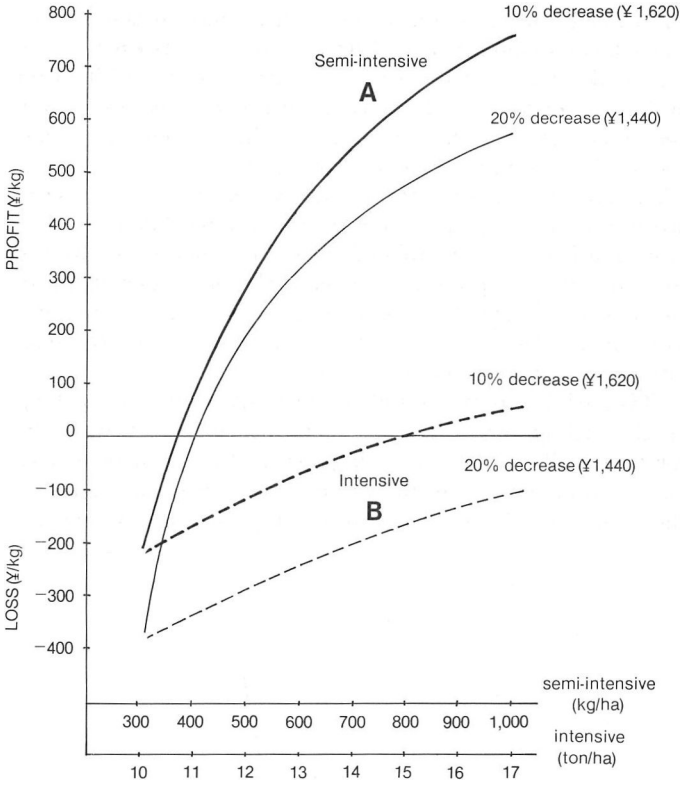

Fig. 17. Profit and loss per kilogram given a decrease (by 10 and 20% of present levels) in selling price.

In kuruma shrimp culture, the colour of ponds in which diatoms have grown very well becomes dark brown and the transparency of water falls below 30 cm. High intensive culture in such a pond may show the possibility of rearing large numbers of shrimp at a faster growth rate than in other ponds. Culturists are now trying to produce the dark brown colour of water. Thus, with proper management, it is surely possible to enhance the natural productivity of ponds in Asia.

The cost curves of B as shown in Fig. 15 may in reality rise a little at high levels of productivity because of the drop in feed efficiency. On the other hand, the cost curve in case A may descend more rapidly at initial production levels with increased natural productivity. The result of increasing productivity can be great in semi-intensive and extensive culture.

Intensive culture firms can remain in business only if they have a good selling price to compensate for high costs. Even if the profit per kilogram is small, the intensive culturists will still get adequate profit per hectare from the high intensive ponds due to the high production of shrimp. Fig. 16 illustrates this relationship by productivities and profit. In the figure, the upper graph shows profit per kilogram in A

and B. Both horizontal lines were set to meet at the productivity level of 300 kg/ha in A and 10 ton/ha in B where there is a break-even point for both. Of course, profit per kilogram in A is larger than in B. However, profit per hectare in B is very much greater than in A, even where productivity per hectare is beyond this break-even point.

The object of culturists has always been to gain a large profit and not to gain the high profit rate per kilogram. The intensive firms are capable of achieving much profit by the sheer quantity of production even if the profit per kilogram becomes small. Due to these conditions, culturists are eager to improve their culture methods from extensive to semi-intensive, and from semi-intensive to intensive.

This path has been pursued by intensive culturists as long as the selling price has exceeded the cost. However, the situation will change as soon as the price of shrimp decreases due to an increase in future production. When this happens, the intensive culture firms will not stay in business, because there are no ways to cut down production cost per kilogram in intensive culture due to high percentage of variable cost. Fig. 17 shows the changes in profitability in A and B in cases where the producer price changes by 10 and 20%. Present producer price of tiger shrimp is about ¥1,800/kg. It is clear that the profit in intensive culture will soon disappear with a small reduction in selling price. On the other hand, semi-intensive culture can remain profitable with a little effort to raise productivity.

The future situation of shrimp culture will be decided by the contribution of each type of culture method to the total production change. Intensive culture will be forced to drop out when the production of extensive and semi-intensive culture becomes dominant. After the dropping out of intensive culture, semi-intensive culture firms may have severe competition from extensive culture. However, semi-intensive firms can survive because there is plenty of room for them to raise productivity. On the other hand, production from extensive culture may not be dominant in the market, even if many new areas suitable for culture are found, because of low productivity.

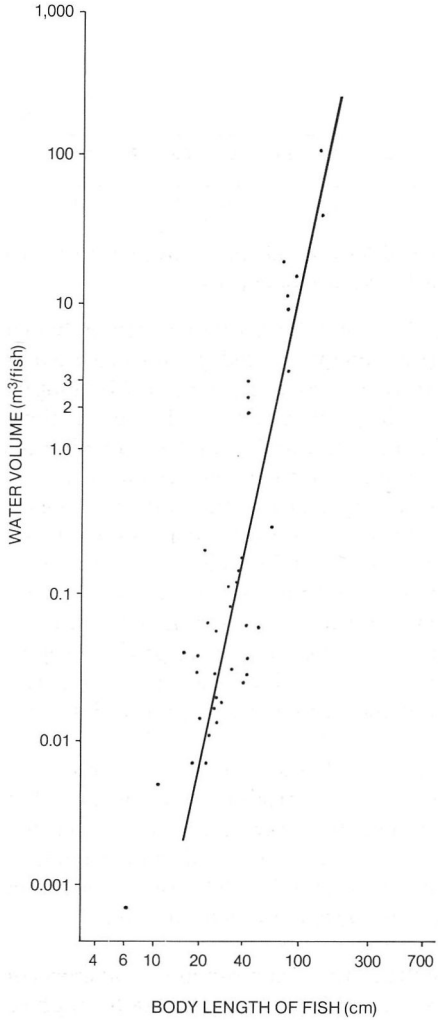

Fig. 18. Relationship between length of fish and quantity of water needed in intensive cage culture of fish in Japan. Source: Ishida, Y. 1977. Annual report of the Kochi Fisheries Laboratory.

Continuing and circulating methods of pond use

Cost forecast for cultured shrimp seems to indicate that extensive and semi-intensive methods will become dominant in the Asian area once they can raise their productivities a little. At present, however, these methods only result in small profit due to their low productivity levels. Therefore, this section deals with how to increase the productivity in extensive and semi-intensive culture without an increase in supplementary feeds. As in the case of extensive culture, it is difficult to raise productivity to a high level as supply is dependent on natural conditions, the only management being practised is to prevent predators and to selectively catch large shrimp.

Results of cage culture experience in Japan are presented in Fig. 18. The relationship between the amount of water per piece and the body length of fish in high intensive culture indicates that small fish require a small amount of water and vice-versa. This seems to be a very ordinary phenomenon. However, it is important to show the direct proportion in the relationship. The total weight of fish reared in a cage is solely dependent on the amount of dissolved oxygen, independent of any distinction in fish size.

In shrimp culture, the weight of shrimp in the Seto Inland Sea pond is about 500 g/m^2 at the time of harvest in December. This is the limit to which culturists can stock. In the traditional single harvest method of shrimp culture, seedlings are stocked into ponds in May or June and harvested once in December at the level of 500 g/m^2.

In this operation, culturists were limited to under 20 pieces of seedling per square meter in the pond as the marketable size is about 25 g per piece. Considering 20% mortality, the number of seedling stocked should be about 25/m^2. Initially, shrimp are small and there is more than adequate dissolved oxygen in the pond. However as they grow larger, their requirement becomes greater, until reaching over 25 g per piece or 500 g/m^2. Thus, in the traditional Seto Inland Sea

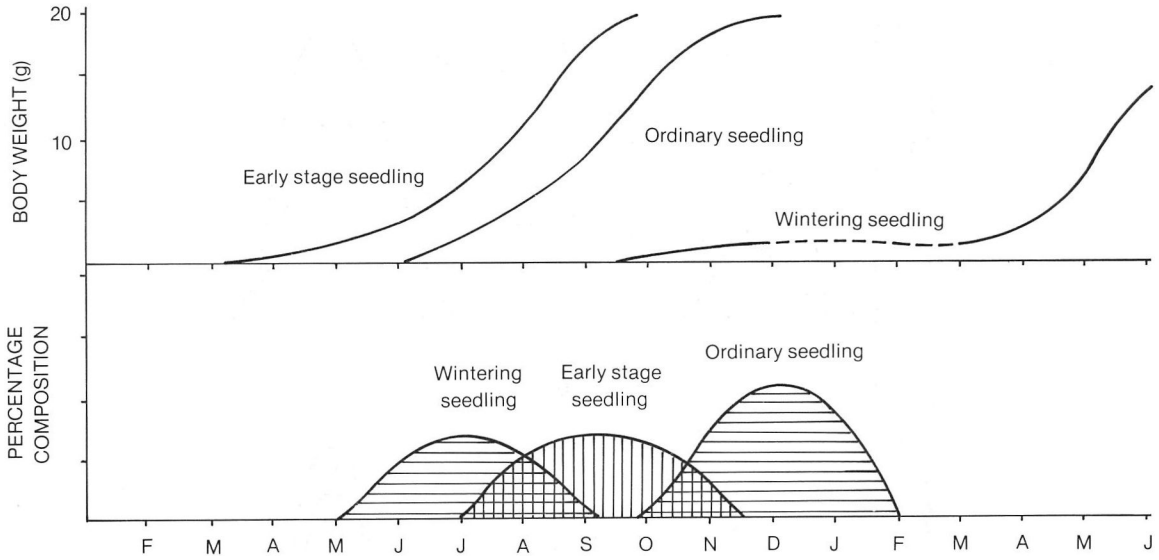

Fig. 19. Recent changes in pond use in the Seto Inland Sea (% composition refers to proportion of monthly shipment to total shipment from a given area).

operation there was no alternative other than to ship all the shrimp by December. However, the recent expanding market for live kuruma shrimp may allow a great change in the operation. As a result of the growing market, harvests are carried out many times a year, and culturists are able to raise shrimp throughout the year, and to ship them regularly every month.

Culturists stock early seedlings into the ponds in March, and ordinary seedlings in May or June (Fig. 19). These early seedlings reach a marketable small size of 13-15 g apiece in August or September. Previously, there was no market for such a small size. Culturists have also started to stock seedlings into the pond in August or September as winter seedlings in some particular ponds. Winter seedlings can grow to a size of 5-6 cm before the winter hibernation. In the Seto Inland Sea, however, it is necessary to build special nursery ponds for them. It is possible to market these seedlings in July or August the following year when they reach 19-20 g in size. Thus, the harvest period in the Seto Inland Sea area has extended to July through December.

Even with pond capacity stable at 500 g/m^2, expected production is about twice that of the old culture method. This is possible if seedlings are stocked into ponds to the limit of pond capacity, and are harvested regularly every month. Selective harvest of large shrimp allows additional room for smaller shrimp. Ponds can be restocked again with young

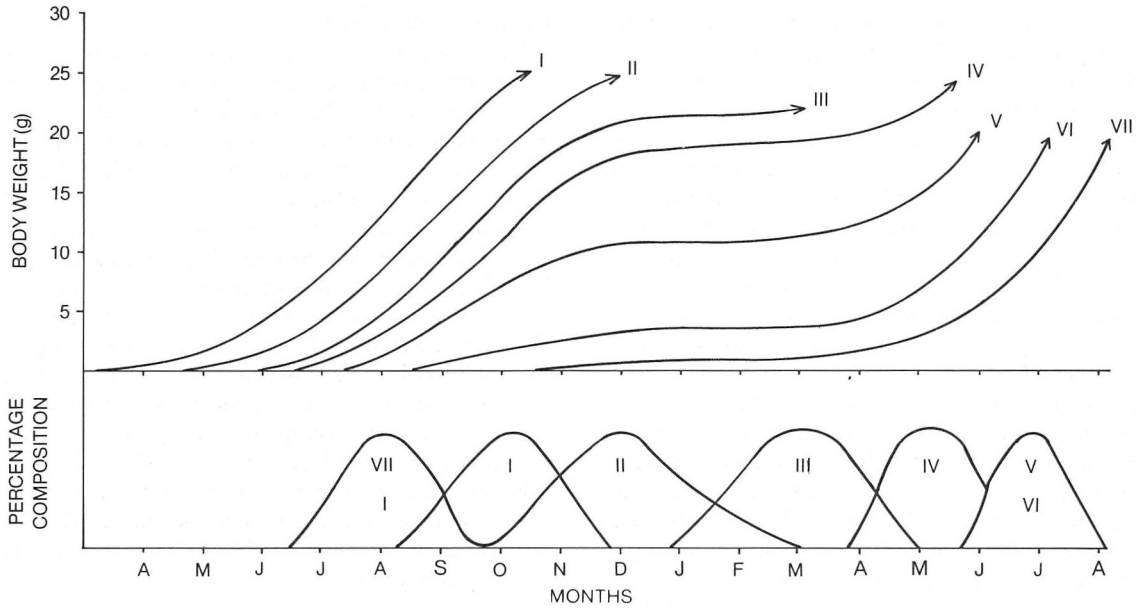

Fig. 20. Typical use of circular pond, Amakusa or type C (% composition refers to proportion of monthly harvest to total harvest of a given crop, e.g. I, II, etc.). Lines show time of stocking in the pond, culture period and growth; numerals refer to crops.

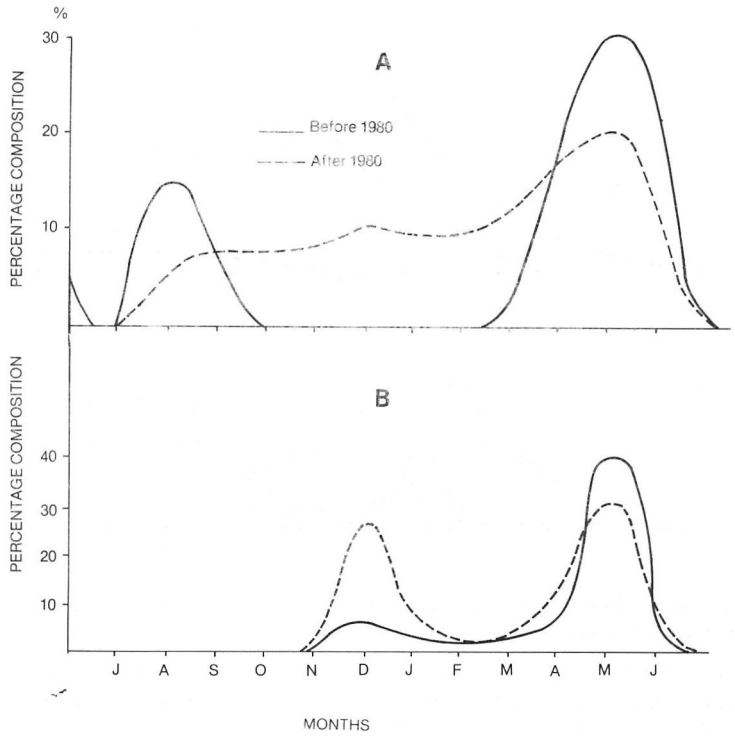

Fig. 21. Change in harvesting period of large (A) and small (B) firms in Japan before and after 1980 (% composition refers to proportion of monthly harvest to total yearly harvest of a given firm.)

shrimp. This is a way of using the pond more efficiently. The present productivity level in the Seto Inland Sea is about 500-600 g/m^2. Production of 1,000 g/m^2 in the near future is possible when this schedule of stocking and harvest is applied to new operations.

The circular ponds in Kagoshima are a typical example of this operation (Fig. 20). Kuruma shrimp in the ponds here do not hibernate in winter, so it is possible to use a pond throughout the year. Culturists in Kagoshima had been stocking ponds only once a year just as in the Seto Inland Sea. But recently they have started stocking their seedlings into ponds several times a year. Culturists may have planned for peak production in May and April when the highest price occurs. However, the balance or allotment of production for each month becomes important in maximizing profit. Impor tant factors to consider include: managerial techniques of how to use the pond efficiently; expected price every month: periods of restocking seedlings; and growth rate of shrimp

In the traditional operation, harvest and shipment wenconcentrated in a particular month. Culturists hired a small number of full-time workers and hired many part-time workers during the harvest period. In the new operation, culturists will ship a small fixed quantity of product regularly. Good pond management is achieved by increasing the number of trained full-time workers and hiring fewer part-time workers. In the traditional operation, culturists bought seedlings from the outside due to the shortage of full-time employees. In the new operation, there are enough skilled hands. With more full-time workers, many culturists have started hatcheries. It has become cheaper to produce seedlings than to buy them. In addition, the number of seedlings stocked and the frequency has been increasing so that it is critical to have adequate seedlings at the appropriate time.

This new way of operation may be called the "continuing method" of pond-use. That is, culturists put in different-sized shrimp approaching the limit of pond capacity and harvest the marketable ones daily. Young shrimp are stocked in the available space. Using this method, the productivity of the pond will almost double.

However, the continuing method is possible only in large-scale farms, because many ponds or many sections of ponds are needed for the distribution of the many sizes of shrimp. Small-scale culturists cannot distribute their shrimp efficiently among a small number of ponds. Thus, they cannot apply this new method.

Recently, small-scale culturists have started to use another strategy. Shrimp are produced for private demand to be sent live as gifts at the end of the year. The shrimp for this demand have a good price of about 10,000 ¥/kg while the ordinary market price is now about 6,500 ¥/kg. However, to sell shrimp like this, culturists have to pack 500 g to 1 kg into every package. This is time-consuming work. Large-scale culturists do not attempt it as they prefer to ship to the big city markets where large amounts of shrimp are accepted at a lower price than in the private gift market. On the other hand, small-scale culturists can adjust to this time-consuming work, as they can easily gather part-time workers from nearby as required.

Figure 21 shows recent changes in marketing periods between large and small firms. Just 3 to 4 years earlier, both types of firms shipped at similar times, but now have clearly changed and followed different patterns.

Besides the "continuing use," another new operating method has been developed. It is called the "circulating use" of ponds. This operation was developed to raise productivity. In the Philippines, culturists have been dividing their ponds into three parts: nursery, intermediate and main growing pond. The nursery pond and intermediate pond allow for better care of small-sized shrimp. This method has been introduced to increase the survival rate of seedlings and juveniles.

In Taiwan, the reason for the high productivity relates to the use of this culture system with effective water change. Fig. 22 illustrates a schedule of pond usage. Two and a half or three harvests are possible when shrimp can be reared all year round. In contrast, in the traditional method of pond-use in South Asia, only one or one and a half harvests are possible in places where shrimp are now reared only in the rainy season. With proper use of the circulating method, it may be possible to harvest three or four times a year.

Culturists in Taiwan stock their seedlings after finishing the previous harvest (Fig. 22). Thus, the pond capacity is not utilized fully while shrimp are small at the beginning and middle of the rearing period. To use a pond more efficiently, it may be best to divide it into several sections of different sizes and to put small shrimp into small sections first. After some growth, they can be shifted into larger sections. Immediately after moving the first batch of shrimp, the small section should be completely cleaned and restocked with another batch of small shrimp to repeat the process. After three months or so, every section of the ponds will be full of different-sized shrimp. In other words, all sections of the ponds are utilized to the upper limit of capacity. Thus, culturists can ship shrimp every month from the main growing section (Fig. 23). The main growing pond area is about half the total pond area. About five harvests in eight months can be expected from a main growing pond during the rainy season. Therefore, two and a half harvests from the whole pond complex can be obtained. If it is possible to raise shrimp throughout the year, it should be possible to harvest six times or so.

Nursery and intermediate ponds are rather small, and do not require much water. Fresh subterranean water can be supplied to these ponds in the same way as in Taiwan, and juvenile shrimp can be supplied at the beginning of culture periods as seedlings can be raised even in the dry season in small well prepared ponds. When this is done, the main growing pond can be used from the start, and more harvests can be achieved.

There are two important conditions in realizing this circulating use of pond. First, the pond must be prepared sufficiently. Nothing can be done with extensive or rough ponds.

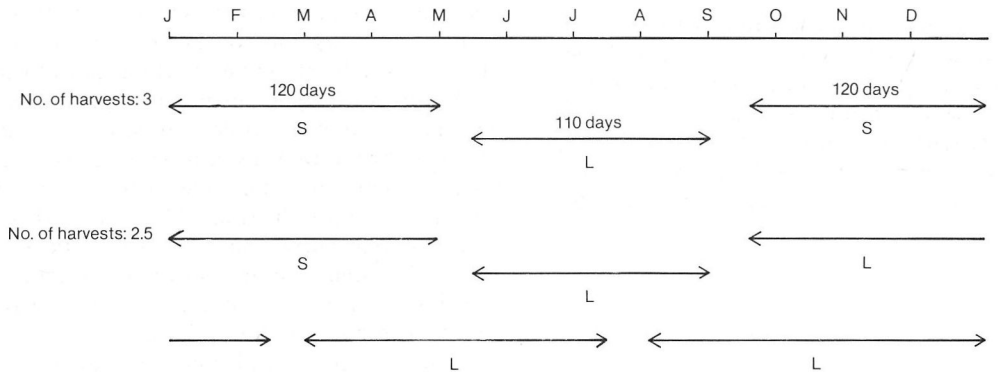

Fig. 22. Present schedule of pond use by month in the Tungkang area, Taiwan. Size of shrimp; S, small (32-35 g); L, large (35-40 g).

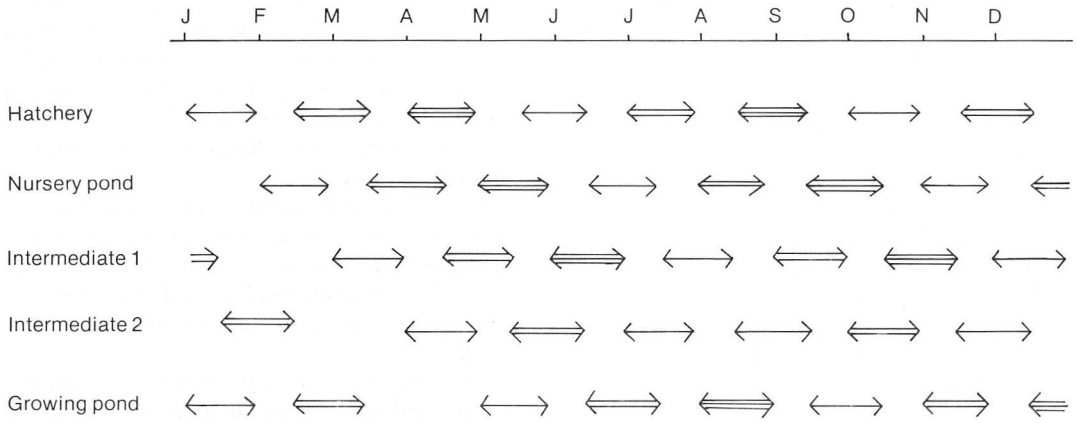

Fig. 23. A model of circulating pond use. Individual stocking or crop (as identified by number of horizontal lines) may be followed through the various production phases.

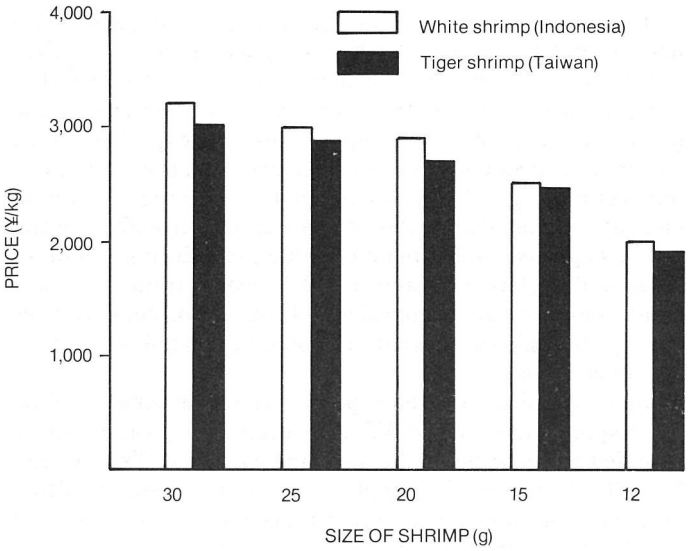

Fig. 24. Wholesale price of shrimp in the Tokyo Fish Market, September 1984.

Ponds with thick mud deposits are not suitable either. Moreover, some experience in dividing whole ponds into sections of varying dimensions is necessary. Second, it is important to be able to obtain plenty of seedlings when they are needed. Although Taiwan is well-supplied with tiger shrimp seedlings, at present it is very difficult in other Asian areas to procure sufficient tiger shrimp seedlings. It may be necessary to start white shrimp culture and also to develop the stunting method of tiger shrimp seedling production.

Although the merit of using the circulating method is primarily to increase production, it is also a way to raise productivity without any increase in supplementary feeding. Variable cost per kilogram is unchanged. Moreover, ponds can be allowed dormant periods by eliminating one harvest. In addition, by decreasing the number of seedlings put into the pond, disease is minimized and the required quantity of subterranean fresh water is reduced.

Of course, there is high initial investment in preparing existing extensive and semi-intensive ponds for this method. This should easily be recovered due to the decrease in the fixed cost per kilogram as productivity increases. It is very important to have good control of water change and to increase production of more natural food.

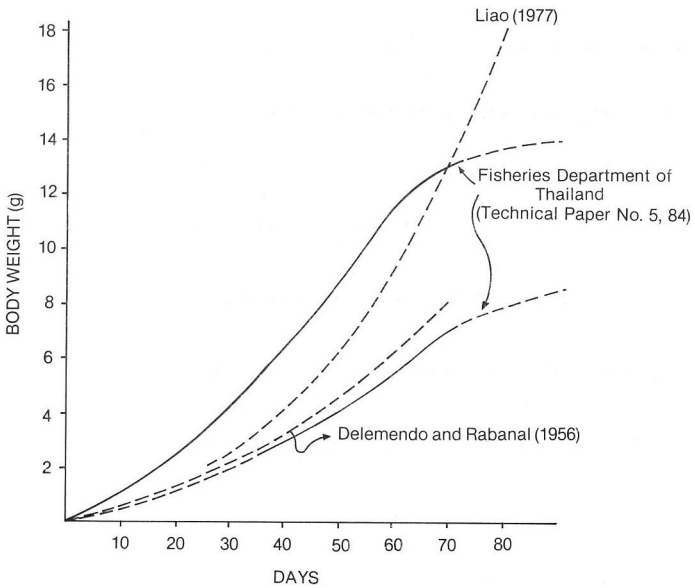

Fig. 25. Growth rate of black tiger shrimp. *Penaeus monodon* (– – –) and white shrimp. *P. merguiensis* (——).

The potential for white shrimp culture

In the development of shrimp culture in Asia, one major problem is how to increase the supply of tiger shrimp seedling. Due to the shortage of adults, the high price of seedlings may remain in the near future unless artificial breeding techniques of shrimps are successful. With this situation, there is a possibility that white shrimp culture will expand in addition to tiger shrimp culture.

Shrimp culture in the Asian areas apart from Thailand is directed mainly towards tiger shrimp. Reasons for this include the fact that techniques for larval rearing have already been developed in Taiwan and may soon be available. Secondly, the price of this shrimp is higher than others. In addition, the large size of the shrimp commands a high price and its growth rate is better than that of other species.

The price of tiger shrimp is higher than that of white shrimp in Taiwan, while the prices of tiger shrimp and kuruma shrimp in Taiwan are about the same. But the production conditions for tiger shrimp are better than for kuruma shrimp in Taiwan. Thus, tiger shrimp culture is of great interest there. However, the situation is entirely the reverse in Japan market. The price of tiger shrimp in the Central Fish Market in Tokyo is always cheaper than that of white shrimp at any size (Fig. 24).

Tiger shrimp is a traditional ingredient of Chinese cooking in Taiwan and throughout Southeast Asia. This shrimp commands a special price in the regional market. It is logical to try to culture high-priced fish, so it is also logical that the interest of aquaculturists has been directed to tiger shrimp. However, in the international market, alternatives to tiger shrimp as the object for culture are available. White shrimp is more esteemed than tiger shrimp in the Japanese market. Recently, tiger shrimp export from Taiwan to Japan has increased because of its lower price compared to the same size of white shrimp.

In out-of-home consumption, the black colour of tiger shrimp is not detrimental to marketing, as it is cooked before being served. However, the out-of-home market for shrimp in Japan is now approaching its limit if the price remains the same. The home consumption market, however, is expected to expand.

The weak point of tiger shrimp for home consumption is the difficulty in selling them in retail shops or supermarkets to people who think of shrimps as red or pink. The appearance is the deciding factor for sales, as sashimi, or raw

flesh, is valued at the highest price in Japan. Many supermarkets have in fact tried to sell tiger shrimp, but they have not had any success in expanding sales so far. Importers of tiger shrimp have established a strong base in the out-of-home consumption market, where tiger shrimp is used as a substitute for larger white shrimp because of its comparatively cheap price. However, medium-sized white shrimp is best for home consumption, with its price lower than larger ones and its colour preferred by people.

Figure 25 shows the comparison between the growth rate of tiger shrimp and white shrimp. Starting from P_{10}-P_{15}, the growth rate of white shrimp is faster within 70 days rearing, but after that the growth rate of both species diverge greatly. In the case of white shrimp culture, it is best to stop rearing at this point where the growth rate of the shrimp goes down severely.

Table 8 shows a rough economic estimation in culturing both species for 240 days. An assumption is that one rearing period for white shrimp is 70 days giving 3.4 harvests and that for tiger shrimp is 120 days giving two harvests. The number of white shrimp seedlings per hectare stocked into ponds is assumed to be twice that of tiger shrimp due to the availability of seed. Assuming the price of white shrimp is 60% that of tiger shrimp (Thailand), revenues per hectare are about 76% that of tiger shrimp. However, if costs such as seedling costs are considered, profit will be equal or larger in white shrimp culture. Seedling of white shrimp has not been sold due to a good natural supply for extensive culture. At present there is but a small demand for artificial seedling of white shrimp in Thailand or other countries because of richness of natural supply so that there have been no trials to produce white shrimp seedling commercially even in Thailand. Although the price per piece of artificially reared seedling is not clear at present, it is probably about 0.2 to 0.1 times that of tiger shrimp seedling price due to the ease of artificial hatchery rearing from a technical point of view. The ease of rearing white shrimp seedling may provide young shrimp for the main growing pond at the beginning of the culture year. This means that it is possible to harvest over four times a year and to achieve about the same sales as for tiger shrimp culture. Thus, profit will surely be high in white shrimp culture.

Table 8. A trial estimation for white shrimp and tiger shrimp culture based on Thailand experiments.

	White shrimps	Tiger shrimps
Size of shipment (g), A	13	35
Rearing period (days), B	70	120
Growth rate (g/day), $C=\frac{A}{B}$	0.19	0.29
Rearing days/year, D	240	240
Number of harvests, $E=\frac{D}{B}$	3.4	2.0
Number of seedlings, F	20,000	10,000
Survival rate (%), G	80	80
Production of one harvest (kg), $H = A \times F \times G$	208	280
One year harvest (kg), I	707	560
Price (¥/kg), J	1,080	1,800
One year revenue ($\times 10^3$ ¥), $K = I \times J$	764	1,008

Table 9. Economic status of white shrimp culture in Thailand (1984).

	Area (ha)			
	0.8-4.6	4.8-9.4	9.6-15.8	16
1. Productivity (kg/ha)	532	506	472	454
2. Producer price (¥/kg)	648	670	620	765
3. Production cost (¥/kg)	297	269	375	365
4. Net profit (¥/kg)	351	401	245	400
5. Return rate (%)*	54.2	59.8	39.5	52.3
6. Total net profit (¥/ha)	187	203	116	182
Number of samples	11	10	6	7

Source: Thailand Agriculture and Cooperative Ministry, Technical Report No. 1, 1984.

*Return rate (%) $= \frac{\text{Net profit}}{\text{Producer price}} \times 100$

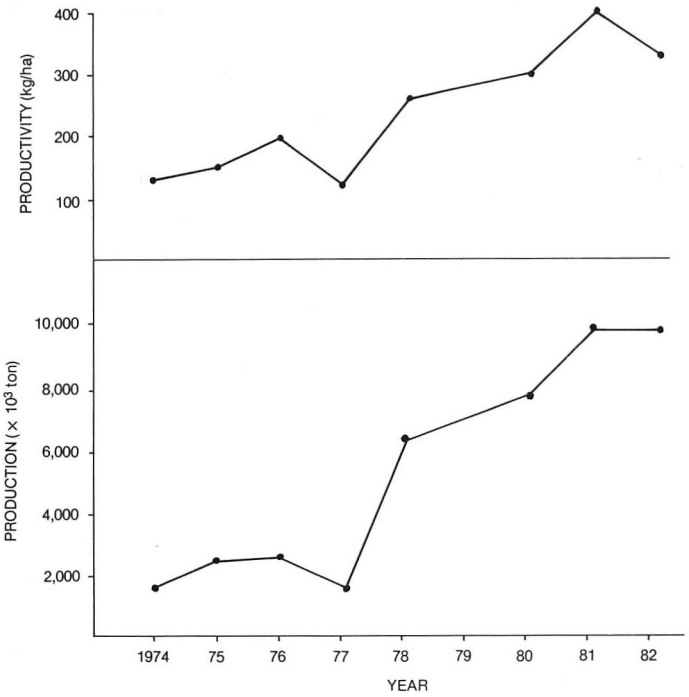

Fig. 26. Production and productivity of white shrimp culture (no feeding) in Thailand. Source: Government of Thailand. 1984. Technical Report No. 1.

There are many adult white shrimp in coastal sea zones and estuary areas. They lay eggs in the ponds and canals naturally. Artificial hatching can be done by laymen. At present in the Philippines, after picking out the seedling of tiger shrimp, the remaining seedlings are discarded. The seedling of tiger shrimp only make up about 10% of the total seedling catch, the rest being mainly white shrimp.

In Thailand, there has been a 50-year history of shrimp culture centered around the white shrimp. Fig. 26 shows a recent development in the shrimp culture of this country. The inner part of the Gulf of Thailand is a main production center of culture. However, new ponds have been sited in the

southern part of the bay recently. While many old ponds were converted from salt fields, most of the new ponds are constructed from mangrove areas.

Table 9 shows some results of extensive culture in the inner part of Thailand. Due to the limited number of samples, it is not possible to point out a general trend in the productivity and cost by farm scale. However, the family farm having a 4.8-9.4 ha pond is the most profitable size based on the profit rate. In Thailand, a government employee who has recently graduated from college or university can earn about 360,000 ¥/year. Culturists can earn about 180,000 ¥/ha in net profit. Thus a person who has a 5-ha pond can live in comfort.

In Thailand, the present average production level is under 200 kg B.T.C./ha. This productivity level is low. However, even extensive culture can reach this level without any supplementary feeds and seedlings. If seedlings can be produced in the hatchery and ponds can be prepared to minimize the entry of predators, it is possible to raise the productivity two-fold. In addition, by use of the circulating or continuing method, productivity can be expected to attain levels of about three or four times present levels.

In addition to the current emphasis on tiger shrimp culture, there are significant opportunities for white shrimp culture in Asia. These must not be overlooked.

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Economics of Penaeid Culture in the Americas

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Abstract Shrimp culture in the Americas began in the early 1970's and has experienced rapid growth in some Latin American countries. Currently, Latin America produces one-third of all cultured shrimp with Ecuador as the leading country in the world. Availability of postlarvae and a favorable year-round climate have been the most important factors causing a "Gold Rush" expansion in Ecuador. The long-term potential for shrimp mariculture in Latin America is promising. Projections for 1990 production of cultured shrimp by Latin American countries are between 60,000-70,000 metric tons (mt). Shrimp culture in the United States has begun with the entry of a few small firms.

In this paper, investment and production costs are examined for a semi-intensive farm that purchases postlarvae and operates in the southern United States. Total investment decreases as pond size increases for a given size facility. Investment per kilogram of annual average production ranges from just under US $20.00 for a 20-surface ha farm using 2-ha ponds to $80.00 for a 400-ha system using 20-ha ponds. Operation costs per kilogram decline as the size of the system and the size of the ponds increase. It costs $10.10 to produce one kilogram of shrimp on a 20-surface ha farm using 2-ha ponds compared to $5.50 on a 400-surface ha farm using 20-ha ponds.

In comparing the operation of a semi-intensive 200-ha farm in Ecuador with a similar farm in the United States, costs of production were $3.12 and $5.83 per kilogram, respectively. The after-tax internal rate of return (IRR) was 59% in Ecuador and 21% in the United States. These IRR's were calculated under the assumption that production, costs and prices received are constant over the investment period (10 years) considered. When risk and timing of investment are considered, these IRR's are reduced.

Introduction

Shrimp mariculture is becoming a reality in many countries on the American continent. Some countries which had only a small amount of cultured shrimp are now beginning to report growth of their industry. Other countries that have not been significantly involved are taking steps to encourage shrimp culture. The Branch of the Foreign Fisheries Analysis of the United States reports that of the 16 countries in the world producing cultured shrimp, half are located in Latin America and half are in Asia (Table 1). Latin America produced over one-third of the cultured shrimp in the world in 1982 and Ecuador is the largest producer of cultured shrimp (D.M. Weidner, pers. comm., 1984).

The long-term potential for shrimp culture is promising. Factors affecting the advancement of shrimp culture in the Americas, as well as the world, are economic, technology, environment and politics (D.M. Weidner, pers. comm., 1984). In terms of economics, international demand and supply determine world shrimp prices. Cultured shrimp are only a minor part of total supply which is determined mostly by the harvest of wild stocks. Harvest of wild stocks is at or near maximum sustainable yield (National Oceanic and Atmospheric Administration. 1980; Robinson, 1982) and any significant increase in world supply will come from cultured shrimp. The expansion of cultured shrimp will depend on its cost of production relative to world shrimp prices.

The major objective of this paper is to examine the cost of producing shrimp in the Americas. A review of shrimp culture in the Americas will first be given. Second, costs of producing shrimp relative to size of pond and total size of facility will be examined. The cost of producing postlarvae will also be briefly examined. Third, cost and returns comparisons will be made between the United States and Ecuador for constructing and operating a 200-ha shrimp farm. Finally, some indication of risk will be discussed.

Review of the Americas

It is reported that shrimp farming in Ecuador began by accident in 1962 (Hirono, 1983). A perimeter berm around a farmer's plantation, where he had planted coconut palm trees, was damaged by unexpected high tides. When the farmer returned some months later, he noticed birds dining on large shrimp in a pool of water. This gave rise to the idea of shrimp farming in Ecuador. The first shrimp farm was constructed in 1969 (Shrimp Notes, Inc., 1983).

The most important factor leading to the development of shrimp farming in Ecuador was the availability of postlarvae caught from the wild. These postlarvae, predominantly *Penaeus vannamei*, are caught by artisanal fishermen in estuaries and sold to shrimp farmers for stocking in ponds or nurseries. The major limitation to the development of commercial shrimp farming in Ecuador and the Western Hemisphere is maturation/reproduction in captivity with the production of viable larval nauplii (Lawrence et al., 1984). The natural abundant source of postlarvae along with cheap labor and absence of legal restrictions allowed rapid growth of shrimp culture in Ecuador. Other important factors influencing the development of shrimp culture were favorable climate, inexpensive coastal land, fuel, and wage rates (D.M. Weidner, pers. comm., 1984). These conditions plus high prices for shrimp led to a "Gold Rush" fever in Ecuador (Hirono, 1983). In 1982, there were 112 farms in Ecuador ranging from less than 50 ha to more than 200 ha (Table 2). The area in production increased over 13 times and production increased over 18 times from 1977 to 1982 (Table 3).

Other Latin American countries on the Pacific possess favorable conditions similar to Ecuador and culture methods developed in Ecuador and Panama are now spreading to other countries. *P. vannamei*, the dominant species used in these countries is not available on the Atlantic coast and is, at certain times of the year and for some geographical locations, in short supply on the Pacific coast. As a result, companies are building hatcheries to produce postlarvae but they have had problems. Agromarina, S.A., a division of Ralston-Purina, has had the largest hatchery success and supplies approximately 80% of the postlarval requirement for their more than 600 ha of grow-out ponds (D.M. Weidner, pers. comm., 1984).

Table 1. Cultured shrimp production in the world in 1982, by country (D.M. Weidner, pers. comm., 1984).

Continent/country	Production (mt)
Asia	
India	15,000[a]
Indonesia	11,313
Taiwan	9,575
Thailand	10,091
Philippines	3,900[b]
China	1,400[a]
Malaysia	157
Korea (ROK)	109
Total	51,545
Latin America	
Ecuador	21,500
Brazil	200[a]
Peru	600[a]
Panama	1,500
Honduras	250[a]
Guatemala	100[a]
Martinique	150[a]
Jamaica	25
Total	24,325

[a]Estimated

[b]Production in 1981

Table 2. Total numbers of Ecuadorian marine shrimp farms by size in 1982 (Shrimp Notes, Inc., 1983).

Farm size (ha)	No. of farms
<50	52
51-100	25
101-150	14
151-200	7
>200	14
Total	112

Brazil, which has the most extensive coastal area for shrimp culture, has been discouraged with native species. The import of exotic species, however, has been encouraging. *P. japonicus* has been cultured in their tropical climate and Brazilian farmers report that this species has reproduced in ponds. Therefore, they can produce their own postlarvae without the necessity of maturation/reproduction in captivity. Other Caribbean countries are now beginning to copy this method of shrimp mariculture (D.M. Weidner, pers. comm., 1984).

Although the long-term potential for the Americas is encouraging, it is not without problems. Shortages of postlarvae slow the growth rate at which the industry can expand. Advances in the technology of larval (nauplii) production with construction of hatcheries will allow significant increases in production.

Some governments promote shrimp culture, but on the whole government policies tend to slow expansion of the industry. Some countries prevent or discourage private domestic or foreign investment. Mexico, which has one of the greatest potentials, has restricted shrimp culture to the fishermen's cooperatives. Ecuador, as well as other countries, controls the exchange rate which discourages investment. Some countries have complicated shrimp hatchery and farm operations by restricting the import and export of *Artemia*, shrimp nauplii, postlarvae, broodstock and some equipment. Those countries which do not have a culturable native species will not be able to develop a shrimp farming industry until a reliable source of postlarvae can be imported (D.M. Weidner, pers. comm., 1984).

Despite these difficulties, shrimp culture in the Latin American countries will continue to grow. When maturation/reproduction and hatchery technology that can produce healthy postlarvae becomes available, shrimp culture will most likely increase at a rapid rate. This unknown of postlarvae availability, plus the other problems mentioned above, make projecting production difficult. However, projections are that Latin America will produce between 60,000-70,000 mt by 1990 (Table 4). If technical problems are overcome early, then production could exceed this estimate (D.M. Weidner, pers. comm., 1984).

Unlike the Latin American countries, the United States has a limited growing season for culturing shrimp. Shrimp culture has been researched for 15 years in the United States and growing shrimp has been attempted since the early

1970's with limited technical and no economic success. Currently, there are 16 farms in the continental United States or Hawaii that are either in the planning or pilot stage of production. At least six of these have or plan to have hatcheries for postlarvae production. These farms range from a large 60-ha pond extensive system to very small 0.2-ha intensive ponds.

Investment and operation costs

This section deals with investment and operating costs for semi-intensive shrimp farms using *P. vannamei* as the cultured species. Farms in this analysis range in size from 20 to 400 ha and use ponds ranging in size from 2 to 20 ha. The major objective of this section is to determine the economies of size associated with total size of the farm and size of the pond. Investment and operating cost are developed in this analysis using the Generalized Budget Simulation Model (Griffin et al., 1983) and research data. Although the generated investment and operating costs are for a farm located in the southern United States, the relative investment operating cost relationship between size of farms will be the same regardless of where a farm is located.

Investment costs

Table 5 shows the total investment of major items for a semi-intensive 200-surface ha shrimp farm using 20-ha ponds. This is similar to a typical large farm being constructed in Ecuador today. Notice that land and construction cost are by far the major investment items. Land prices ranged from $1,500 to $8,000/ha. A price of $3,750/ha was used in this analysis. Land is 43% of total investment cost. Pond construction includes earth moving, pipes, gate valves, engineering fees, etc., and is 40% of total investment which for this 200-ha facility is slightly under $2 million.

Figure 1 shows total investment by all size farms considered in this analysis. For the 200-ha system just discussed, the total investment would increase from $1.9 million to $2.2, $2.7 and $3.4 million as the size of the grow-out pond is decreased from 20 to 10, 4 and 2 ha, respectively. Investment cost increases because it requires more land, earth moving and inflow and outflow equipment to maintain 200-surface ha of production as the size of ponds decreases. Clearly, as the grow-out pond increases in size, investment cost per surface hectare will decrease for any given size farm.

Figure 2 shows the same investment cost as Fig. 1, but on a per kilogram of shrimp basis. Production per hectare is assumed to be held constant at 1,159 kg/ha across all size facilities and is based on research data from the Research Facility at Corpus Christi, Texas, U.S.A. Investment cost per kilogram of annual production, assuming a single crop per year in the United States, would be $8.30 for a 200-ha farm using 20-ha ponds. For the same size farm, the investment cost would be $6.00 higher ($14.60) if 2-ha ponds were used. Fig. 2 illustrates that there are significant economies of size to be captured relative to investment cost both by increasing the size of farm and ponds. This analysis is consistent with other aquaculture systems studied (Giachelli et al., 1982).

Table 3. Total marine shrimp farm harvest (heads-off) for Ecuador, 1977 to 1982 (preliminary) with projection from 1983 to 1986 (Shrimp Notes, Inc., 1983).

Year	Area (ha)	Production (mt)	Production ($\times 10^6$ lb)	Productivity (kg/ha/yr)	Productivity (lb/acre/yr)
1977	3,000	818	1.8	273	243
1978	5,500	1,682	3.7	306	273
1979	8,200	2,545	5.6	310	277
1980	18,570	5,909	13.0	318	284
1981	27,000	9,091	20.0	337	301
1982*	40,000	15,040	33.1	376	335
1983	45,000	17,818	39.3	396	353
1984	55,000	24,955	55.0	454	405
1985	62,000	34,955	77.1	564	503
1986	65,000	48,909	107.8	752	671

*Preliminary data based on 80% aquaculture production.

Table 4. Cultured shrimp production in 1982 and projected production in 1990 for Latin America (D.M. Weidner, pers. comm., 1984).

Country	Production (mt) 1982	1990
Ecuador	21,500	40,000
Brazil	200*	4,000
Peru	600*	3,500
Panama	1,500	3,000
Honduras	250*	2,500
Colombia	—	2,000
Mexico	—	2,000
Venezuela	—	1,500
Belize	—	1,500
Bahamas	—	1,300
Guatemala	100*	1,000
Martinique	150*	750
French Guiana	—	750
Dominican Republic	—	500
Puerto Rico	—	500
Costa Rica	—	500
Haiti	—	400
Guadeloupe	—	250
El Salvador	—	200
Nicaragua	—	200
Dominica	—	200
Suriname	—	100
Jamaica	25	100
Cuba	—	50
Guyana	—	50
Uruguay	—	—
Argentina	—	—
Chile	—	—
Others	—	250
Total	24,325	67,110

*Estimate

Operating costs

Costs considered in this analysis do not include income tax. The only operating cost (fixed and variable) not included is interest since it is assumed that private investors will provide all capital needed to build the facility (opportunity cost

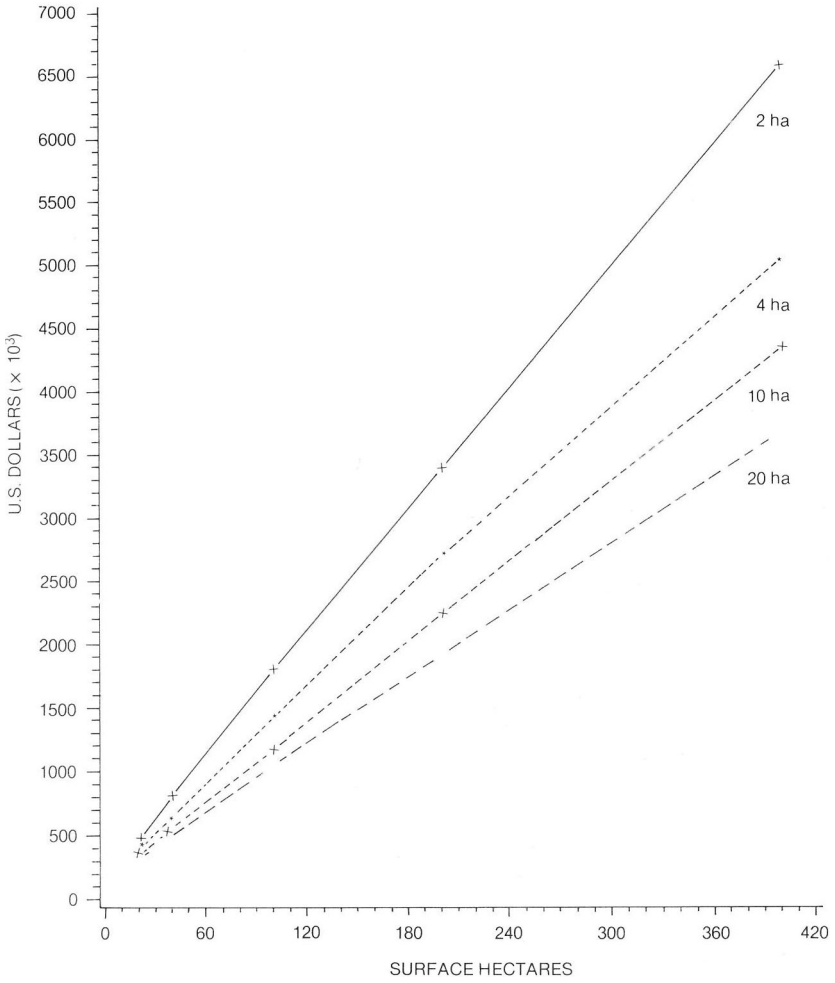

Fig. 1. Total investment costs for semi-intensive shrimp farms ranging from 20 to 400 total surface ha using 2- to 20-ha ponds producing *Penaeus vannamei* located in the southern United States, 1984.

of capital not included in cost figures). This cost represents the total annual cost of producing shrimp in ponds when under conditions of certainty (no risk).

Table 6 presents the annual variable and fixed costs of operating a 200-ha shrimp farm using 20-ha grow-out ponds. Farms in this analysis are assumed to stock 150,000 postlarvae/ha at a cost of $12/thousand. Only one crop is produced during the growing season of 185 days. After stocking, water is exchanged in the pond from 3 to 5% daily until harvest. Shrimp are fed 3 to 18% of their body weight depending on the average size of animals in the pond. The average food conversion ratio is 2.5:1.

Table 5. Investment cost in a semi-intensive 200-surface ha shrimp farm using 20-ha ponds producing *Penaeus vannamei* located in the Southern United States, 1984.

Item	Cost (US $)
Land	828,000
Pond construction	764,232
Building construction	64,155
Equipment	183,529
Machinery	74,724
Total	1,914,640

Feed, which costs $440/mt in the United States, is the most expensive item listed in Table 6 and represents 36% of variable cost. Postlarvae is second to feed at 32% of variable cost. Labor is the next highest (12%) followed by harvest cost (10%). Total variable cost is in excess of $1 million and is 83% of total cost.

Depreciation is more than half of total fixed cost (53%) and overhead, which includes a manager and an assistant manager's salary, is 36% of total fixed cost. Total annual cost for producing one crop of shrimp per year is $1.3 million. Cash operating expenses are $1.2 million per year.

Figure 3 shows the variable, fixed and total cost per year for various size systems using four different size ponds. Notice that as size of the system becomes larger, costs (variable, fixed and total) increase. The difference in total cost for using different size grow-out ponds is almost the exclusive result of fixed cost. Thus, once a system is built, it takes basically the same amount of variable cost to operate

the system, regardless of size of grow-out pond used. This is because postlarvae, fuel, fertilizer and harvest cost per hectare are constant across all size facilities. Some small economies of size are available for repairs, labor, utilities and payroll taxes.

Figure 4 illustrates the cost per kilogram (heads-off) to produce shrimp for the various size systems. A 400-ha system using 20-ha ponds can produce shrimp for $5.50/kg (heads-off) where a 20-ha system using 2-ha ponds cost almost twice as much. Increasing the pond size from 2 to 20 ha for a given size system reduces the cost of production by almost $0.70/kg.

Hatchery costs

In the above analysis it was assumed that a farmer would purchase his postlarvae from an outside source which is the basic practice in Ecuador. However, in the United States, only two companies have begun to sell postlarvae in limited amounts. Therefore, supply and demand are erratic and uneven. If a farm does not have its own supply of postlarvae, it may not be able to stock its ponds at the beginning of the season. By the time postlarvae are acquired, a significant portion of the limited growing season may be lost.

Table 6. Annual cost for operating a semi-intensive 200-surface ha shrimp farm using 20-ha ponds producing *Penaeus vannamei* located in the Southern United States, 1984.

Item	Cost (US $)
Variable cost	
Postlarvae	360,000
Repairs	27,729
Fuel	45,093
Feed	408,000
Fertilizer	10,845
Labor	132,640
Utilities	3,912
Harvest	109,545
Payroll taxes	20,185
Total	1,117,949
Fixed cost	
Overhead	80,795
Depreciation	118,944
Insurance and taxes	11,023
Taxes	14,131
Total	224,893
Total cost	1,342,842

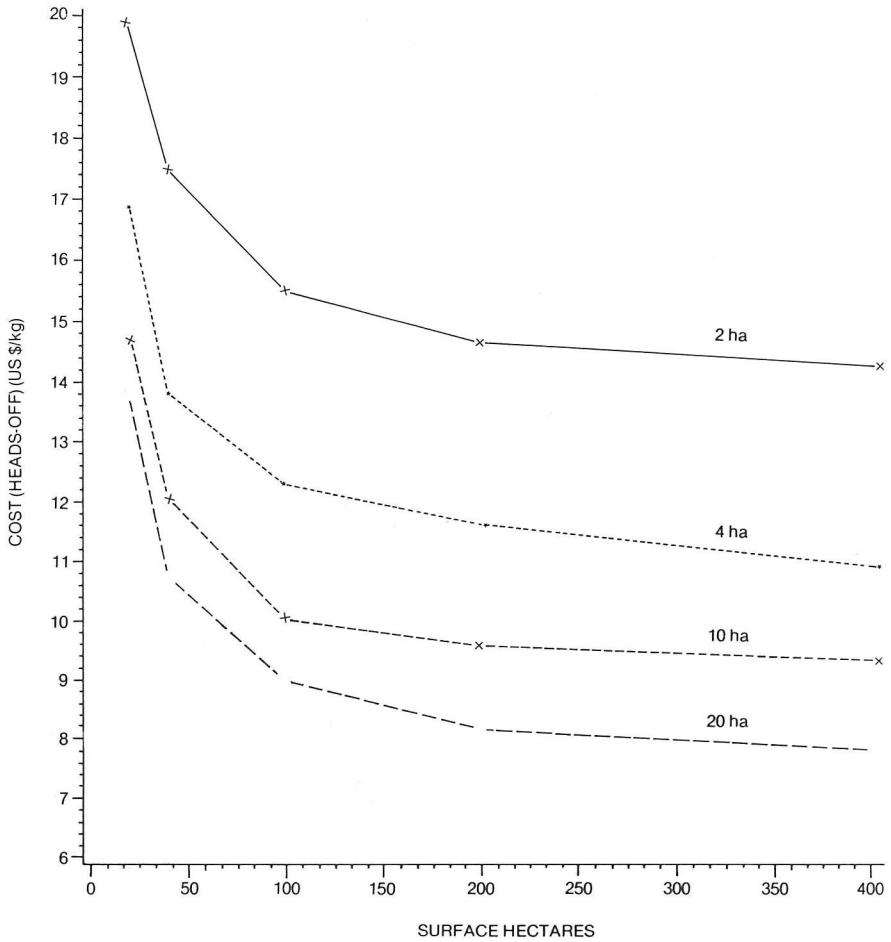

Fig. 2. Investment cost per kilogram for semi-intensive shrimp farms ranging from 20 to 400 total surface ha using 2- to 20-ha ponds producing *Penaeus vannamei* in the southern United States, 1984.

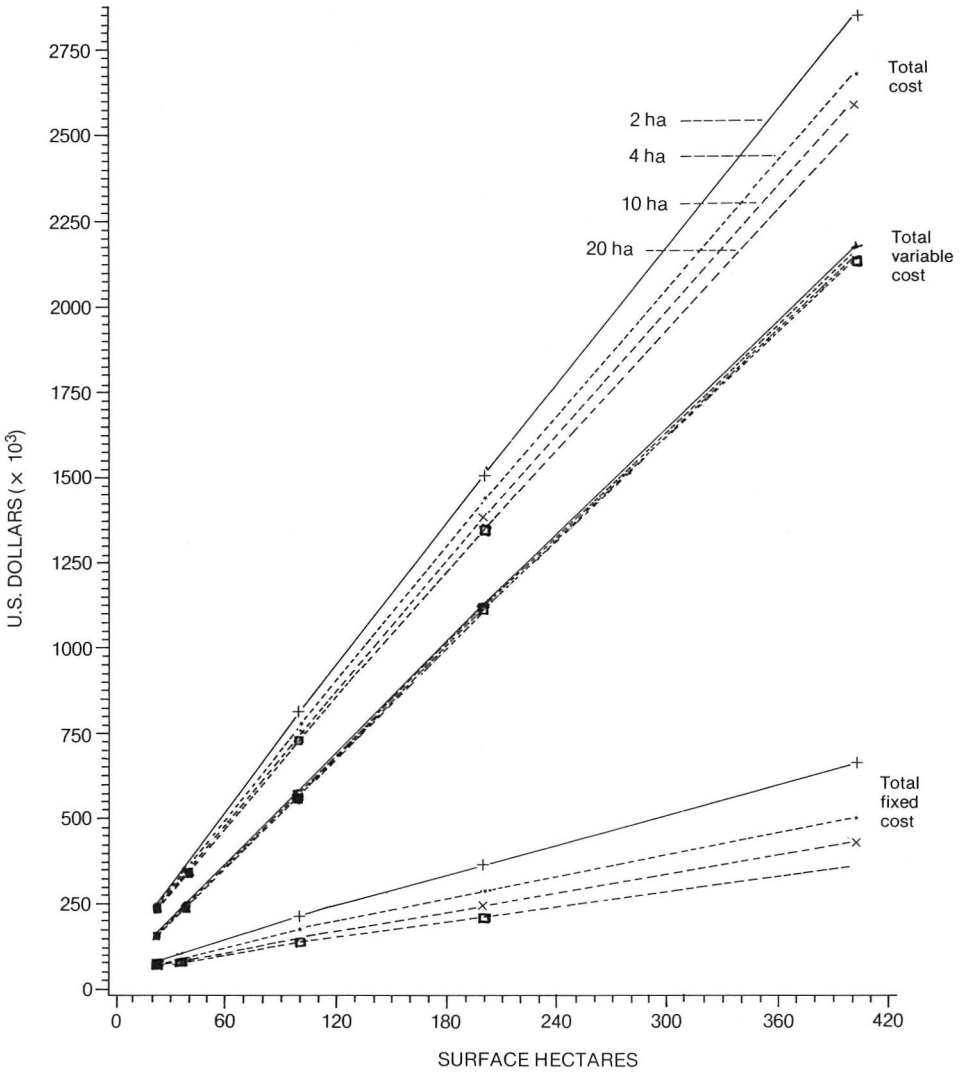

Fig. 3. Total fixed cost, total variable cost and total cost for semi-intensive shrimp farms ranging from 20 to 400 total surface ha using 2- to 20-ha ponds producing *Penaeus vannamei* located in the southern United States, 1984.

Table 7. Break-even price (US $) for production of *Penaeus vannamei* postlarvae utilizing an onsite reproduction unit to stock the entire farm in two reproduction unit runs for a farm located in the Southern United States that produces one crop per year, 1984.

Pond	Total surface hectares				
size	20	40	100	200	400
2	15.00	13.83	11.13	11.97	11.38
4	17.00	13.83	11.47	11.97	11.38
10	19.67	13.83	11.13	12.00	11.38
20	22.00	13.83	11.67	12.00	11.40

Table 7 shows the break-even price per thousand for producing *P. vannamei* in an onsite farm reproduction unit. It assumes that the farm produces a single crop per year and two 20-day hatchery cycles are required to stock all the grow-out ponds. Shrimp are assumed to spawn at 5% per night with eggs having a 50% hatch rate. Survival in the hatchery is assumed to be 40%.

Postlarvae cost for a pond production system of 100 ha or greater is estimated to be $11.00 to $12.00/thousand. It was assumed in the above cost analysis that farmers could buy postlarvae for $12.00/thousand. If the market price for *P. vannamei* is $12.00/thousand, then farmers would be indifferent between buying or producing their own postlarvae. If the market price exceeds $12.00/thousand, it would be better for farmers to produce their own postlarvae. If the market price is less than $12.00/thousand, farmers would not buy from an assured source of supply.

For farms less than 100 ha in size, the farmer would benefit by purchasing postlarvae if the market price was $12.00/thousand. The price per thousand for producing postlarvae for these smaller farms increases as pond size increases due to restrictions on how fast a pond or hatchery tank must be stocked. A 20-ha farm using a 20-ha pond requires the pond to be filled in one hatchery run causing it to have the highest unit cost for postlarvae production. In countries with year-round growing season, the size of the re-

production unit can be reduced substantially since it could be operated year-round to stock ponds, thus reducing fixed cost. The cost of postlarvae in Ecuador is approximately $4.00/thousand, however, the need for reproduction units in Latin American countries is based more on shortage of postlarvae rather than a high market price.

Comparison of Ecuador and the United States

This section will compare the economics of operating a shrimp farm in Ecuador and the United States. For this comparison, a 200-surface ha farm using 20-ha ponds will be used. A semi-intensive farm in the United States (SI-US) will be compared to a semi-intensive (SI-E), semi-extensive (SE-E) and an extensive (E-E) operation currently used in Ecuador.

Although there are several differences between Ecuador and the United States in their ability to produce shrimp in ponds, the two most important differences are availability of postlarvae and length of growing season. Ecuador has wild postlarvae available through fishermen and a year-round growing season. The United States, on the other hand, does not have a ready source of postlarvae and the growing season is limited to 180 to 240 days/year.

Table 8 shows the production specifications for comparing the farms. The United States farm is based on data from research ponds at Corpus Christi, Texas. Ecuadorian farms are based on actual farms as described by Hirono (1983).

Stocking density of the SI-US farm is triple that of the SI-E farm. Stocking density decreases as the intensity of production decreases for the Ecuadorian farms. Percent survival generally increases as the stocking density decreases. A 19 g animal is produced in approximately 190 days on the SI-US farm, whereas a 21 count animal is produced in approximately 175 days (45 days in nursery and 130 days in grow-out ponds) on the SI-E farm. Only one crop is produced per year on the SI-US farm. As the farms in Ecuador become more intense in their operation, the number of crops produced per year increases.

The total number of kilograms produced with one crop on the SI-US farm is only a little less than the SI-E farm that produces 2.4 crops/year. The annual production decreases

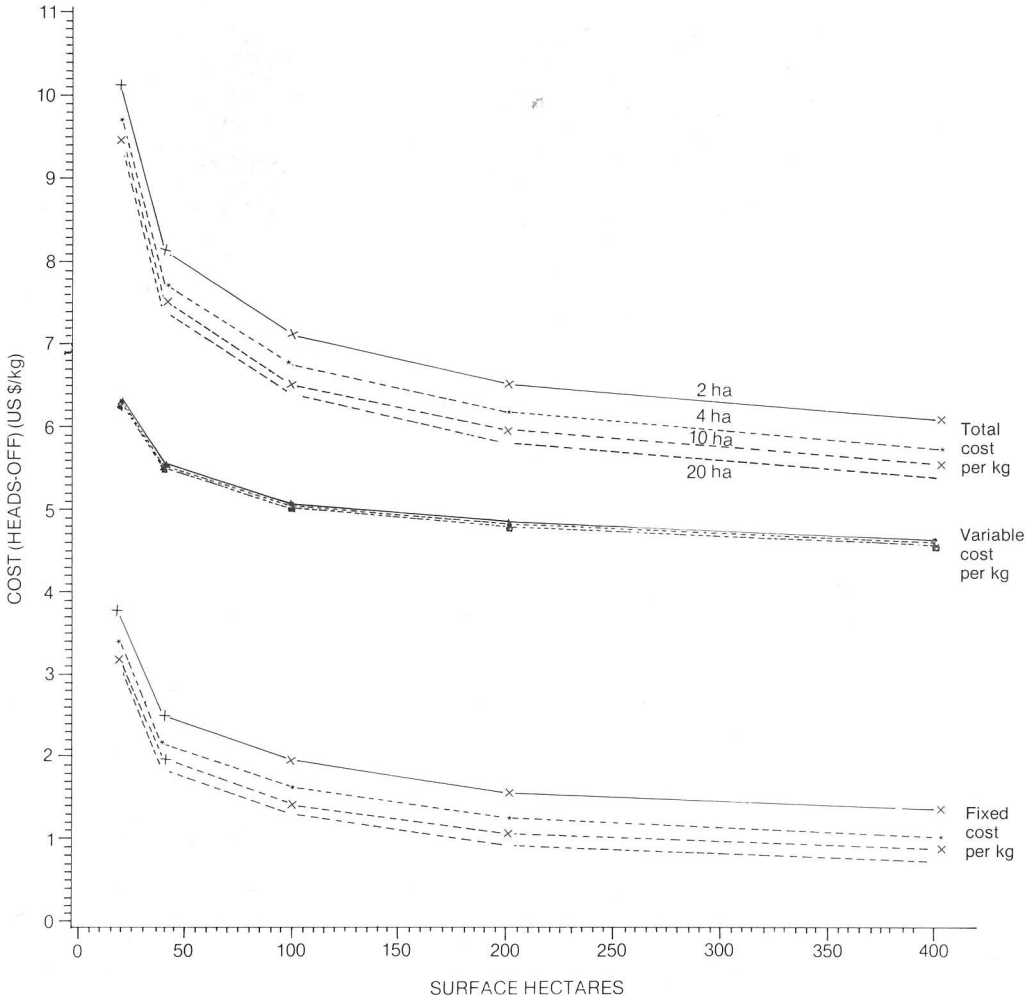

Fig. 4. Fixed cost, variable cost, and total cost per kilogram for semi-intensive shrimp farms ranging from 20 to 400 total surface ha using 2- to 20-ha ponds producing *Penaeus vannamei* located in the southern United States, 1984.

Table 8. Production specifications for a semi-intensive farm located in the United States and a semi-intensive, semi-extensive and extensive farm located in Ecuador (Hirono, 1983).

Item	United States	Ecuador		
	Semi-intensive	Semi-intensive	Semi-extensive	Extensive
Stocking density/ha	150,000	50,000	25,000	12,000
Survival (%)	65	75	80	85
Harvest size (g)	19	21	22	25
Number of crops	1	2.4	1.8	1.3
Total production (heads-off) (kg/ha/yr)	1,159	1,323.1	554.4	232.1
Food conversion ratio	2.5:1	2.5:1	1:1	—
Fertilizer	Yes	Yes	Yes	No
Water exchange	Continuous	Continuous	Continuous	Minimal
Nursery ponds	No	Yes	Yes	No

substantially as farms become less intensive in their operation.

Only the E-E farm does not use fertilizer and only uses minimal water exchange. The SI-US farm and the E-E farm do not use nursery ponds. A 5 day-old postlarva is stocked in the SI-US and a 10 to 40 mm shrimp is stocked in the E-E farm. Since nursery ponds are used with the SI-E and SE-E farms, a 1 to 3 g shrimp is usually stocked in the grow-out ponds.

Results of the economic analyses are presented in Table 9. Economic data for a SI-E farm were obtained through personal communication (S. Horton, 1983; C.R. Mock, 1984; B. Price, 1984) and through Shrimp Notes, Inc. (1983). The SE-E and E-E farm cost information was developed by modifying the data for the SI-E farm based on descriptions by Hirono (1983) of each type of farm. All analyses are in United States dollars at the official exchange rate of 54 sucres: US$1. Prices received and unit cost for this analysis are based on beginning 1984 dollars.

Production per hectare is greatest for the two semi-intensive systems (Table 9). The SI-E farm produces 14% more kilograms shrimp per hectare per year than the SI-US farm. The reason is the SI-E farm produces 2.4 crops through a full year of production using a nursery pond system whereas the SI-US farm produces only one crop per year without a nursery pond in a 185-day growing season. Production per crop is much greater in the SI-US since stocking density is three times larger and the crop is growing in the pond almost 50% longer. Production on the SE-E and E-E farms are only 42% and 18%, respectively, of production on the SI-E farm.

The difference in prices received by each type of farm is a result of the different sizes of shrimp produced. As the size of shrimp increases, the price increases. Prices received by Ecuadorian farmers for a given size shrimp are only slightly lower than those received in the United States (Shrimp Notes, Inc., 1983).

The value of the annual production of the SI-E farm is 22% greater than that of the SI-US farm. The production value of the SE-E and E-E farms are only 47% and 21%, respectively, of the SI-E farm.

The most significant variable cost item for the two semi-intensive systems is feed. It is 37% of variable cost on the SI-US farm and 43% of variable cost on the SI-E farm. The unit cost of feed was estimated to be 18% higher in the United States than in Ecuador. Postlarvae cost is the second most significant variable cost in the SI-US farm and ranked third for the SI-E farm. Postlarvae cost per thousand used in this analysis was three times greater ($12.00 vs. $4.00) in the United States than Ecuador and the total shrimp stocked in one year is 25% greater for the SI-US farm than the SI-E farm.

The second most important cost for the SI-E farm is miscellaneous which is composed of miscellaneous, payroll tax (40% of wages) and meals. Wages are the third most important item for the SI-US farm, but rank fifth for the SI-E farm. Even though wages are much higher for the SI-US farm, it has only 11 employees compared to 30 for the SI-E farm.

Table 10 shows the percent value of the crop produced for variable cost, fixed cost and total cost for each type of farm. Cost per value of crop produced is approximately 50% higher for the SI-US farm compared to the Ecuadorian farms.

Income tax is assumed to be 50% for all type farms. The authors are not familiar with the tax rate in Ecuador, however, Ecuadorian farmers have to exchange 70% of their dollars to sucres at the official exchange rate (54 to 1) and 30% can be exchanged at the market rate (approximately 100 to 1) causing a significant tax on all shrimp exported to the United States (Shrimp Notes, Inc., 1983). However, it must be remembered that all costs in this analysis were converted at the official rate making returns above cost a conservative estimate.

The cost to produce one kilogram of shrimp (heads-off) is greatest for the SI-US farm and least for the SI-E farm (Table 9). For Ecuador, the less intensive the farm operation, the higher the cost per kilogram to produce the product. It should be noted that two of the major cost items for the SE-E and E-E farms are repairs and miscellaneous. These values are rather arbitrarily estimated and, therefore, could be significantly over-estimated. However, the cost for maintenance in Ecuador would be greater than the United States because of low availability of replacement parts and skilled labor. If these costs were reduced by half, then the cost to produce shrimp for the SE-E and E-E farms would be approximately the same as the SI-E farm.

The after-tax internal rate of return (IRR) based on a

Table 9. Economic comparison (per hectare) of a 200-surface ha shrimp farm using 20-ha ponds by intensity of system for the United States and Ecuador, 1984.

Item	United States	Ecuador		
	Semi-intensive	Semi-intensive	Semi-extensive	Extensive
Kg/ha/yr (heads-off)	1,159	1,323	554	232
$/kg	8.47	9.00	10.00	11.00
Value/ha ($)	9,798	11,908	5,544	2,553
Total variable cost ($)				
Postlarvae	1,800	480	180	62
Wages	663	317	190	78
Fuel	225	106	75	40
Feed	2,040	1,995	334	0
Fertilizer	54	269	269	0
Repairs	138	311	234	179
Packing	548	448	188	79
Miscellaneous	120	687	339	129
Total	5,588	4,613	1,809	567
Total fixed cost ($)				
Overhead	404	230	130	100
Depreciation	595	396	268	192
Miscellaneous	175	91	57	50
Total	1,174	717	455	342
Total cost ($)	6,762	5,330	2,264	909
Revenue before taxes ($)	3,036	6,578	3,280	1,644
Taxes ($)	1,518	3,289	1,640	822
Revenue after taxes ($)	1,518	3,289	1,640	822
B-E price/kg (heads-off) ($)	5.83	4.03	4.09	3.91
IRR (%)	21	59	39	25
Total investment (× $1,000)	1,915	1,243	937	715

10-year planning horizon is attractive for all farms considered. It should be noticed that the IRR is much greater for most of the Ecuadorian farms which explains the rapid rise of shrimp culture in Ecuador. Also, the significant increase in the IRR as the intensity of the farm increases explains why investors are putting in more semi-intensive systems.

Risk and time considerations

In the two previous sections, no consideration was given for risk and time consideration. It was assumed that production, prices and unit cost were known with certainty and they did not vary from year to year. In addition, it was assumed that in the year the initial investment was made, the farm would be in full production. When these assumptions are made, the results can lead to over-confidence in the economic feasibility of the investment.

Large shrimp farms are usually built in stages. The first year will, more than likely, not have production. The second year will partially produce while in the third year full production could be realized.

There are many factors that investors will not know with certainty and that will vary over time. Price received, inflation and interest rates will vary and can be rather volatile at times. Production can vary from pond to pond through growth rates and mortality. Temperature variation in the United States can affect the growth of shrimp. Environmental conditions, such as hurricanes in the United States and heavy rainfall in Ecuador, can cause damage and loss of production.

Table 10. Total variable cost, total fixed cost, and total cost as a percent of the value of the crop produced per year.

Cost	United States	Ecuador		
	Semi-intensive	Semi-intensive	Semi-extensive	Extensive
Total variable	57	39	33	23
Total fixed	12	6	8	13
Total	69	45	41	36

A firm level simulation model (MARSIM) was developed to simulate the annual activities of a shrimp farm taking into account timing and risk. A firm is replicated 50 times over a 10-year planning horizon. Random values for pond growth, pond survival, temperature, hurricanes and prices received in each of 10 years are generated from empirical probability density function for these variables.

When all timing and risk are incorporated into the analysis, it can have a substantial impact on the IRR. Table 11 shows that when producing *P. stylirostris* on a

Table 11. Comparison of after-tax internal rate of return for producing *Penaeus stylirostris* in semi-intensive ponds and operating a postlarvae reproduction unit in the Southern United States, 1984 (Hanson et al., 1984).

Total surface ha	Surface ha per pond	IRR: No risk and full production since Year 1 (%)	IRR: Risk and production developed over 2-3 years + (%)
40[a]	4	7.3	1.56
	10	9.1	2.19
	20	10.2	3.44
100[a]	4	15.9	9.69
	10	19.3	11.41
	20	20.8	15.31
200[b]	4	20.1	9.65
	10	23.8	10.68
	20	26.8	11.80
400[b]	4	24.7	13.20
	10	28.0	13.98
	20	31.6	14.06

[a]Developed in two years
[b]Developed in three years

200-surface ha farm using 20-ha ponds, the IRR is less than half when risk and timing of production are considered. The high IRR in Ecuador allows for a larger margin of error when an investor is performing a feasibility analysis. The United States does not have the luxury of error through overly high returns.

Conclusions

Shrimp culture in the Americas is in the infant stages in all countries, except Ecuador and Panama. How fast cultured shrimp production will expand will depend on technology to produce larvae (nauplii). Those countries having a year-round growing season have a much lower cost of production than countries like the United States with a limited growing season. Expansion then will be very dependent on the price received for shrimp. If production is significantly increased by cultured shrimp so as to cause the real price of shrimp to decrease over the next 10 years, development of shrimp culture in the United States will most likely be curtailed. However, prices can fall considerably for countries like Ecuador and investors can still receive a fair rate of return on their investment.

Acknowledgements

The authors wish to thank Dr. John Nichols and Mr. Scott Hanson for their critical review and helpful comments of this paper. Also, the authors want to thank the American Soybean Association for their financial support allowing travel to the First International Conference on the Culture of Penaeid Prawns/Shrimps.

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PART II

ABSTRACTS OF CONTRIBUTED PAPERS

Proceedings of the First International Conference on the Culture of Penaeid Prawns/Shrimps, Iloilo City, Philippines, 1984

Oral Presentations

Advances in Shrimp Culture in China

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Shrimp experimental ecology studies and the shrimp farming industry in China developed rapidly in the 1970's, and great strides have been made in the mass production of shrimp fry and the growing-out of marketable size shrimp since 1978. The total production of artificially reared shrimp fry and cultivated shrimp increased dramatically in the last few years.

The improvement of water quality management and feed supply in larval rearing have resulted in increased production of shrimp fry up to 100,000-200,000 or even 300,000 fry/m^3. Advances in the nutritional physiology and biochemistry of the digestive enzymes of juvenile and adolescent shrimp have enabled us to develop different kinds of for mulated feeds with high efficiency and low cost. Techniques for the transplantation and propagation of small benthic crustaceans (e.g. *Corophium* spp.) or polychaetes (e.g. *Nereis* spp.) to increase the benthos biomass for natural food of juvenile shrimp in nursery ponds have been developed and successfully practised. Improvement of culture techniques including shrimp pond management, has decreased the mortality of juvenile and young shrimp and increased yields of cultivated shrimp in the country. Highest production of 9,000 kg/ha has been achieved in the semi-intensive culture pond.

Culture of the Blue Shrimp, *Penaeus stylirostris* in Sonora, Mexico

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The Centro de Investigaciones Cientificas y Tecnologicas de la Universidad de Sonora has been conducting research on the culture of the blue shrimp *Penaeus stylirostris* since 1972. Most of the programs carried out are related to intensive culture in the Puerto Peñasco facilities. However, some experiments on semi-intensive and extensive culture have been conducted since 1975.

This paper describes the principal aspects of the technology developed; spawners, larval culture, nursery, growth, feed, environmental parameters, water supply and others. While in intensive culture it is possible to attain over 5 kg shrimp/m^2, in semi-intensive systems about 1 kg/m^2 is obtained. The intensive system uses raceways for the grow-out of shrimp, the semi-intensive and extensive systems use ponds.

Brackishwater Shrimp Culture in India and its Impact on Socio-Economics

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Utilization of potential area for shrimp culture in the traditional system was very meager — just 1.8% of total estimated available area of 1.45 million ha. The traditional paddy and fish culture and paddy cum fish culture systems and the return on investment (ROI) are explained. To adopt intensive culture, there is adequate scientific information based on many successful achievements through experimental trials indicating body weight of 16.7 g in 45 days for *P. indicus* with more than 80% survival rate proving economic viability. Basic studies were also made to find out the seasonal seed availability in different regions. Shrimp production to the extent of 500-700 kg/ha was achieved in many demonstration ponds organized by the Marine Products Export Development Authority indicating commercial reality of shrimp culture in India. As vast potential areas are available, shrimp culture will minimize the present 75% idle capacity of the Indian seafood processing industry which is over-dependent on shrimp as its major product for export.

Furthermore, adding more areas to culture has direct impact on the socio-economic status of the rural population. Three thousand self-employed people are now known to be directly engaged in seed collection. In addition, the shrimp farmer realizes returns two to three times more than his

counterpart in paddy cultivation, in the same field and for more or less the same period of time. In West Bengal, of total export value of 43 crores, up to 25 crores is realized by farmers for their production of shrimp through culture reflecting better unit return for their raw material than that realized by the processor/exporter of the end-product. Therefore, bringing additional areas under shrimp culture will directly affect the socio-economic status of the rural people employing an average of 5 persons/ha, and indirectly affect no less than 15,000 casual workers in the seafood processing industry by additional utilization of manpower and working hours.

As productivity from capture appears bleak, brackish-water shrimp culture has been accorded top priority in India's national developmental programmes for more harvest from aquatic sources otherwise termed the "Blue Revolution."

Larval Growth and Survival Optima for Four Species of Penaeids from Australia, as Indicated by their Distribution and Abundance in the Field

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Prawn catches from tropical northern Australia are dominated by four species of prawns: *Penaeus merguiensis*, *P. semisulcatus, P. esculentus* and *P. latisulcatus.* Three of the species (*P. merguiensis*, *P. semisulcatus* and *P. latisulcatus*) are widespread throughout the Indo-Pacific, while *P. esculentus* is endemic to northern and eastern Australia. The species appear, however, to have well defined and limited distribution on a smaller scale. Surveys of the larvae in the Gulf of Carpentaria, northern Australia, have shown both spatial and temporal heterogeneity in the abundance of all four of these species.

Assessing the temperatures and salinities in which the larvae were caught may be a realistic indicator of conditions suitable for reproduction, as well as growth and survival of the larvae. Means of these distributions may be deemed optima and ranges indicate tolerances.

Most of the larvae of all four species are found in water above 26°C and 31 ppt. However, the mean temperatures and salinities vary significantly between species. *P. merguiensis* has the lowest salinity optimum (31.8 ppt) and the highest temperature optimum (29.0°C). the other three species are similar for both temperature and salinity optima. *P. latisulcatus* has the lowest temperature optimum of 27.4°C compared with *P. semisulcatus* at 27.9°C and *P. esculentus* at 28.5°C. The salinity optima for these three species are almost indentical at approximately 33.2 ppt.

While the ranges of temperatures of all four species are similar (21.5-30.6°C), the ranges of salinities in which the larvae are found coincide with the size of the biogeographic distribution of the species. The three widespread species have large salinity ranges: *P. merguiensis,* 26.2-34.9 ppt *P. semisulcatus,* 27.8-34.9 ppt: and *P. latisulcatus,* 28.6-34.9 ppt. The Australian endemic, *P. esculentus,* has the smallest and highest range, 30.1-34.6 ppt. This apparent inability of *P. esculentus* to tolerate low salinity water may restrict dispersal during the larval stages.

Description of the Embryonic Stages of *Penaeus notialis* and the Influence of Some Abiotic Factors on the Species

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The embryonic development of the shrimp *Penaeus notialis* Farfante, 1967 is studied. The duration from spawning to hatching of the nauplii was 14-16 hr. As soon as spawning occurs, a sequence of transformations is observed in the characteristic cell mitosis up to the formation of the embryo which breaks the membrane and emerges as the first naupliar stage. The process of development is very similar to other penaeids and the duration of each stage is characteristic of the species. The influence of salinity and pH on spawning, hatching rate and survival, and the optimal values for each factor were determined.

Thermal Tolerance of Larval Greentail Prawn *Metapenaeus bennettae* (Racek and Dall) — A Comparison with School Prawn *Metapenaeus macleayi*

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The thermal tolerance of four larval stages of *Metapenaeus bennettae* was studied in the laboratory. Critical Thermal Maximum (CTM), One hour Median Lethal Temperature (lhLT50), and Median Resistance Time (MRT) were measured. Moulting rate of larvae and hatching rate of embryos were also monitored to study the delayed effect of thermal stress.

Thermal tolerance was shown to be strongly dependent on acclimation temperature (TA) at all larval stages, which

showed ontogenetic development of thermal resistance. Moulting of larvae was hindered at temperatures (37.2°C for nauplius when TA=25°C) well below lhLT50 (38.1°C for nauplius when TA=25°C). The embryonic stages were more susceptible to thermal stress than the larval stages. The salinity effects were also significant. Nauplius and protozoea stages showed their highest CTM values at the salinity in which they were spawned.

When compared with another penaeid *M. macleayi* (offshore breeder), *M. bennettae* (estuarine breeder) was found to have higher thermal resistance, but was less adaptive to changes in acclimation temperature.

Growth and Productivity of Juvenile Banana Prawns, *Penaeus merguiensis* in Natural and Laboratory Systems

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Growth and survival of *Penaeus merguiensis* juveniles were measured over four years in the Norman River estuary, south-eastern Gulf of Carpentaria. Growth in carapace length for the first 8-9 weeks after settlement was essentially linear and averaged 1.2 mm/week in summer at 29.5°C and 0.45 mm/week in winter at 19.5°C. A comparison of different cohorts under varying temperatures and salinities indicated that growth was temperature- but not salinity-dependent. Survival of newly settled postlarvae varied seasonally and was highest in spring (October-November).

In the laboratory, a study of moulting rate and moult increment at 15, 20, 25, 30 and 35°C demonstrated that the optimal temperature for growth was 25-30°C. Survival of juveniles was also highest at intermediate temperatures. Effects of salinity and food ration amounts are discussed.

Water Quality Criteria for Farming the Grass Shrimp, *Penaeus monodon*

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Physiological and growth effects of pH, salinity, temperature, heavy metals, pesticides and others on juvenile grass shrimp *Penaeus monodon* have been investigated to determine the biologically safe concentrations. Optimal pH, salinity and temperature are found to be in the range of 8.0-8.5, 15-25 ppt, and 28-33°C, respectively. A dissolved oxygen concentration of 3.7 ppm seems to be the critical oxygen pressure to support the normal life of grass shrimp. To avoid poor survival and retarded growth, the recommended level for each pollutant are: heavy metals, 0.0025 ppm Hg, 0.1 ppm Cu, 0.15 ppm Cd, 0.25 ppm Zn; pesticides, 0.0004 ppb parathion, 0.001 ppb malathion, 0.008 ppb rotenone, 0.01 ppb Azodrin, 0.033 ppb Saturn, 0.01 ppb paraquat, 0.01 ppb Endosulfan, 1 ppb Butachlor; surfactants, 0.1 ppm Dunall OSE, 0.2 ppm BP 1100, 0.5 ppm Seagreen 805; and others, 0.033 ppm H_2S, 0.1 ppm NH_3.

Genetic Changes During Development of Penaeid Shrimp

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As penaeid shrimp grow from the earliest naupliar stages, through protozoeal and mysis stages, to postlarvae, they develop greater morphological and behavioral resemblance to the adults. Electrophoretic analysis of cytoplasmic enzymes from nauplii, protozoea, mysis, postlarvae, and adults show that each stage has a unique pattern of gene activity. Thirteen enzyme stains and a general protein stain have been used on larval samples from *Penaeus stylirostris, P. vannamei* and *P. aztecus.* Some enzymes, such as phosphoglucose isomerase, are produced in the same isozymic form during all of the stages. Other enzymes exhibit changes in the number and position of isozymic bands during development, e.g. glutamate dehydrogenase. Some of these differences among developmental stages can only be explained by changes in the number and/or identity of the genes that are active at each stage. This finding suggests larval and adult responses to selection may be relatively independent.

Osmotic, Total Protein and Chloride Regulation in *Penaeus monodon*

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The osmotic, total protein and chloride ion regulation in two size groups (10 and 30 g) of *Penaeus monodon* Fabricius was investigated. Preliminary experiments showed that osmolality, total protein and chloride concentrations tend to

become stable 24 to 36 hours after molting. Thus, hemolymph values 36 to 240 hours after sampling were not significantly different from each other. Based on these results, only 36 hours (or more) postmolt animals were sampled after transfer from control (32 ppt) to five test salinities (8, 16, 24, 32 and 40 ppt). Hemolymph samples were then taken 1, 2, 3, 5, 7 and 10 days after transfer. Results showed that in general, osmolality, total protein and chloride concentrations in the hemolymph did not vary with time within the same salinity.

Both sizes exhibited hyperosmotic and hyperionic regulation in lower salinities and hypoosmotic and hypoionic regulation in higher salinities. The isosmotic values obtained were approximately 676 to 720 mOsm (24 to 28.8 ppt) for the 10 g, and 724 to 792 mOsm (26 to 28.5 ppt) for the 30 g size group. For chloride, the isoionic values ranged from 324 to 339 mM in 10 g prawns. Slopes of the regression lines of hemolymph osmolality versus salinity in 10 g prawns were not significantly different from slopes of similar regression lines in 30 g prawns. These results suggest that the ability to regulate osmotic and total protein concentration in the hemolymph is similar in the two size groups.

Induced Ovarian Maturation and Rematuration by Eyestalk Ablation of *Penaeus monodon* Collected from Indian Ocean (Phuket Province) and Songkhla Lake

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Because of the difficulty involved in maintaining a supply of sexually mature female shrimp for larval production in hatcheries, experiments on induced ovarian maturation in tiger shrimp, *Penaeus monodon* by eyestalk ablation were carried out from March to August, 1983. These shrimps were collected from two areas of Thailand: Phuket on the Indian Ocean and Songkhla Lake with entry to the Gulf of Thailand. Every female had one eyestalk pinched before being stocked together with males in various female-male ratios in 50-ton cement tanks with continuous water flow. The shrimp were fed 10% of their body weight daily with a diet of 90% green mussel (*Mytilus edulis*) and 10% cow liver.

Results show that of those female shrimps collected in the Phuket area which is a natural spawning ground, 51% became gravid. However, of those collected in Songkhla Lake which is not a spawning area, only 19.51% became gravid. There was also a large difference in the number of days between eyestalk ablation and first spawning: 4-5 days for the Phuket samples and 20-30 days for those from Songkhla Lake. The survival rate of the larvae until P_{20} averaged 8.5% (total 732, 259) for the Phuket samples and 4.0% (total 300,000) for the Songkhla Lake samples. Results show mass mortality during the nauplius and mysis stages of shrimp from both locations which may indicate a greater susceptibility to bacterial and fungal infections in larvae produced from artificially matured females.

Further studies should be undertaken to determine the proper nutritional diet for maximum production of gravid females, and to discover methods to increase sperm production in males from areas other than natural spawning grounds.

Variation in Tissue Lipid Content and Fatty Acid Composition During Ovarian Maturation of Unablated and Ablated *Penaeus monodon* Broodstock

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The tissue lipid content and fatty acid composition in the hepatopancreas, tail muscle and gonad of unablated and ablated *Penaeus monodon* were determined. Females at various stages of maturity were collected from offshore spawning grounds in Tigbauan and Guimbal, Iloilo, Philippines. Ablated females were reared in captivity.

The hepatopancreas showed the highest lipid content at 15.72 to 25.20% in unablated females and 22.47 to 34.90% in ablated females. Fresh lipid levels averaged 2.60% with no marked variation throughout the maturation period. Ovarian lipid increased from 5.80% (unablated) and 7.50% (ablated) in Immature Ovaries to more than two-fold in Early Maturing Ovaries coupled with a drop in hepatopancreatic lipid suggesting lipid mobilization to the ovaries. In ablated females, ovarian lipid progressively increased to a maximum of 21.90% in Fully Mature Ovaries with a corresponding rise in hepatopancreatic lipid. Both the ovarian and hepatopancreatic lipids declined in spent females. Fatty acid profiles of the tissues consistently showed the presence of polyunsaturated fatty acids (PUFA) 20:4ω6, 20:5ω3 and 22:6ω3. These fatty acids were reflected in the spawned egg. The lipid level in the hepatopancreas appeared to be inversely related to the total PUFA concentration in the ovaries. Lipid accumulation in ablated females was significantly higher than in unablated females.

The findings suggest storage and subsequent utilization of lipids for maturation and spawning processes. The type of polyunsaturates present in the maturing ovaries is indicative of their metabolic and physiological importance in the reproductive process.

Studies on the Artificial Insemination and Fertilization of Grass Shrimp, *Penaeus monodon*

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The culture of grass shrimp, *Penaeus monodon* has become a fast-growing enterprise in Taiwan since formulated shrimp feed was successfully developed in 1978. In 1983, the total postlarval production for stocking reached 600 million at the price of 12.5 U.S. cents each. This high price of the postlarvae resulted from (1) limited availability of wild gravid females, (2) undesirable spawnings obtained by using the method of eyestalk ablation, manifested by a low average hatching rate of 20%, and (3) high demand from grow-out farms. The eyestalk ablated females induced to spawn were often found unmated which partly explained the poor spawnings and low hatching rates. Consequently, re-use of ablated females was not practised by farmers in the past.

The present paper describes the results of artificial insemination and fertilization of wild or pond-reared females whose gonadal development was induced by eyestalk ablation. The hatching rates from unmated soft-thelycum females implanted with two spermatophores are 84.7% and 43.7% while those implanted with only one spermatophore, 74.1% and 16.8%, for the first and subsequent spawning, respectively. These results positively confirm that the unmated condition of ablated females is the main reason for low hatching. Through artificial insemination, the spawning and hatching can be improved and ablated females can be reutilized. For unmated hard-thelycum females, artificial fertilization was done by releasing spermatozoa into the spawning tank right before spawning. Out of 15 attempts, three were successful with hatching rates of 63.1, 52.3, and 49.9%.

Induced maturation of pond-reared shrimps was attempted by manipulation of temperature and salinity. Under constant temperature of 22±2°C, salinities ranging between 25 and 37 ppt were experimented. The best results with 67% success were obtained at salinities of 30 and 35 ppt. Continued efforts will be made to improve spawning performance through the technique of artificial insemination under controlled conditions.

Factors Affecting Maturation and Spawning of *Penaeus esculentus* in the Laboratory

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Adult tiger prawns *Penaeus esculentus* were held in laboratory tanks under varying conditions of tank size, density, temperature and photoperiod for assessment of ovarian maturation and spawning. Both eyestalk ablated and intact females were studied. Maturation and spawning of intact females was favored by conditions of warm temperature (26°C) and long days (14.5 hr), whereas ovary maturation did not occur at lower temperature (20°C) and short days (12 hr). Tank size was a critical factor with intact females as maturation and spawning required a large tank (4 m^2). Spawning did not occur in small tanks (1 m^2) despite ideal temperature and photoperiod conditions. Unilaterally ablated females matured and spawned under both short day-cold temperature conditions and in small tanks, but the success rate was greater under long day-warm temperature conditions in large tanks. Intact females required 40-60 days before onset of ovary maturation, whereas ablated females showed maturation to ovary stage III approximately 20 days after ablation. Mating success was severely limited under small tank conditions but occurred normally in the large tanks.

Induction to Ovary Maturation by Ablation in the Pink Shrimp *Penaeus notialis*

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A partial unilateral ablation was carried out on immature females of the pink shrimp *Penaeus notialis*. They were maintained in 1,600 ℓ asbestos-cement tanks together with apparently mature males, not submitted to treatment, at a ratio of 2 females: 1 male. A quick development of the ovary was attained, which did not present significant differences in average diameter of the ovocytes in the anterior, median, and posterior lobes, and with similar histological characteristics to those described for naturally mature females. Viable spawnings were obtained three days after the treatment and onwards. The larvae obtained showed normal activity and development.

Observations on the Nauplii Production from Wild, Cultivated and Mixed Populations of the Blue Shrimp (*Penaeus stylirostris*)

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Due to low nauplii production from cultivated broodstock and to minimize dependence on wild stock, an experiment was run in which four treatments, consisting of combina-

tions of 400 adult blue shrimp (*Penaeus stylirostris*) from wild and cultivated (F_6) populations, were applied (wild females and males, wild females and cultivated males, cultivated females and wild males, and cultivated females and males). Females were inspected every third day. Those observed with spermatophores were captured and transferred to individual 100-ℓ spawning tanks. Water was treated with EDTA and erythromycin phosphate. More than 300 individual spawns were evaluated within a 180-day period. To evaluate the nauplii production per female, an analysis of variance for a factorial arrangement ($4^3 \times 2$) was conducted. The factors considered were: the abovementioned treatments, different ovarian maturation stages, adhesion of the spermatophore, and kind of spawning (complete or partial). The mixed populations had higher nauplii production than the cultivated broodstock. All the females were tagged around an eyestalk and examined for rematuration. Up to six rematurations per female were registered as well as a minimum of four days between successive spawnings for the same female. The effect of rematuration on the quantity of nauplii is discussed. Gonadosomatic index for wild and cultivated females is compared. Selective criteria for spawners are given.

Nutritional Value of Marine Yeast Fed to Larvae of *Penaeus monodon* in Combination with Algae

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Saccharomyces cerevasiae and *Rhodotorula aurantica*, two marine yeast species, were fed to *Penaeus monodon* larvae (N_6 to M_1) singly and in combination with *Tetraselmis* sp. and *Chaetoceros calcitrans* in varying proportions. Larvae fed combination diets gave survival rates comparable to or higher than those fed algae or yeast alone. Chemical analyses show that the yeasts have low fat, moderate protein and high carbohydrate content. They also contain essential amino acids but are different in the fatty acids found to be essential for prawns. When used in combination with algae, the nutritional value of the yeasts seemed to have been improved.

The use of marine yeasts in larval rearing could reduce economic and technological inputs in the production of natural foods for larval rearing. They are cheaper and easier to mass produce. They can be grown to very high densities using cheap carbon sources like molasses, brown sugar and coconut water with added nutrients in relatively shorter periods of time.

The Growth of a Bialgal Culture and its Use as Food for Shrimp Larvae

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The cultivation of the microalga *Tetraselmis chuii* with the protection of the extracellular products of *Chlorella kessleri*, grown in a bialgal culture, allows its development in outdoor tanks without special conditions of sterilization or aeration. Fish meal and agricultural inorganic compounds are used as fertilizers. The growth of the mixed species is analyzed comparing it with monoalgal cultures. The best fit of growth data to a logistic curve is performed and the whole curve is compared using a covariance analysis. The stratification of *T. chuii* in the tank favors its harvest at high concentration. A bialgal culture (based on *T. chuii* at 50 cells/mm^3) as food for the larvae of the shrimps *Penaeus notialis* and *P. schmitti*, together with hard boiled egg yolk and rotifers, achieves good development and survival.

The Integrated Use of *Artemia* in Shrimp Farming

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The use of freshly hatched *Artemia* nauplii in penaeid hatcheries is a common practice, although a broader application of *Artemia* in shrimp farming is gaining more and more interest. In this regard, an integrated use of *Artemia* in shrimp culture is presented in this paper.

Artemia booster in combination with Fleischmann yeast has been proven to be a suitable algal substitute and the early feeding of decapsulated *Artemia* cysts at protozoea I to II stages has been shown to improve larval growth. Freshly hatched *Artemia* nauplii may be introduced at protozoea II to III and the use of enriched nauplii from mysis stage on clearly improves postlarval production. Enriched nauplii, pre-adult and adult *Artemia* can be successfully used in a nursery phase in order to improve weaning success and performance in grow-out ponds. Furthermore, the use of adult *Artemia* in broodstock feeding has been shown to be effective for inducing maturation.

All *Artemia* products mentioned can be purchased from commercial dealers but can be produced as well on the spot in

most cases. *Artemia* cysts may be harvested from natural or inoculated populations occurring in adjacent salt works while decapsulation of the cysts can be done in the hatchery. Enrichment of *Artemia* nauplii can be done routinely using enriched formulated diets during hatching of the cysts or after separation of the nauplii. Pre-adult and adult *Artemia* can be produced either extensively in nearby salt ponds or intensively in flowthrough raceway systems using nutrient-rich effluent water from the hatchery.

In this regard, an integrated use of *Artemia* in shrimp farming will not only increase postlarval production but will decrease costs as well by production on the spot of the most expensive and valuable live food: *Artemia.*

Heterotrophic Bacteria Associated with Eggs and Larvae of *Penaeus indicus* in a Hatchery System

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Total viable aerobic heterotrophic bacteria (THB) associated with egg, nauplius, zoea, mysis and postlarva of *Penaeus indicus* and seawater in a hatchery system were estimated for three years from 1981 to 1984. The bacterial population varied from 1.3×10^4 to 8.72×10^7/g in egg, 1.5×10^4 to 6.17×10^7/g in nauplius, 4×10^3 to 3.14×10^7/g in zoea, 1.35×10^6 to 1.25×10^8/g in mysis, 1.6×10^5 to 8.44×10^6/g in postlarva. Water contained a THB population of 1.2×10^5 to 2.8×10^8/100 ml.

Species of *Vibrio, Pseudomonas, Aeromonas, Acinetobacter, Moraxella,* members of the family Enterobacteriaceae, *Micrococcus, Bacillus*, and Coryneform group were encountered. Gram-negative bacteria were found to be dominant in all stages and showed an increase from egg (81.3%) to postlarva (92.7%). However such an increase was not recorded in the respective water samples even though gram-negative bacteria were found to be dominant. *Vibrio* spp. were found in high numbers in postlarvae and it was to be increasing from egg (10.4%) to postlarva (80%). The number of larvae in culture pools gradually declined as the nauplii metamorphosed to postlarvae through zoea and mysis. In general, coincidence of higher percentage of *Vibrio* spp. and larval mortality was recorded. Physico-chemical factors such as salinity, temperature, pH, oxygen, inorganic phosphorus, organic phosphorus, inorganic nitrogen and organic nitrogen of water did not show much variation in the same set of pools. Relationship between the physico-chemical parameters, bacterial population and the number of larvae is discussed.

A New Approach in Intensive Nursery Rearing of Penaeids

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The need for a nursery phase between the hatchery and the growing pond to avoid mortalities of young postlarvae, and provide a better assessment of stocked animals is general in crustacean aquaculture.

The Centre Oceanologique du Pacifique recently developed a new culture technique using strong aeration, no water exchange and no external filter or artificial substrates. The technique relies on the development of a phytoplankton and bacterial medium with both nutritive and purifying qualities. Early postlarvae (PL_3) are grown for a month or less up to 0.1 g mean weight, in 10 to 100 m^3 tanks, at densities of 1 to 10 individuals/ℓ. The mean daily growth rates are around 20% for *Penaeus indicus, P. stylirostris* and *P. vannamei* and only 12-15% for *P. monodon.* For all species tested, density has little or no influence on growth. The final survival rates are generally high.

Floating Cage Nursery Culture System for *Penaeus monodon*

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The use of floating cages as nursery for *Penaeus monodon* postlarvae was tried at the Batan, Aklan Substation of the SEAFDEC Aquaculture Department. The cages were made of bamboo and measured $2 \times 5 \times 1.5$ m (effective volume 10 m^3) with cement-coated styrofoam sheets as floats. Two nets were installed inside a cage. The outer net (3 mm mesh size) protects the inner net (0.5 mm mesh size) from floating debris in the bay. The cages were installed offshore where water depth was at least 2 m during the lowest tide, and were attached to bamboo posts by metal rings. Postlarvae were stocked at ages ranging from PL_5 to PL_{16}. Feed consisted of raw ground fish paste applied to a feeding net which also served as substrate. Average survival based on 25 production runs was 40.98% after 2 to 3 weeks of culture. Stocking density ranged from 4,000 to 16,895 PL/m^3.

Unlike nursery tanks, this system is easier to manage and needs no aeration and pumping, thus reducing operational costs. Floating nursery cages should be located in protected areas; they can also be installed inside fishponds.

The Effects of Stocking Densities on Growth and Survival of *Penaeus vannamei* in Cow Manure-Enriched Ponds

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Ecuadorian *Penaeus vannamei* were stocked in eight dirt ponds (approximately 163 m^2) at four different types of density, i.e., 5 shrimp/m^2, 10 shrimp/m^2, 15 shrimp/m^2, and 20 shrimp/m^2. The initial body weight ranged between 1.1 and 3.8 g. No commercial feed was given to the shrimp. The only input to the pond was 30 kg of cow manure/week. Shrimp were sampled either weekly or bi-weekly for body weight measurements. Water quality parameters, such as temperature, pH, DO and turbidity were recorded twice daily; nutrients (nitrite, nitrate, ammonium and phosphate) and BOD were measured twice weekly. The chemical composition of the cow manure was analyzed. After 14 weeks' experiment, the shrimp were harvested, weighed and counted. Survival and total yield were compared among treatments.

The results showed negative correlation between stocking density and growth. The weekly growth of shrimp was between 0.7 and 1.0 g. There was no relationship between stocking density and survival. Survival averaged 68%. The most suitable stocking density should be judged by profit. However, the total yield of shrimp was higher in the higher stocking density.

Role of Bacteria and Meiofauna in the Productivity of Prawn Aquaculture Ponds

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Detrital food chains, based on the use of manures and compost have been used in aquaculture for centuries. Heterotrophic bacteria convert organic detritus into protein and thus constitute an important food source in ponds. Bacterial growth rates, and thus productivity, in natural environments can be calculated from the rate of tritiated thymidine incorporation into DNA. Rates of oxygen consumption by bacteria can be estimated from values for production. The tritiated thymidine method has been used to measure bacterial production in aquaculture ponds where a pelleted food was fed to penaeid prawns. It was found that most of the pelleted food was supporting bacterial growth, with bacterial production ranging from 0.43 to 2.1 $mgC\ell^{-1}d^{-1}$ in the water and 150 to 500 $mgC\ m^{-2}d^{-1}$ in the sediment. Bacterial biomass and growth rates were shown to be regulated by meiofauna, which in turn were eaten by the prawns. Primary production was not significant in the ponds. More oxygen was consumed by bacteria in the water column than was produced by photosynthesis of phytoplankton.

Average shrimp yields at harvest were: chicken manure, 262 kg/ha; cow manure, 218 kg/ha; feed, 387 kg/ha; and control, 160 kg/ha. Average survival for each treatment was 50, 76, 58 and 79%, respectively. The percent yield of *P. vannamei: P. stylirostris: P. occidentalis* by weight for the four treatments was 85:15:0, 87:13:0, 78:22:0, and 92:9:0, respectively. *P. occidentalis* suffered 100% mortality during the production period. Average weights of shrimp at harvest were 8.72, 7.32, 12.07, and 5.98 g for the respective treatments. Ratios of average individual weights for *P. vannamei: P. stylirostris* for the treatments were 2.00:1, 1.99:1 and 2.22:1, respectively. Manures and feed significantly increased yield over the control ($P < .0002$). Feed significantly increased yield over that of the manures ($P < .0001$); while yields for manures did not differ ($P > .05$). Survival was not significantly different among treatments ($P > .05$).

The Effects of Manures and Pelleted Feeds on Survival, Growth and Yield of *Penaeus stylirostris* and *Penaeus vannamei* in Panama

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Brackishwater ponds (0.8 m deep and 600 m^2) on the Pacific Coast of Panama were stocked at 5/m^2 with postlarval shrimp (1 cm, 0.05 g) collected from the wild. Species composition at stocking was 56% *Penaeus vannamei,* 33% *P. stylirostris* and 11% *P. occidentalis.* Experimental treatments received different nutrient inputs consisting of cow manure (4,500 kg/ha dry wt.), chicken manure (4,500 kg/ha), 25% protein pelleted feed (790 kg/ha) and a control (no nutrient input), each replicated five times, in random order. Water was exchanged 5 to 10% per day and the production period was 120 days during the 1982 rainy season.

An Improved Strategy for Building Brackishwater Culture Ponds with Iron Pyrite Soils in Mangrove Swamps

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The problems associated with acid sulfate soil limit the potential utilization of vast coastal areas of mangrove swamps for brackishwater aquaculture. There is an estimated 4.8 million ha of mangrove area in the ASEAN countries alone. Until recently, most attempts to build earthen ponds in these areas have yielded poor results.

Aquatic Farms, as technical consultants for a 250 ha-prawn farm in Johore Peninsula, Malaysia, developed a construction technique that utilized the volcano-like burrow mounds of the mud lobster (*Thalassina anomala*) to cover and seal pond embankments that has minimized the culture problems usually experienced with iron pyrite soil. The strategy, pond design and construction technique are described. Pond dynamics and performance are discussed since the commencement of culture operations and these are compared with a nearby prawn farm that was constructed using conventional techniques. A cost benefit analysis is given in conclusion.

Penaeid Larval Culture Using Microencapsulated Diets

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Whilst it has been possible for many years to feed postlarval penaeids successfully on artificial diets, problems of nutrient leaching, particle breakdown, and water fouling have prevented the use of such diets for early planktonic larval stages. It has recently been demonstrated that the technique of microencapsulation may be used to overcome these problems. Live foods used for penaeid culture have been successfully replaced by microencapsulated diets, both in the laboratory and at the hatchery level. The technology has now reached the level at which dietary requirements of individual species can be met by the incorporation of specific nutrients. Capsules can be supplied to function either as complete nutrient delivery systems or as food supplements.

The present paper reviews this progress towards the total replacement of live foods in penaeid culture, and assesses the results of recent culture trials.

The Use of Microencapsulated Feeds to Replace Live Food Organisms in Shrimp Hatcheries

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An adequate supply of hatchery produced shrimp fry is the major constraint to the intensification and growth of shrimp culture practices. If even 20% of the more than 500,000 ha of the world's existing tropical and sub-tropical brackishwater ponds were to stock at the relatively low density of 50,000 fry/ha/year, it would take thousands of new hatcheries to produce the 25 billion fry required. The availability of artificially produced diets to replace cultured live food organisms would alleviate many of the problems currently limiting shrimp hatchery production by: (i) reducing the level of technical skill required to operate a hatchery; (ii) assuring a reliable supply of a nutritionally balanced larval feed; (iii) reducing sources of contamination and larval disease; and (iv) simplifying hatchery design and capital cost requirements, thereby facilitating small scale hatchery development.

Aquatic farms has been working with the Mars Microencapsulation Research Group (MMRG) to develop techniques for adapting current shrimp hatchery technology and design so that MMRG feeds can be used in existing hatcheries as a live feed replacement. Feeding trials have been conducted in commercial hatcheries in Hawaii, Malaysia and Thailand. The results of these trials and the techniques employed are discussed. Growth and survival of larvae fed microencapsulated diets as total or partial replacement of live foods was comparable to larvae cultured in control tanks using the standard operating procedures of the hatchery in which the trials were conducted. In trials to date, larval survival from nauplii to postlarvae has been as high as 70%.

The Response of *Penaeus monodon* Juveniles to Varying Protein/Energy Ratios in Test Diets

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The response of *Penaeus monodon* juveniles (0.71±0.11 g) to varying protein/energy ratios in test diets was determined. Purified diets consisting of different levels of protein, lipid and carbohydrates were formulated. Two sets of experiments were conducted with the following diet combinations: (1) 30, 30, 50% protein, 5, 10, 15% lipid and 0, 10, 20%

carbohydrate and (2) 40, 45, 50% protein, 5% lipid and 20, 25, 30% carbohydrate. Protein and energy ratios ranged from 89-198 mg protein/Kcal while the energy values for all diets were 165-415 Kcal/100 g. The diets were given twice daily at 10% of the body weight.

Results showed that a two- to three-fold increase was observed in the body weight of prawns fed with diet combinations of 40-50% protein, 5-10% lipid and 20% carbohydrate with energy values of 285-370 Kcal/100 g. Reduction in protein content of the diet from 50 to 40% while maintaining the total energy level (285 Kcal/100 g) resulted in a change in growth that was not significant. An increase in energy level, at constant dietary protein level, resulted in improved utilization of protein and feed conversion efficiency.

Effect of Various Levels of Squid Protein on Growth and Some Biochemical Parameters of *Penaeus japonicus* Juveniles

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An unknown growth factor previously suspected in squid meal was found in the protein fraction of squid (*Loligo vulgaris).* It is clearly different from hydro-alcohol-soluble feed attractants that are also present in squid meal. This squid protein fraction (SPF) improves the growth of *Penaeus japonicus* juveniles when added either in a semi-purified or in a more complex mixed diet. This growth-promoting effect does not seem to be related to the amino acid composition of SPF. In order to obtain more information on its action, several levels (1.5 to 16.0%) of SPF were added to a mixed diet. The diets were isoproteic (59% D.M.), isolipidic (8.5% D.M.), supplemented with vitamins, cholesterol, glucosamine, etc. They were fed as wet pellets to 3 replicates of 15 shrimp; blue mussel was used as the control. The growth of shrimp increased with the SPF level and attained a plateau above 6%. Body weight was significantly higher than that of the control group at this level. RNA content and RNA:DNA ratio increased with the SPF level indicating that growth was improved more by hypertrophy than by hyperplasy of the cells.

The hepatosomatic ratio remained unchanged. The assay of two digestive enzymes, proteases and amylases, showed no clear effect of SPF on protease or amylase activities. More experiments are needed to explain the effect of the unknown growth factor of SPF.

Imperatives for the Future Development of Prawn Culture in the Cochin Backwater System (Kerala, India)

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A traditional system of prawn culture practised in the Cochin Backwater System, the largest backwater system in Kerala State, has an estimated yield of 4,000 tons from about 4,500 ha. Governmental investments to encourage prawn production on a scientific basis continue to grow with the dual objective of improving the socio-economic conditions of fisherfolks and augmenting prawn exports. A geographic study of land and water uses and an assessment of environmental impact of these uses point to basic incompatibilities of city expansion and semi-intensive prawn culture. Population growth, urban expansion and industrial development projections for Cochin City and its surrounding areas support the view that water quality will deteriorate further making culture of prawns for export a difficult proposition. Functioning horizontal-communications between city and fisheries planning units are essential as are improvements in environmental protection than presently evident. Attention is directed towards examining other options for improving socio-economic conditions of fisherfolks and increasing prawn production and developing public policy for protecting prawn culture areas elsewhere.

The Economics of Different Prawn and Shrimp Pond Culture Systems: A Comparative Analysis

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The paper aims to present a comparative economic evaluation of different pond culture systems for prawn (*Penaeus monodon*) and shrimp (*P. indicus* and *P. merguiensis*) using standard economic tools and methods of analysis. The different culture systems include extensive and semi-intensive monoculture of prawns and shrimps and the extensive polyculture of these species with milkfish (*Chanos chanos*). Data used in the analysis were taken from both SEAFDEC AQD and industry experience. The technical data were gathered from researchers and private sector experiences in prawn and shrimp farming. Financial estimates were determined after the peculiarities of aquaculture *vis-a-vis* other business ventures in agriculture and industry were taken into consideration.

The study shows that the extensive monoculture of prawns and the extensive polyculture of prawn with shrimp and milkfish are profitable culture systems. Return on investment (ROI) and payback period for prawn extensive monoculture systems range from 10 to 65% and from 1.4 to 8.6 years, respectively. For polyculture systems, ROI ranges from 8 to 85% and payback period from 1.1 to 10.5 years. The semi-intensive culture of prawn shows moderate results. This is largely due to higher capital requirements for semi-intensive culture as compared to extensive culture. The extensive and semi-intensive monoculture of shrimps on the other hand show poor results, with semi-intensive monoculture registering net losses after all costs are considered.

A Preliminary Economic Analysis for Extensive and Semi-Intensive Shrimp Culture in South Carolina, U.S.A.

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South Carolina has some 28,500 ha of impounded coastal wetlands. These impoundments are remnants of the rice culture industry of the 19th century and are now of interest for waterflow management and possibly aquaculture. The purpose of this study was to evaluate and compare the potential for extensive commercial culture of shrimp in salt-marsh impoundments with that for semi-intensive production of shrimp in highland ponds.

A hypothetical farm consisting of four 8-ha impoundments or ponds was chosen as the basis for the analysis, and it was assumed that only one crop of shrimp could be produced per year. Two alternative strategies for stocking the impoundments were evaluated: option 1, stock by natural recruitment via tide gates; option 2, stock at low density (25,000/ha) with hatchery-reared postlarvae. Highland ponds were to be stocked at a density of 75,000 PL/ha with hatchery-reared animals. Major fixed costs other than land purchase were considered, including renovation of existing impoundments by cross-diking to form 8-ha units and addition of extra tide gates. Estimates of annual and variable costs for postlarvae (where applicable), feed, labor, chemicals, pumping, supplies, vehicle use, mowing, interest, overhead, and miscellaneous items were also included in the analysis.

Results indicated that extensive shrimp culture in salt water impoundments is likely to be a break-even or profitable activity for production levels of 90 kg whole shrimp/ha for stocking option 1, while option 2 would require yields of ≥225 kg/ha. In comparison, semi-intensive culture in highland ponds is likely to be successful if yields of ≥ 800 kg/ha are obtained. This preliminary analysis suggests that both extensive and semi-intensive culture of shrimp may be economically feasible in South Carolina, but this potential is as yet unproven and shrimp aquaculture must be considered a high risk venture in this area.

Cause of Musty Flavor in Pond-Cultured Penaeid Shrimp

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In 1983, penaeid shrimp shipped into the United States from culture ponds in Ecuador were found to have an intense earthy-musty flavor which made them unmarketable. High concentrations of geosmin (trans, 1-10-dimethyl-1-9 decalol), a musty odorous compound, were found in the tail muscle of the shrimp. The level of geosmin, 78 mg/kg muscle, was much higher than levels usually found in pond-cultured freshwater catfish of 13±3 mg/kg muscle. Cause of the rare occurrence of off-flavor in the shrimp is hypothesized to be severe reduction in salinity in the coastal culture ponds which allowed growth of odor-producing blue-green algae.

Proceedings of the First International Conference on the Culture of Penaeid Prawns/Shrimps, Iloilo City, Philippines, 1984

Poster Presentations

The Biology of *Penaeus monodon* in the Capture Fisheries off Orissa Coast, India in the Context of Occurrence of Natural Broodstock

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The tiger prawn of India, *Penaeus monodon* Fabricius has a differential distribution in the two coasts of India. Density is high in the northeastern part of the Bay of Bengal gradually declining towards the mid-east and becoming quite scarce towards the south. On the west coast, the distribution is more sparse and limited to a few months, off Bombay. The only known inshore areas of capture fisheries are the Godavari estuarine system, and the lagoons off Orissa at Chilka and Madras at Pulicat. The only known offshore capture exists off the Orissa coast at Paradip and Puri extending south to Visakhapatnam and Kakinada Bay. The greatest production comes off the brackishwater "bheri" (wild culture) system in the extensive "sunderbans" of West Bengal on the northeast where millions of seed recruited to the Hooghly estuarine complex are drawn in along with tidal waters and "cultured." The distribution profoundly affects the maturity, breeding and recruitment of this highly euryhaline species.

The distribution can be related to the cyclic currents in the Bay of Bengal which have a profound effect on the salinity and temperature profile. It can also be related to the immense quantity of freshwater inflow from the mighty Hooghly-Matlah-Roopnarayan Padma estuarine complex at the head of the Bay and the other major riverine estuaries on the mid-east coast viz., the Mahanadi, Godavari and Krishna. The pattern of circulation and estuarine flows is such that it might also positively influence the food distribution, both live and detrital, in this region.

Ripe (gravid) and ripening females and males of *P. monodon* in the size range of 100-250 g are captured off Paradip coast in the not very deep (30-40 m) waters where coastal trawlers operate, from October through April corresponding to the post-monsoon stability in the water movement and the increasing salinity. This offers a good augury for setting up hatcheries in adjacent zones using naturally mature forms. Catch records from one major freezing plant are presented to indicate the density and distribution of the species at the Paradip-Puri coast.

Seasonal Abundance of Penaeid Prawn Seed in the Ennore Estuary, Madras in Relation to Hydrography and Lunar Phase

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An estimate of seed resources in the coastline, estuarine, and backwater bodies is an important prerequisite for developing prawn farming. A one-year (1983) survey on penaeid seed, based on tide and lunar periodicity, indicates the following species: *Metapenaeus dobsoni, Penaeus indicus, P. japonicus, M. monoceros, P. semisulcatus* and *P. monodon* in order of their abundance. *P. indicus* and *P. japonicus* are predominant in February and March (77.5 and 82.06% of total seed, respectively) when the average salinity ranges from 33.6 to 35.1 ppt followed by *M. dobsoni.* A second peak of *P. indicus* is observed in June when *M. dobsoni* showed its highest peak (47.35%) with continued abundance up to December.

During the northeast monsoon, when the average salinity fell to a lower range of 19.9 to 24.6 ppt, *P. monodon* and *M. monoceros* showed moderate abundance. As the site chosen is very near the bar mouth, most of the seed collected were postlarvae. In *Penaeus* and *Metapenaeus* genera, total size range is 7-15 mm and 3-4 mm, respectively. Afternoon collections showed greater abundance followed by forenoon and night collections. Low tide and Full Moon collections showed greater abundance than those made during high tide and New Moon. Differences in seasonality may reflect breeding intensity of the respective prawn species in the sea. Variations in hydrographic features may also significantly contribute to seasonal abundance. A strong correlation between salinity and seed abundance is seen. The seed potential of these prawns in Ennore estuary is discussed.

Morphometric Studies on Three Penaeid Shrimps, *Penaeus japonicus, P. vannamei* and *P. marginatus* in Hawaii

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Penaeus japonicus, P. vannamei and *P. marginatus* cultured at the Oceanic Institute in Hawaii, were sampled and measured. The shrimps sampled ranged from 1 to 15 g in body weight. The measurements included carapace length (CL), body length (BL), total length (TL) and body weight (BW). The results showed significant linear relationships between TL and CL, BL and CL. The relationships between CL and BW, BL and BW, TL and BW are well expressed by exponential curve. These relationships were found for all three species. However, *P. japonicus* has more similar morphometric characteristics to *P. marginatus* than *P. vannamei.* The carapace portion in *P. vannamei* is smaller than either *P. japonicus* or *P. marginatus.* In other words, *P. vannamei* has a greater edible portion than *P. japonicus* and *P. marginatus.* Equations for length-weight relationships can provide means of converting one characteristic into another.

Diseases, Parasites, Commensals and Fouling of Commercial Penaeid Prawns of the Portonovo Coast of South India

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There are very few reports on the diseases, parasites, commensals and fouling in penaeid prawns. During the regular collection of marine and estuarine prawns in the east coast of India, a number were found to be infested with various organisms.

The prawn *Penaeus (Fenneropenaeus) indicus,* was infested with a microsporidian which causes a condition known as milk or cotton prawn. The infestation was spread throughout the abdominal musculature of the prawn. The marine prawn *Parapenaeopsis stylifera* had epibiotic growth of athecate hydrozoans, probably of the genus *Tubularia,* on the dorsal side of the carapace and abdominal segments. This is the first report of athecate hydrozoans infesting the prawn. The prawn *Metapenaeopsis stridulans* was observed to be parasitized by a bopyrid isopod, *Orbione thielemanni* and the prawn *Sicyonia lancifera,* parasitized by another bopyrid isopod, *O. kemi.* The bopyrid isopod *O. kemi* infesting the prawn *S. lancifera* is also recorded for the first time. Both bopyrid isopods were found in the branchial cavity of the prawns. The Pontoniinid prawn *Chernocaris placunae* is a commensal living in the mantle cavity of the bivalve, *Placenta placenta.* Barnacles were found attached to the carapace and first abdominal segment of the prawn, *Parapenaeopsis uncta,* whereas they were found in the telson region also in the prawn *P. stylifera.* Most of the barnacles were very small with a basal diameter of less than 1.5 mm.

Seasonal and Local Occurrence of Adults and Postlarval Stages of *Penaeus merguiensis* and *Penaeus indicus* in Batan Bay, Philippines

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Studies on seasonal and local occurrence of adults (spawners) and postlarval stages of *Penaeus merguiensis* and *P. indicus* in Batan Bay and Banate Bay, Aklan yielded the following results: 1) small-sized *P. merguiensis* and *P. indicus* dominated the rivers and interior bays, 2) *P. merguiensis* and *P. indicus* spawners appeared throughout the year with varying monthly abundance in Batan Channel and Banate shoreline, and 3) larval stages of penaeids were found in interior bays but were more abundant in the channel and offshore areas. Postlarval stages of penaeids are more abundant along the shoreline than in water edges of mangrove swamps which indicate that channels and offshore waters may be primary spawning grounds while interior bays and rivers are secondary spawning grounds. Moreover, size distribution of carapace length of *P. merguiensis* suggests that the channel and offshore areas are utilized as primary spawning grounds while the inner portions of the bay are nursery grounds and secondary spawning grounds.

Lunar phase did not show a positive correlation with abundance of both spawners and postlarval *P. merguiensis* and *P. indicus.* The minimum size at sexual maturity for both male and female *P. merguiensis* is about 11 mm CL. Female *P. indicus* appear to become sexually mature at a smaller size (13 mm CL) than males (20 mm CL).

Recruitment of Postlarval Penaeid Prawns in the Vellar Estuary, South India

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The northern bank of Vellar estuary (Parangipettai, India) is ideal for postlarval penaeid prawn recruitment. The annual recruitment, distribution and the substratum preference of postlarval immigrants at three different stations in the estuary were studied in detail.

Among the postlarvae of *Penaeus, P. (Fenneropenaeus) indicus* was dominant followed by *P. (Penaeus) monodon, P. (P.) semisulcatus, P. (F.) merguiensis* and *P. (Melicertus) latisulcatus.* In *Metapenaeus,* postlarvae of *M. monoceros* were abundant followed by *M. dobsoni, M. affinis, M. brevicornis* and *M. lysianassa.*

Two peaks were observed in the postlarval penaeid prawn population. In *P (F.) indicus* and *P. (P.) monodon,* the primary peak occurred from January to April and the secondary peak from July to September. In *M. monoceros* and *M. dobsoni,* the primary peak was from March to May and the secondary peak from August to September. The postlarvae of *P. (F.) indicus, P. (P.) monodon, M. monoceros* and *M. dobsoni* were available throughout the year while the others were seasonal. The distribution of postlarvae in the estuary is related to the type of substratum, salinity and temperature. The postlarval population declined during the northeast monsoon (November-December) and in peak summer (May-June). Their abundance decreased in the lower salinity areas of the upper reaches of the estuary.

Environmental Physiology of the Prawn *Penaeus (Melicertus) latisulcatus*

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There are a number of intrinsic and extrinsic factors which affect the normal routine activity of the prawn. The present study attempts to elucidate the optimum levels of various environmental factors for the culture of prawns.

The salinity tolerance capacity of *Penaeus* (*Melicertus*) *latisulcatus* was estimated in 13 different test salinities from 0 to 60 ppt (at 5 ppt increments). The prawns can tolerate a wide salinity range of 20-50 ppt. Maximum survival, however, was between 25 to 45 ppt. The extreme low (0-10 ppt) and high (60 ppt) salinities were highly lethal to the prawns. The change in acclimation temperature from 30 to 35°C increased the upper incipient lethal level from 38.5 to 39.5°C. The prawns acclimated to 30°C tolerated 42°C for 275 sec and 45.5°C for 13 sec, while prawns acclimated to 35°C tolerated 42°C for 505 sec and 46.5°C for 11 sec.

Prawns were acclimated to a salinity of 26 ppt and oxygen consumption was measured at 5, 15, 26, and 38 ppt in a continuous water-flow method. The total oxygen consumption showed an inverse relationship with weight. Oxygen consumption declined with increase in salinity. The resistance of prawns to hydrogen sulphide was tested in 18 different concentrations of sodium sulphide mixed with seawater. The prawns tolerated sodium sulphide concentrations up to 20 mg/ℓ. The dissolved oxygen in the water was found to be reduced to very low levels with the increase in the concentration of sodium sulphide (from 5.9 ml O_2/ℓ to 0.54 ml O_2/ℓ). This may cause heavy mortality of the prawns.

Molt Staging in Adult *Penaeus monodon*

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Changes and formation of cuticular layers and setae bordering the uropods and endopodites of the pleopods of adult *Penaeus monodon* were examined under a light microscope. Observations and photographs were made at 0, 12 and 24 hours after molting and every 24 hours thereafter until second molting occurred. Results show that the internal structures of the setae and cuticle undergo marked changes throughout the molt cycle. It was possible to identify the molt stages A, B, C and D. Rapid examination of the molt stages allows the proper timing of eyestalk ablation to induce ovarian maturation.

Effect of Temperature and Salinity on the Hatching of Eggs and Larval Development of Sugpo, *Penaeus monodon*

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Incubation of *Penaeus monodon* eggs and rearing of different larval stages were undertaken at nine temperature-salinity combinations. The eggs, nauplii, zoea and mysis from one spawner kept as stock culture at ambient temperatures of 26-30°C and salinity of 32-33 ppt were exposed to temperature levels of 23, 28 and 33°C and salinity levels of 23, 28 and 33 ppt.

Eggs and nauplii survived the sudden change of temperature and salinity (from ambient to experimental) but the zoea and mysis did not. However, salinities of 23 and 28 ppt in combination with any of the temperature levels produced weak larvae. Highest mean hatching rate was obtained at the temperature-salinity combination of 23°C-33 ppt, followed by 28°C-33 ppt and 33°C-33 ppt. Incubation periods for these treatments were 22, 16 and 14 hr, respectively. Survival rate of nauplius (taken from stock cultures) to first zoeal stage was highest at 28°C-33 ppt, followed by 33°C-33 ppt and 23°C-33 ppt with molting time of 50, 45 and 75 hr, respectively.

The nauplii exposed to 33°C-33 ppt molted to zoea stage within 38 to 40 hr but later died. Those exposed to 23°C-33 ppt and 28°C-33 ppt reached zoea stage within 57 to 60 hr and 48 to 50 hr, respectively. Similarly, the nauplii taken from the stock cultures and reared until postlarval stage (P_1) under experimental conditions completed the zoea and mysis

stages in 9 to 11 days at 28°C C-33 ppt, 7 to 9 days at 33°C-33 ppt, and 13 to 15 days at 23°C-33 ppt.

Statistical analysis showed that salinity had highly significant effect on rates of hatching of eggs and survival from nauplius to first zoeal stage but not temperature although the latter had an apparent effect. However, both factors affected time of hatching of eggs and time of molting from nauplius to zoea. Interaction effect was significant only on rate and time of hatching. Different sources (spawners) of eggs and nauplii did not have significant effect on time of hatching and molting from nauplius to zoea, but significantly affected the hatching rate of eggs and survival rate of nauplii to zoea stage.

The Influence of Temperature and Salinity on Oxygen Consumption of *Penaeus monodon* Postlarvae

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The effect of salinity and temperature on oxygen consumption at different developmental ages of *Penaeus monodon* postlarvae (P_5 to P_{60}) was studied. The design was a 2×5 factorial, using two levels of temperature (15 and 30°C) and 4 levels of salinity (10, 15, 20 and 30 ppt). One-day old postlarvae (P_1) were acclimated to various salinities prior to the start of the experiments. Oxygen consumption was determined after three hours using a YSI dissolved oxygen meter *vis-a-vis* Winkler titration method.

Respiratory activity as affected by temperature and salinity varies, dependent on the postlarval stage tested. Statistical analyses showed that temperature did not significantly influence oxygen uptake at early stages (P_5-P_8) until P_{25}-P_{28}. Its effect started to become apparent when the postlarvae were P_{35}-P_{38} and was most pronounced at P_{49}-P_{52}. general, the postlarvae consumed more oxygen at higher temperature and the variation in the oxygen consumption of the postlarvae under the two temperatures become less obvious as the postlarvae were older. Salinity seemed to affect the oxygen consumption of the young postlarvae, P_5-P_8 and P_{25}-P_{28}, more than temperature. Differences in rate of oxygen consumption at various salinities were greater in younger postlarvae (P_5-P_{38}) than in older postlarvae (P_{42}–P_{60}). The relationship between rate of oxygen consumption and body weight is nearly linear in the various salinity-temperature treatments. In all cases, the regression was significant at 1% level. *P. monodon* postlarvae behaved as respiratory conformers in all the salinities tested at ambient temperatures.

The least oxygen consumption rate was noted at salinities of 20 and 30 ppt at low temperature (15°C) and 20 ppt at high temperature (30°C). The importance of these findings is discussed and related to improvement of postlarvae transport methodology.

Effect of Carrageenan Micro-Binded Diet on the Larval Stages of *Penaeus indicus*

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At present, most hatcheries depend on live food like diatoms, *Chlorella,* rotifer and brine shrimp to rear the larval stages of various penaeid species. Mass production of live feed requires much space (tanks) and labor, and is often affected by environmental conditions. The possibility of substituting live food with artificial diet for *Penaeus indicus* larvae was evaluated. Carrageenan micro-binded diet (C-MBD) was selected as test diet and its composition was modified from C-MBD designed for *P. japonicus* (about 45% protein).

Larvae stocked at 100/ℓ and fed five times/day at 0.8 mg/larva/day had an average survival rate of 45% from Z_1 to M_1. Water temperature was 26.5-30.5°C and salinity 32-33 ppt. An average survival rate of 70.2% from M_1 to PL_1 was attained when the stocking density was 30/ℓ and feeding was three times/day at 0.3 mg/larva/day (water temperature 25.5-28.5°C, salinity 27-32 ppt). From PL_1 to PL_5 at stocking density of 20/ℓ with feeding rate of 0.3 mg/larva/day (fed 3 times a day), the average survival rate was 64.9% (water temperature 25.5-28.5% C, salinity 28-32 ppt).

The results show that the present composition of C-MBD is highly effective for myses up to the early postlarval stages of *P. indicus*.

Effects of Diet on Reproductive Performance of Ablated *Penaeus monodon* Broodstock

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Four practical diets were compared for their effects upon ovarian maturation and spawning of ablated *Penaeus monodon* broodstock. Diets were formulated based upon the fatty acid profile of wild *P. monodon.* Diets 1 and 3 were cod liver oil-based while Diets 2 and 4 were soybean oil-based. Experimental treatments consisted of each of the formulated diets given in combination with natural food (squid, mussel, and annelids). An all-natural diet served as control. The fatty

acid composition and total lipid content of the diets and of *P. monodon* fed with these diets were assessed.

Reproductive performance was evaluated in terms of number of spawnings, fecundity, egg and nauplii production and hatching rate of eggs. Broodstock response was best in Diet 1 and comparable with the control, followed by Diets 3 and 4, and was poorest in Diet 2.

Broodstock performance appeared to be related to the fatty acid patter n of the diet. All pelleted diets contained similar levels of total lipids. However, there were differences in amounts of important polyunsaturated fatty acids (PUFA): 20:4ω6 (arachidonic), 20:5ω3 (eicosapentaenoic) and 22:6ω3 (docosahexaenoic) acids. The fatty acid profiles of Diets 1 and 3 more closely resemble the profile of maturing ovaries of wild *P. monodon*; the PUFA content of these diets and ω3/ω6 ratios were higher compared to Diets 2 and 4. Diet 2, showing the poorest profile among the diets, was low in ω3/ω6 ratio and contained minimal levels of PUFA.

Study on the Larval Rearing of *Penaeus merguiensis*

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Nursing postlarvae of *Penaeus merguiensis* in the same tank as rearing always results in low survival rates, around 30%. One reason is that stocking density for P_1 is too high for postlarvae grown to P_{20} size. Another reason may be that it is impossible to sufficiently clean a tank containing culture stock. In order to overcome the first constraint and to test whether the second is valid, rearing of nauplii to early postlarval stage was done in one tank, then early postlarvae were moved to another tank for nursing to P_{20}.

Rearing was done in rectangular, concrete tanks (5 m × 5 m × 2m) of 50 ton capacity, with an initial stocking density of 20-40 nauplii/ℓ. *Chaetoceros* sp. at adensity of 3-4 $\times 10^4$ cell/ml, or *Tetraselmis* sp. at 1-3 × 10^4 cell/ml were fed to zoea stage, then rotifer was given when the larvae metamorphosed to mysis stage. Within 8-10 days, when all of the larvae metamorphosed to postlarval stage, they were transferred to the nursing tank. Postlarval nursing was done in rectangular, concrete tanks with a capacity of 12 or 30 tons. The stocking rate was 12 postlarvae/ℓ in the 12-ton tanks and 8 postlarvae/ℓ in the 30-ton tanks. The early postlarvae were fed constantly with brine shrimp, and the older postlarvae were fed 4-5 times daily with squid meat. Fifty to seventy percent of seawater was exchanged, and siphoning of food remnants was done daily. The postlarvae grew to an intermediate size (1.0-2.5 cm total length) for stocking in grow-out ponds within 12 to 20 days.

The results of rearing in 50-ton tanks with an initial stocking density of 20-25 postlarvae/ℓ, 25-30 postlarvae/ℓ and 30-40 postlarvae/ℓ produced survival rates of 74.3%, 63.6% and 47.6%, respectively. The survival rate for nursing in 12-ton tanks, with stocking density of 12 postlarvae/ℓ was 85.0% and for 30-ton tanks with stocking density of 8 postlarvae/ℓ was 61.7%. These results seem to indicate that the rearing and nursing of shrimp would be more efficient if carried out in separate tanks.

Characterization of Ovarian Maturation Stages in Wild Unablated *Penaeus monodon*

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At least five wild-caught *Penaeus monodon* from various maturation stages (initially classified *in vivo* as 0, I, II, III, IV, V) were measured, weighed and dissected for histological and histochemical studies. The anterior and posterior parts of the thoracic and abdominal regions of the ovary were sampled and stained with Mallory trichrome, alcian blue-periodic acid-Schiff (AB-PAS) and Sudan black.

Results showed that the ovary is composed of the ovarian wall and its extensions, zone of proliferation, follicle cell layer and oocytes. The proliferating cells are less than 10 μm, have thin rims of cytoplasm, and increase in size as maturation proceeds. Based on histology, the stages were finally classified into groups (1) previtellogenic (stage 0), (2) vitellogenic (stages I and II), (3) cortical rod (stages III and IV), and (4) spent (stage V). The previtellogenic group consists only of perinucleolar oocytes (46-72 μm) which are stained negatively with AB-PAS and Sudan black. Oocytes bigger than 55 μm are enveloped by a single layer of follicle cells. The vitellogenic group is composed mostly of yolky oocytes (121-211 μm) with the following cytoplasmic inclusions: small granules of glycoproteins, medium-size globules of lipoglycoproteins, and few large lipid droplets. The cortical rod group consists mostly of yolky oocytes (288-408 μm) with additional rod-like bodies which contain acid and basic mucopolysaccharides but no lipid. The presence of cortical rods is a characteristic feature of mature penaeid ovaries. The spent group is similar to the previtellogenic group but contains some yolky oocytes, thicker follicle cell layers, or irregularly shaped perinucleolar oocytes. Th GSI ranges of the four groups are 0.899-1.937, 3.099-7.598, 5.631-12.000 and 1.848-2.919, respectively.

The Use of Haptophyceae in Rearing Experiments on Larval *Penaeus orientalis*

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The food value of five clones of Haptophyceae, *Coccolithus pelagicus, Dicrateria zhanjiangensis, Isochrysis galbana*,

Tahitian *Isochrysis* aff. *galbana*, and *Pseudoisochrysis paradoxa* were tested for larval *Penaeus orientalis.* The algae were semi-continuously cultured in 5,000 ml carboys with 4,000 ml of Guillard f/2 medium, under 2,000 lux continuous light and under aeration. The algal density was up to 1×10^7 cell/ml. Rearing experiments were conducted in round tanks with diameter of 45 cm. Algal density was controlled at 1×10^5 cell/ml in the course of the experiments. The larval density was 18 individual/100 ml; water temperature, 21-24°C; pH, 7.5-7.7; and sea water specific gravity, 1.019.

The results showed that of five clones used, Tahitian *I.* aff. *galbana* and *D. zhangjiangensis* proved to be the best. It took 9-11 days for nauplius I to develop into mysis I with survival rate of 73.5% and 73.4%, respectively.

The Tolerance of *Penaeus monodon* Eggs and Larvae to Fungicides against *Lagenidium* sp. and *Haliphthoros philippinensis*

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The *in vivo* effect of mycostatic levels of fungicides against the fungi *Lagenidium* sp. and *Haliphthoros* sp. were tested on *Penaeus monodon* eggs and larvae. Hatching rate and survival of nauplii, zoeae, myses and postlarvae exposed to 10 mg/ℓ Benzalkonium chloride, 1 mg/ℓ Clotrimazole, 1 mg/ℓ Crystal Violet, 10 mg/ℓ 2,4-D, 10 mg/ℓ Daconil, 20 mg/ℓ laundry detergent, 1 mg/ℓ Econazole nitrate, 10 mg/ℓ Resiguard, 0.2 mg/ℓ and 10 mg/ℓ Treflan-R, 0.01 mg/ℓ and 0.2 mg/ℓ Trifluralin were monitored daily for 96 hr in a static bioassay in glass aquaria. Results showed that all test chemicals had no inhibitory effect on hatching rate but survival rate of hatched nauplii was significantly reduced in most treatments except that of 0.2 mg/ℓ Treflan-R. Tests with zoeae, myses and postlarvae indicated that 0.2 mg/ℓ Treflan-R and 0.01 mg/ℓ and 0.2 mg/ℓ Trifluralin did not adversely affect survival. In addition, Benzalkonium chloride caused no significant mortalities among exposed myses.

Growth and Survival of *Penaeus monodon* Postlarvae with Different Feeding Regimes and Stocking Densities in Earthen Brackishwater Nursery Ponds

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The effect of different stocking densities (50, 100 and 150/m^2) and two feeding regimes (natural food, consisting mainly of lablab, and natural food plus artificial diet) on the growth and survival of *Penaeus monodon* postlarvae (PL_4 to PL_5) were evaluated in eighteen 40 m^2 earthen brackishwater nursery ponds using tidal water exchange for a period of 45 days.

Results of the experiment indicated that the effect of different stocking densities was highly significant ($P<0.01$) on growth but not on survival for the two feeding regimes. Likewise, no interaction effect was discerned. Shrimps given artificial feed (Treatments II, IV and VI) obtained higher mean weight gains of 1.55, 1.17 and 1.05 g, respectively, than those that were not given artificial feed (I-1.44 g, III-0.92 g, and V-0.66 g). Similarly, those reared with artificial feed attained better survival of 41.62% (II), 67.44% (V) and 52.14% (VI) compared to shrimp that were not given artificial feed (I-42.53%, III-54.61% and V-46.90%).

An exploratory economic study showed that the nursery operation gave promising results in all treatments. High rate of investment (ROI) was obtained to give a safe margin for the risk involved in this kind of business. Among all treatments, treatment V had the highest ROI of 693% and shortest payback period of 0.19 years.

Intermediate Culture of Chinese Prawn Without Feeding in Nursery Ponds

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The aim of the experiments is to find a new way to accomplish intermediate culture of the penaeid prawn in nursery ponds. Experiments have been carried out in prawn farms in Haiyang County, Shandong Province. Prawn fry were stocked at high density in a nursery pond. Commercial fertilizer was added to the nursery pond to fertilize the pond water as nutrients for the planktonic and benthic organisms. The prawn fry in the pond fed only on the available natural food organisms without any special feed supply and grew normally. The survival and growth rate of the prawn fry are discussed.

Survival, Growth and Production of White Shrimp *Penaeus indicus* in Brackishwater Ponds

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This study was conducted in 4 one-ha ponds, 70-100 cm deep and 2 two-ha ponds, 40-70 cm deep to evaluate the survival, growth and production of white shrimp, *Penaeus indicus* stocked at 50,000/ha and cultured within a period of 90 days with supplementary feeding.

It was observed that mean survival and yield per ha obtained were significantly higher in deeper ponds, 70.36% and 343.2 kg/ha, respectively, compared with those in shallow ponds, 37.50% and 180 kg/ha, respectively ($P < 0.05$). There was no significant difference in mean body weight at harvest for deep ponds (9.80 g) and shallow ponds (9.55 g). Results suggest that white shrimp production is better in deeper ponds than in shallow ponds.

Effect of Dietary Fatty Acids on the Fatty Acid Composition of *Penaeus monodon* Juveniles

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Six purified diets containing either pollack liver oil or a combination of dietary fatty acids (18:1ω9, 18:3ω3, 20:5ω3) at 5% level and a control (no lipid) were assessed for their influence on the fatty acid composition of *Penaeus monodon* juveniles (0.2-0.5 g). After a 35-day feeding period, the fatty acid composition of the neutral lipid (NL) and polar lipid (PL) fractions of prawn total lipids was analyzed. All treatments showed that the prawn lipid contained high level of polyenoic acids (20:4ω6, 20:5ω3, 22:6ω3); likewise the sum of ω3 series fatty acids were high in the PL fraction. The component fatty acids of prawns showed a correlation with those of the diet. However, some dietary fatty acids were incorporated more into the NL fraction (18:1ω9, 20:5ω3) than in the PL fraction (20:4ω6). The ratios of 18:1ω9/22:6ω3 and (18:1ω9 + 20:1ω9)/(20:5ω3 + 22:6ω3) were found to be the lowest in the PL of the prawn pollack liver oil.

Lipids and Essential Fatty Acids in the Nutrition of *Penaeus monodon* Larvae

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Total lipid levels and fatty acid distribution during larval development of *Penaeus monodon* were determined. Larvae were cultured utilizing standard rearing procedures and feeding schemes adopted by the Crustacean Hatchery of SEAFDEC Aquaculture Department in Tigbauan, Iloilo, Philippines. At each developmental stage (spawned egg, nauplius, protozoea, mysis, postlarva), samples were collected for biochemical analysis.

Lipid content decreased with developmental stage (from egg to postlarva), indicating utilization of lipids as energy source during larval development and metamorphosis. The major fatty acids in the egg lipid were 16:0 (palmitic), 16:1 (palmitoleic), 18:0 (stearic), 18:1 (oleic), 18:3 (linolenic), 20:4 (arachidonic), 20:5 (eicosapentaenoic), and 22:6 (docosahexaenoic acids. As the larvae developed, levels of 16:1 and 18:1 fatty acids decreased with a corresponding increase in polyunsaturated fatty acids (PUFA), particularly 20:5ω3 and 22:6ω3. These indicate the importance of PUFA as dietary components.

Comparison was made between fatty acid changes during larval development and the fatty acid constituents of commonly used larval feeds (algae, rotifer, brine shrimp, egg yolk) for *P. monodon*. The algae and zooplankton were found to contain 20:5ω3, while egg yolk was high in total lipids but low in polyunsaturates. Most larval diets were deficient in 22:6ω3 fatty acid.

Crustaceans have been shown to have a limited capacity to biosynthesize long-chain PUFA; these have to be provided in their diet. These essential fatty acids must be available in appropriate amounts to ensure successful larval development and survival.

Lecithin Requirement of *Penaeus monodon* Juveniles

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An 8-week feeding experiment was carried out to determine the lecithin requirement of *Penaeus monodon* postlarvae. Six shrimps with initial mean weight of 0.11 g were stocked in oval fiberglass tanks in a flowthrough system with 40 ℓ of seawater. There were 5 replicates or a total of 30 shrimps per treatment. Diets were similar for all treatments except for the source of lipid and levels (0, 1 and 2%) of added soybean lecithin. Cod liver oil (treatments 1 to 3), crude degummed soybean oil (treatments 4 to 6) and refined soybean oil (treatments 7 to 9) were the three sources of lipid.

Differences in mean weight gain due to source among treatments were not significant after the fourth week of feeding but were significant after the sixth week. Mean survival rate was affected by source of lipid after the fourth and sixth weeks. Levels of lecithin significantly affected mean weight gain after the fourth and sixth week of feeding. Mean survival rate was significantly different among treatments after the sixth but not the fourth week. Although feed conversion or feed efficiency was generally poor, a trend is discerned. Feed conversion improved as dietary levels of lecithin increased from 0 to 2%. *P. monodon* juveniles need lecithin but the amount has yet to be defined.

Carbohydrate Requirements of *Penaeus monodon* Juveniles

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Penaeus monodon juveniles (initial mean weight=0.62 g) were fed semi-purified diets containing 10, 20 and 30% trehalose, sucrose or glucose for eight weeks. Results showed that shrimps fed 20% trehalose gave the highest growth rate. Of the three types of sugars tested, trehalose promoted the best growth rates, followed by sucrose and glucose. When the level of sugar was considered, 20% gave the best growth rate and 30%, the lowest. The type as well as level of sugar greatly affected the body crude protein and body lipid ($P < 0.01$), while survival was mainly affected by type of sugar alone ($P < 0.01$). Trehalose and sucrose diets promoted better survival than glucose diets. A negative linear correlation ($r = -0.70$) between the body crude protein and body lipid was obtained.

Earthworm, Marine Annelids and Squid as Feed Ingredients in Formulated Diets for Juvenile *Penaeus monodon*

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Earthworm and annelids were incorporated in diets for *Penaeus monodon* juveniles (mean weight 0.54 g) either in wet or dry form. These protein sources were added in amounts needed to replace 10% of the animal source of protein. Other sources of protein in the diet were shrimp head meal, fish meal, and defatted soybean meal. Diets were computed such that two-thirds of total protein came from animal sources and one-third from vegetable sources. Other components of the diet were rice bran, sago palm starch, cod liver oil and a vitamin-mineral mixture. Another diet, used as maintenance diet, served as control. Postlarvae were randomly stocked at 6 individuals/tank in a flowthrough system with 5 replicates/treatment. Each of the oval fiberglass tanks had three 10-cm diameter PVC pipes for shelter. The prawns were fed 10% of biomass twice daily.

Although treatment means for percent weight gain were not significantly different, the diet that contained dried earthworm or annelid meal gave higher weight gain than diets containing the wet form. The earthworm diet gave higher weight gain than diets containing annelids. Survival rate also followed a similar pattern as that of weight gain. Shrimp fed earthworm (wet or dried) gave survival rates numerically higher than those fed marine annelids. Shrimp fed the control diet had survival rates lower than those fed earthworm-containing diets but higher than those fed the wet annelid diet.

In another experiment, earthworm or squid was incorporated in the diet. Survival rates of shrimp with earthworm or squid in the diet were significantly higher than those fed the control. Weight gains were not significantly different from each other. Food conversion was generally low. The drawback in the use of earthworm, annelids and squid is that they are relatively expensive compared to fish meal and shrimp head meal.

Effects of Some Water-Soluble Vitamins on the Growth of *Penaeus monodon* Juveniles

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The response of *Penaeus monodon* juveniles (ave. wt.= 0.076 g) in terms of survival and growth rates to vitamin test diets was observed in a 35-day feeding experiment. The prawns were reared in 60-ℓ oval tanks containing filtered seawater in a flowthrough system of ambient temperature and salinity. The treatments consisted of a control (complete vitamin mix), a vitamin-free diet and nine other diets, each lacking one of the vitamins in the mixture. At the end of the feeding trial, the survival rates in all treatments ranged from 80 to 100%, while weight gain ranged from 74 to 40%. Significantly lower weight gains were obtained from choline chloride-free diet ($P<0.05$) and vitamin-free and inositol-free diets ($P<0.01$) than from control.

Ruppia maritima and *Najas graminea* as Natural Foods for *Penaeus monodon* Juveniles

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Ruppia maritima (*kusay-kusay*, Hiligaynon) and *Najas graminea* (*digman*, Hiligaynon) are macrophytes growing in local brackishwater ponds believed to provide food and shelter to prawns and fishes. Their effect on growth and sur-

vival of *Penaeus monodon* juveniles (PL_{50}; carapace length, 4.01 mm; body weight, 0.053 g) were studied in 80-ℓ glass aquaria. The treatments were: (a) a commercial pellet (40% protein); (b) *live Ruppia;* (c) decaying *Ruppia*; (d) live *Najas*; and (e) decaying *Najas.* The pellet was offered to satiety (approx. 100% of body weight) twice daily. Live *Ruppia* and *Najas* were transplanted in the aquaria using pond soil a week prior to the experiment. Decaying *Ruppia* and *Najas* were transferred from ponds. Salinity was maintained at 15 ppt and 50% of the water was changed regularly.

Highly significant differences ($P < 0.01$) in mean carapace length (CL) and mean body weight (BW) on the 10th, 20th and 30th days were observed among treatments. Increase in CL was fastest with decaying *Najas* and slowest in live *Ruppia* (14% vs. 17% after 30 days). Growth with decaying *Ruppia* was comparable to pellets on the 10th and 20th days but was faster after 30 days. Body weight on all sampling days was highest in decaying *Najas* and lowest in live *Ruppia.* Percentage increases were 122, 273 and 565% on the 10th, 20th and 30th days, respectively, with decaying *Najas.* Those given live *Ruppia* registered increases of 11, 67 and 94%, respectively. The rapid growth rate of animals on decaying *Najas* was compensated negatively by a low survival rate (31%), significantly lower than on live *Najas* (100%). Other survival percentages were: decaying *Ruppia,* 59% and pellet, 53%.

Hepatopancreas Cells as Monitor Cells for the Nutritional Value of Prawn Diets in Aquaculture

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The hepatopancreas is considered to be the central organ of metabolism in decapod Crustacea. It is a system of blind tubules consisting of four cell types. The E-cells at the summits of the tubules develop into R-cells (for resorption of nutrients), F-cells (for production of digestive enzymes) and B-cells (function unknown).

The ultrastructure of *Penaeus monodon* R-cells changes largely after starvation and feeding different diets. B-cells show slight reactions, while F- and E-cells are rather constant. Thirteen day-starvation results in a large decrease of the cell size and in a significant reduction of all cell organelles. After seven days starvation and four days refeeding with various extreme diets, the R-cells develop completely different food-specific ultrastructures. A distinct proliferation of the endoplasmic reticulum is characteristic of protein diets. Large fat drops are the main feature after refeeding with cod liver oil. Sucrose feeding results in "empty" cells with only few organelles. The most diversified ultrastructure with fat droplets and a high amount of all cell organelles is obtained by feeding a mixed diet.

The study indicates that R-cells are very sensitive to the application of different diets. They could be used as monitor cells for the nutritional value and the availability of a diet for prawns. Particularly poor or badly formulated feed could be detected early by electron microscopy. This method may be very helpful for the development of artificial prawn diets in aquaculture, especially if natural sources will be used as food components.

Effect of Cholesterol in Artificial Diets for Mediterranean Prawns

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Mediterranean prawn (*Penaeus kerathurus* Forsskal) postlarvae (2 months old) were fed *ad libitum* with previously tested artificial diet (41% D.W., mainly of vegetal origin) supplemented with different percentages of cholesterol (0, 0.1, 0.5, 1.0 and 3.0%) and fresh bivalve mussel. Growth and survival rates were determined twice.

Considering supplemented formulas only, data show that: (a) individual weights were higher with 0.1% cholesterol in the diet; (b) survival sharply dropped in the last week of the experiment, in particular with 0.1 and 3.0% cholesterol diets; and (c) with 1.0% cholesterol, mortality and growth counterbalanced giving over-all better results.

No artificial feed can compete with the natural diet, either for survival rate or for individual growth.

Evaluation of Artificial Feeds for Shrimp (*Penaeus monodon*) Production in Brackishwater Ponds

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The experiment was conducted in fifteen 500-m^2 brackishwater ponds to determine the response of *Penaeus monodon* juveniles fed with various artificial diets. Five treatments with three replicates each were: two commercial feeds containing 45% and 40% crude protein (treatments I and II), two experimental diets formulated to contain 35% crude protein (treatments III and IV) and control, without

feeding (treatment V). Shrimp were fed twice daily at feeding rates based on shrimp consumption.

Highest mean harvest weight was attained in treatment I (23.47 g) > III (19.25 g) > II (18.86 g) > IV (11.29 g) > V (9.27 g). Statistical analysis showed that differences in growth were significant at 5% probability level. However, growth in treatments I, II and III are comparable, also growth in treatments II, III and IV. Growth in treatments I, II, III and IV was significantly different from treatment V. Highest mean survival was attained in treatment III (91.82%) > I (88.93%) > II (86.95%) > IV (83.62%) V (82.62%). Statistical analysis showed no significant differences among treatments at 5% probability level.

Projecting on a hectare basis, mean yield for each treatment was: I (628.37 kg) > II (496.35 kg) per crop in 120 days culture. Good yield was attributed to provision of formulated feeds, use of pumps in addition to tidal change for water exchange and control of predators, and pest eradication through proper pond preparation.

Staggered Harvesting as a Method of Increasing Prawn Production with Supplemental Feeding

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Prawns, like any other animals, exhibit dissimilarities in growth rates. As they grow, a wide range of body weight distribution from the same population is observed. Staggered harvesting method is commonly practised in cultured animals having this characteristic. Selective or partial harvesting is especially useful in this type of management system. In this case, the larger shrimps are caught earlier than the small ones thus giving chance for the smaller ones to grow bigger.

The study was conducted in four one-ha ponds. Recommended pond preparation was followed. Partial harvesting was employed in experimental ponds by using 2-4 units of 8 knots selective pound nets once a week commencing after three months culture until final harvest. Control ponds were harvested only once at the end of the culture period.

The results show a mean production value of 506 kg from control ponds and 639 kg from experimental ponds. Average survival rate for experimental ponds was higher (92.90%) than for control (77.65%). Final average body weight was higher for experimental ponds (21.8 g) than for control (20.5 g).

Size-wise, production of big size group (30-35 g) is 578.0 kg compared to 434.6 kg for small size group (13.1-13.4 g) from both control ponds with over-all production of 1,012.6 kg. On the other hand, production from the two experimental ponds for big and small size groups is 872.2 and 405.8 kg, respectively. The means of the total weights of marketable size *Penaeus monodon* from control and experimental ponds are 289.0 and 436.1 kg, respectively. That is, 43.5% of the stock reached marketable size in ponds with staggered/partial harvest method compared to only 27.5% from control ponds.

The Production Economics of an Integrated Prawn Hatchery-Floating Nursery Project

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The paper aims to present an economic evaluation of an integrated prawn (*Penaeus monodon*) hatchery-floating nursery project using standard economic tools and methods of analysis. The data used in the analysis were taken from SEAFDEC AQD experience at the Batan, Aklan Research Substation hatchery-floating nursery project. The technical bases were gathered from researchers after the peculiarities of aquaculture *vis-a-vis* other business ventures in agriculture and industry were taken into consideration.

The study shows that an integrated hatchery-floating nursery project is a profitable culture system. The rate of return on investment for this integrated project ranges from 29 to 47% while payback period ranges from 1.8 to 2.6 years. A separate economic analysis of a hatchery project and a floating nursery was also undertaken to determine the profitability of independently operating each subsystem. The analysis shows better results for the floating nursery subsystem as compared to the hatchery subsystem. Return on investment and payback period for the floating nursery range from 23 to 78% and 1 to 3 years, respectively, while those for the hatchery range from 20 to 36% and 2.3 to 3.7 years, respectively.

PART III

SESSIONS AND PARTICIPANTS

Proceedings of the First International Conference on the Culture of Penaeid Prawns/Shrimps, Iloilo City, Philippines, 1984

Sessions

	Chairperson
General Aspects and Country Papers	Jurgenne H. Primavera
General Biology, Ecology and Physiology	Patrick Sorgeloos
Broodstock Development and Gonadal Maturation	Victor J. Mancebo
Larval and Postlarval Rearing	Rolando R. Platon
Grow-out	Herminio J. Rabanal
Nutrition and Feed Development	Emmanuel M. Cruz
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Participants and observers of the First International Conference on the Culture of Penaeid Prawns/Shrimps pose for a souvenir picture.


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Penaeus monodon harvest (photo by J.H. Primavera)