New South Wales State Fisheries

A 1979 REPORT on the PRAWN FARMING INDUSTRIES of JAPAN, the PHILIPPINES and THAILAND

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SECTION 1

INTRODUCTION

This report deals with the period July to October 1977 during which time inspections of the prawn farming industries of Japan, the Philippines and Thailand were made. A total of ten weeks was spent in Japan with shorter periods in the Philippines and Thailand.

Japan not only has the most successful prawn farming industry in the world but its aquaculture research in general is also the most advanced and diverse. Thus it was possible to inspect facilities used for the culture of many species and a brief section dealing with the aquaculture of some of these other species is included, along with observations from the other two countries visited.

The bulk of the report deals with Japanese aquaculture and the aim has been to provide considerable detail but mostly as a supplement to existing works published in English. Much less published information is available for the aquaculture industries of the Philippines and Thailand and thus the sections relating to these countries are written in as much detail as possible. Some understanding of the larval development of penaeid prawns and portunid crabs is assumed in some sections of this report but not in the general summary (Section 10) which also includes recommendations relevant to the Australian situation.

All costings in this report are given in Japanese yen (¥), Filipino pesos (₱) or Thai Baht rather than Australian dollars because exchange rates tend to fluctuate. The Commonwealth Trading Bank selling rates on 28.5.79 were ¥241.00, ₱8.02 and Baht 22.21/A$. These rates should be useful for approximate conversions.

SECTION 2

PRAWN LARVAL REARING AT THE FUJINAGA PENAEID SHRIMP INSTITUTE, AIO, JAPAN

A. Introduction

A period of four weeks in July-August, 1977 was spent at the Institute and a detailed account of the *Penaeus japonicus* larval rearing methods used there is presented. The Institute provided an example of a prawn hatchery where the highly successful, conventional Japanese methods were still being practised. Set up by the founder of the Japanese prawn farming industry Dr. Motosaku Fujinaga, the Institute operated as a commercial hatchery but was also granted taxation concessions in recognition of its importance as a training centre for hatchery technicians. Amongst its impressive array of former employees were Dr. J. Kittaka who developed the method of growing diatoms and prawn larvae together in large tanks and Dr. K. Shigueno whose work is discussed later in this report. The Director during my visit was Mr. Koichi Fujinaga, Dr. Fujinaga's son.

The Institute (Map 1, position A) concentrated on the rearing of *P. japonicus* larvae but at its Amakusa branch (Map 1, position B) *Metapenaeus monoceros* larvae were also being successfully reared. In the colder months the staff were occupied with the rearing of ayu larvae (*Pleccoglossus altivelis*), whilst considerable numbers of other fish larvae were also produced at certain times of the year. These included puffer (*Fugu rubripes*) and red sea bream (*Pagrus major*).

In addition to the following description of *P. japonicus* larval rearing procedures, an example data sheet for a hatchery run (Table I), a summary of rearing methods (Table II) and a summary of larval stages (Table III) are also included.

B. Location and Physical Characteristics

(1) Location

The Institute was situated on the northern shore of the Seto Inland Sea whilst the Amakusa branch had a far more oceanic aspect.

Unless otherwise stated the information in Section 2 relates only to the Institute at Aio and not the Amakusa branch whose operations were only superficially inspected.

(2) Salinity

During July, 1977 the salinity was very high at 36‰. The nearby Fushino R. has at times discharged large quantities of fresh water with the result that the surface water above the Institute's pump intake became fresh. However, at high tide the salinity at the pump intake does not drop below 24‰. Mass mortalities of spawners have occurred when they were placed in larval rearing water of low salinity.

(3) Turbidity and Tidal Range

The Institute drew its water from a tidally flushed rock strewn beach. There were no turbidity problems during my stay but much of the larval rearing water was passed through a layered sand filter which was cleaned weekly by replacing the top 10 cm of fine sand. The rearing water also passed through a 350 μ plankton mesh filter bag.

(4) Temperature

The larval rearing tanks were located within fibreglass greenhouses and hence the rearing water temperatures were often above ambient, with an optimum of 27-28°C and a tolerable upper limit of 31°C. In spring heated steam from an oil burning generator was forced through pipes suspended in the larval tanks so as to maintain the following minimum water temperatures:

Larval stage	Minimum temperature °C
Nauplius (N) and Zoea (Z)	26
Mysis (M)	24 - 26
Postlarva (P)	20 - 22

C. Larval Rearing Tanks

The Institute continued to use the conventional procedure of growing the diatoms and prawn larvae together in large concrete tanks (Figure 1). These were 200 t (in capacity), had an operating depth of 2 m and were square with 10 m sides. Before every hatchery run the tanks were hosed, dried and scrubbed with the aid of a bleach solution containing 1-2 kg of 60% pure $Ca(ClO)_2$/200 t tank, the exact amount depending on the condition of the tank.

D. Spawning

The larval tanks were initially filled, to a depth of 60 cm, several hours before the arrival of the spawners. During summer the rearing water could warm to above ambient temperatures (e.g., up to 31^{o}C) by the time the spawners were added to the tank. Hatchery records indicated that in spring the boiler was used sparingly until 1-2 days after the addition of spawners. Hence they were sometimes placed in water of only 20-21^{o}C with the temperature not reaching 24^{o}C for another two days.

The spawning females were collected with the aid of tangle nets in the Japanese areas of Nagoya, Kyushu and from near the Institute. In spring Japanese spawners have often been unavailable and thus Taiwanese females have been imported. These tend to suffer higher mortalities and spawn less successfully. In contrast approximately 50% of the Japanese spawners were in adequate condition to be sold to the live prawn restaurant trade after removal from the larval tank. Also about 30% of the added spawners could be seen to have spawned although not always completely by the time they were first removed from the tank. It was difficult to estimate total spawning success because unspawned females from one tank were often restocked into another tank in the hope of their spawning in the second tank. This approach was sometimes clearly successful and Table I shows the example of a tank in which all larvae resulted from females given a second chance to spawn.

The spawners were caught at night by fishermen who held the prawns on board in water before selling them to a specialized merchant. His handling involved stocking the females into water which was subsequently slowly chilled to 15°C. The cooled prawns were then packed in chilled dry sawdust within a styrofoam box. A bag of ice plus sawdust was often included and the packing operation took place within a coolroom. Insulated boxes from Kyushu with a capacity of 11 ℓ were sent to the Institute and these held 50-60 large females in 6 ℓ of sawdust. The sawdust temperature at the time of arrival was usually less than 17°C.

The Japanese spawners arrived on the night following that of their capture. In the case of Kyushu females the transport time by train from merchant to the Institute was 6-7 hours but the Taiwanese females had to travel for more than 24 hours. This extended period probably accounted for their poorer spawning and survival rates which necessitated the addition of 200 Taiwanese females as opposed to fewer than 100 Japanese females/200 t tank. A small proportion of the Japanese females, usually less than 10%, were dead or moribund at the time of unpacking from the sawdust and these were not added to the larval tank. The remaining females were dispersed to various parts of the larval rearing tank after being washed and counted. In summer they were left in the tank for 2-3 days whereas in spring they sometimes remained for 5-6 days. Eggs were usually apparent 1-2 days after stocking in summer but in spring they may not appear until after four days. Considerable care was taken to ensure that every female was removed by dip netting from outside of the tank.

E. Diatom Bloom

A diatom bloom was maintained within the larval tanks to provide food for zoeae, mysis and possibly postlarvae and to help prevent a build up of waste products or a bloom of harmful plant cells. The management of this bloom was somewhat atypical at the Institute because of the high nutrient levels in its water supply.

Shigueno (1975) indicated that in Japan fertilizer was usually added to the rearing water during nauplius stage, 2-3 days after the stocking of the females, and that fertilization often continued on a daily basis right through to early postlarva. At the Institute, fertilization did not usually begin until the second day of zoea or later and there might only be three additions of fertilizer for the whole rearing period. Thus the total fertilizer addition might only be NS 700 g according to the following formula:

$$\text{NS } 100 \text{ g} = 100 \text{ g } KNO_3 + 10 \text{ g } Na_2HPO_4 + 5 \text{ m}\ell \; K_2 \; S_1O_3 \text{ solution}$$

$$(19\% \; S_1O_2, \; 9\% \; K_2O).$$

In one tank I observed the development of an excessively dense bloom, during zoea, without the addition of any fertilizer whatsoever.

The Institute staff considered the optimum situation to be one where the diatom bloom increased to 5,000-8,000 cells/mℓ by the second or third day of zoea. Very rapid blooming tended to raise the pH to excessive levels, i.e., a pH of 8.8 was usually fatal to zoeae. If the diatom population was increasing too quickly a black shade cloth was placed over the rearing tank. Table I affords a good example of the effectiveness of this technique. In addition to taking great care with the bloom in zoea and to a lesser extent in mysis, the staff also attempted to maintain a diatom bloom right through until harvest. If the bloom declined excessively several counter measures were possible. Fertilizer could be added, a diatom bloom from another tank could be siphoned in or large quantities of clean seawater could be added. This last measure was often utilized if the diatom entered a phase of slow cell division. This was evident if the individual cells, in a chain of cells, developed a rectangular appearance rather than the rounded shape normally seen under the microscope.

The diatom bloom was made up of many species and apparently the dominant species varied with season. During my stay Chaetoceros sp. was dominant whilst Eucumbia was often dominant during spring. Thalassiosira and Skeletonema were also important components of the diatom bloom.

Although it did not happen during my stay there have been times when the diatom bloom has failed because of cloudy weather. In this situation the zoeae were fed on dry ground soycake, a biproduct of soya sauce preparation, or a liquid which resulted from mascerating clam or tuna meat. Hatchery records showed that up to 400 g of soycake/day were fed to 2 x 10^6 zoeae in a 200 t tank.

F. Supplementary Feeding (1977)

Table II shows the feeding procedure and other data for the Institute and for other hatcheries in several countries.

At the Institute considerable change has been made to the original feeding strategy described by Shigueno (1975). Previously the larvae survived on diatoms until late mysis when live brine shrimp (Artemia salina) nauplii were added. These sustained the larvae until they changed from a planktonic to a benthic mode of life at P_{5-6}, i.e., 5-6 days into the postlarval phase. At this stage the feeding of mascerated clam meat was commenced and continued through to harvest at P_{20-25}. The feeding procedure carried out during my stay was rather inconsistent but the general pattern is given below. At M_{1-2}, i.e., first to second day of mysis, feeding with brine shrimp nauplii and artificial plankton commenced and continued through to P_{3-6}. The feeding rates were 300-500 g of brine shrimp eggs and 400-600 g of artificial plankton/day. The brine shrimp eggs were usually distributed over the surface of the rearing water, whilst the artificial plankton was lightly homogenized in water to suspend it before addition to the tank. The artificial plankton was a patented product of neutral buoyancy and appeared to consist of denatured protein around an egg product which enclosed an oil droplet.

At P_1 the feeding of a dry, water stable, crumbled, artificial diet was commenced and continued through to harvest. The initial feeding rate was approximately 200 g/day and by P_{20} the rate could reach 1.4 kg/day.

Whilst the brine shrimp eggs were usually fed only once/day, the artificial plankton and artificial diet were each fed four times/day. All the above feeding rates were based on a zoeal population of 3.0×10^6 and a P_{20} population of 2.0×10^6 in a 200 t tank. If there was a build up in the brine shrimp population, uneaten artificial diet or excessive artificial plankton waste, the feeding rates were varied.

The change in feeding strategy has been necessitated by massive increases in the cost of brine shrimp eggs. Whereas in 1973 a total of more than 10 kg of eggs would be used for the rearing period in a 200 t tank the 1977 total was less than 3 kg. Artificial diet has replaced clam meat largely because of its convenience and perhaps also because of reduced fouling of rearing water. The changes in feeding were probably responsible for the drop in average body weight of a P_{20} from approximately 0.015 g in 1973 to 0.010 g during my stay. The hatchery has used four main sources of brine shrimp eggs. The high quality Australian eggs had only recently become available.

Country of origin	Hatch rate	Retail price (¥/kg)
China	50%	1,000 (1973)
Canada	50%	30,000 (1977)
San Francisco (U.S.)	60-70%	40,000 (1977)
Australia	80% approx.	40,000 (1977)

G. Supplementary Feeding (1976)

The principal difference between the feeding strategies for 1976 and 1977 was the large scale use of *Brachionus* (rotifer) to spare the amount of brine shrimp used in 1976. Hatchery records showed that in one successful tank brine shrimp was totally replaced by *Brachionus*. However in 1977 the use of *Brachionus* even as a supplement to brine shrimp was discontinued because of the work load involved in producing sufficient *Brachionus* from an inadequate number of tanks.

The Brachionus were produced in tanks separate from the larval tanks and were fed with the flagellate Chlorella and baker's yeast.

H. Aeration and Water Management

The type of aeration used can be clearly seen in Figure 1. A Rootes-type blower pushed air through 25 mm diameter P.V.C. pipes which in turn fed smaller aeration hoses. Each 200 t tank was supplied with 16 of these hoses which were not fitted with airstones but carried large volumes of air.

After the initial addition of 60 t of sand filtered seawater, 10 t were added daily so that the volume reached a maximum of 180-200 t by early postlarva. Thereafter 40-50 t of rearing water were replaced daily by an equal volume of fresh seawater that was merely passed through 350 μ plankton mesh. The maintenance of favourable bottom conditions was effected by sporadically shifting the aeration lines and by manually stirring the bottom when excessive amounts of organic detritus accumulated. The use of a motor driven continuous stirrer was not found to be effective. In extreme conditions, e.g., during disease outbreaks it was necessary to harvest the larvae and shift them to a clean tank. Shifting of larvae was also necessary in overpopulated tanks which could occur when the spawning rate was high. The optimum density was considered to be 3-4 x 10^6 nauplii/200 t tank but during my stay densities in excess of 8 x 10^6 nauplii/200 t occurred. In these situations heavier fertilization rates were used during zoea but the larval population was not split between two tanks until M_2.

I. Sampling, Harvest and Transport

Whilst not being statistically oriented, the sampling procedures were effective for determining feeding rates, management procedures and declines in larval numbers.

Larval samples were collected by plunging a 1 ℓ plastic beaker with straight sides into the top of an aeration column. All larvae were counted by eye and eight concurrent samples were taken at least once/day up to P_1, staff numbers permitting.

After P_1 no quantitative estimates were made until harvest but daily bottom samples were taken with a plankton mesh scoop to allow qualitative estimates of larval numbers and health as well as a check on bottom conditions. No counting of unhatched prawn eggs was carried out. Mysis were relatively difficult to sample because their distribution was strongly related to relative light intensities. Thus mysis sampling was carried out in the early morning and late afternoon and extra mysis samples were taken if possible. Diatom counts were made by totally counting all cells within a drop taken from a 1 ℓ sample of rearing water. A microscope slide with a 1 mm grid pattern was used and replication of drops was carried out if time allowed. Surprisingly credible results were achieved with this method.

The larval tank had a concrete bottom with a 3% slope towards a drainage hole that emptied into a harvest reservoir between pairs of 200 t larval tanks. The drainage hole was normally protected by a plankton mesh box that was left in place for daily water changes but was removed for harvesting. Harvesting was accomplished by passing the effluent rearing water through framed plankton mesh nets supported from below by water in the reservoir. The number harvested was estimated by measuring the volume of moist postlarvae. The harvest was transported to prawn farms or liberation sites in 2 t plastic tanks which were supplied with oxygen and could hold 1 x 10^6 P_{20} each with minimal losses.

J. Production

In recent years the annual production of P. japonicus has been approximately 60 x 10^6 postlarvae at the Institute and 40 x 10^6 at Amakusa. On three occasions more than 3.0 x 10^6 P_{20} have been produced from a 200 t tank and a harvest of 2.0 x 10^6 was considered to be very successful. The Director stated that the average harvest at the Institute was 1.2 x 10^6 P_{20} per 200 t tank. During periods of disease outbreaks harvests would be much poorer.

Also spring rearings have yielded approximately 0.5×10^6 fewer P_{20} per 200 t tank than summer rearings. The normal harvest size for the Japanese market was P_{20} but for the Korean export market the *P. japonicus* were harvested at P_7, i.e., soon after they switched from a planktonic to a benthic mode of life. There was also some demand for P_{50} *P. japonicus* for pond stocking. These were held in a larval tank at a time when spring pond water temperatures were too low to allow growth of *P. japonicus*. From a population of 2.0×10^6 P_{20} approximately 0.5×10^6 P_{50} could be harvested.

K. Problems

(1) Biological Problems

(a) Spawners

The introduction of *P. japonicus* postlarvae was sometimes limited by the supply of spawners. However, the supply was far more reliable than in other parts of Asia because the fishermen specifically attempted to market their whole prawn catch alive.

(b) Disease

The most serious problem facing the Institute was a disease characterized by a change in the colour of the hepatopancreas to a turbid white or orange. This change was often followed very rapidly by massive mortality of young postlarvae. The stage at which the colour change was first apparent varied from P_1 - P_8. The disease appeared in all larval tanks which contained postlarvae during my stay except the one described in Table I. In 1976 20% of the Institute's tanks containing young postlarvae exhibited some hepatopancreas disease. During my stay the loss in one diseased tank was total whilst in others up to 400,000 apparently healthy P_{20} remained after a disease attack. The disease was even worse at the Amakusa branch but in the third major region for Japanese *P. japonicus* larval rearing, Kagoshima, the hepatopancreas disease was not evident.

Shigueno (1975) noted that *Vibrio* bacteria could be isolated from diseased hepatopancreas tissue.

However, these bacteria may have been a secondary infection rather than causal agents. At the Institute numerous antibiotics have been added to the artificial diet or rearing water but no control over the disease resulted. During periods of disease outbreaks lower larval densities and higher flushing rates were used as precautions but the value of these measures was unknown. Once a serious disease outbreak occurred the major treatment involved harvesting the larvae and shifting them to a clean tank. This method appeared to have some value but the success was inconsistent.

(c) Hydrozoans

These were very common inhabitants of the larval tanks during my stay and in 1976 48% of all larval rearings at the Institute were contaminated by these unattached colonial polyps. The hydrozoans apparently compete with the larvae for food, e.g., brine shrimp nauplii and copepods and also have a toxic effect on the larvae. Chemical treatments have been ineffective but a seine net with 1 cm square mesh set in the surface waters of the tank for 1-2 days was considered adequate for controlling the hydrozoan population (Figure 1).

(d) Copepods

These were observed to be in dense numbers in some of the larval tanks. Shigueno (1975) noted densities as high as 60/ℓ in *P. japonicus* larval rearing tanks. The Institute staff considered the copepods to be competitors with zoeae and mysis for diatoms and thus they increased the fertilizer input if copepods were numerous. However, young postlarvae were considered to be capable of eating the copepods and hence they presented no problem after mysis. Indeed they were considered desirable.

(e) Mortality of Spawners, Nauplii or Zoea

In 1976 43 separate larval rearings were attempted at the Institute and of these 7 attempts were total or major failures because of problems with the spawners, nauplii or zoeae.

In two of these failures females imported from Taiwan failed to spawn and in two others the females died. One of these mass mortalities appeared to be related to low salinity levels whilst the other occurred at the same time as a mass mortality of nauplii and zoeae in another tank. Contamination of the water supply was strongly suspected. There was also a loss of one tank of nauplii and zoeae and heavy losses within a tank of zoeae. These failure rates in the initial stages of rearing should be considered to be quite satisfactory. In general, larval rearing in Japan, until the outbreak of hepatopancreas disease, was far more consistent in its success than in other parts of Asia.

(2) Economic Problems

(a) Feed Costs

As indicated earlier brine shrimp costs have risen dramatically. Also the main substitute used at the Institute, artificial plankton, retailed at ¥10,000/kg. The artificial diet most commonly used for postlarvae was relatively expensive for a stockfeed (¥800/kg). However, the F.C.R. (food conversion ratio = feed weight : harvest weight, fertilizer and brine shrimp weights excluded) was quite efficient (1.74 : 1 in 1973) and thus it was not a major cost.

(b) Spawner Costs

The combined 1976 rearing costs (salaries excluded) for the Institute and the Amakusa branch were ¥40 x 10^6. Of this total, spawner purchases amounted to approximately ¥12 x 10^6. The Director expressed the opinion that artificially induced maturation of broodstock would eventually reduce spawner costs which were ¥18,000/kg and ¥9,000/kg in spring and summer respectively. After spawning surviving females could be sold for ¥6,000 - ¥6,500/kg. The optimum economic purchase size for spawners was 50 g per prawn. Large females often spawned poorly as did small females and cost more/prawn.

(c) Value of Postlarvae

The Director stated that the normal market price for a P_{20} was ¥1.8 in spring and ¥1.0 in summer. However, the Institute attempted to maintain a price of ¥1.8/P_{20} for both seasons. The Institute suffered competition from small hatcheries that reared only in summer and could market at prices below ¥1.0 per P_{20}. However, the persistence of the hapatopancreas disease was likely to put many competitors out of business and allow P_{20} prices to rise. The Director considered that for large scale hatchery production a price of ¥3.0/P_{20} would provide a reasonable return and not seriously affect the profitability of prawn farmers.

(d) Labour Costs

The operations of the Institute were highly labour intensive with tank cleaning before stocking accounting for two man days/tank. Artificial plankton and artificial diets were fed four times a day (0800, 1300, 1700 and 2200 hours). Furthermore stocking of females and harvesting of postlarvae took place at night and members of staff worked a roster system to ensure that at least one member of staff was on duty at all times, day and night. Labour costs were also high because the Institute maintained a high proportion of university trained staff for technician training both in Japan and overseas.

(e) Oil Costs

The rearing of larvae in spring for pond stocking necessitated the heating of rearing water and the dramatic price increases for oil have made such heating at the Institute very costly. The economics of winter rearing of fish larvae at the Institute have become quite unfavourable in the last few years for this reason.

SECTION 3

PRAWN LARVAL REARING AT THE OTHER PRAWN HATCHERIES VISITED

A. General

In contrast to my stay at the Fujinaga Penaeid Shrimp Institute, the time spent at the hatcheries discussed below was usually only sufficient for an inspection of the hatchery and an interview with the relevant researcher or hatchery manager. Hence the information from these hatcheries was far less detailed and the opportunities for verifying statements were far fewer than at Fujinaga. Much of the basic information obtained from each hatchery is included in Table II and is not necessarily repeated in the text below.

B. Nagasaki Prefecture Research Station, Nagasaki, Japan

This research station (Map 1, position C) had an oceanic aspect and experienced no salinity or turbidity problems. Sand filtered water was available at the station but was not used in the prawn larval rearing tanks. The station had an annual production of 4 x 10^6 *P. japonicus* P_{20} and these were reared for the purpose of liberation to boost recruitment to the local fishery. Because of the demand that existed for the liberation of *Metapenaeus monoceros* this species was also being reared. The same methods were used for both species and both took about ten days to reach P_1. However, from P_1 30 days was required for M. *monoceros* to reach the size of a P. *japonicus* P_{20}.

C. Yamaguchi Prefecture Naikai Farming Fisheries Centre, Aio, Japan

This centre (Map 1, position A) was situated near the Fujinaga Penaeid Shrimp Institute. It was found to be a highly successful hatchery which liberated its annual production of 40 x 10^6 *P. japonicus* P_{20}. The hatchery reduced feeding costs by partially replacing brine shrimp nauplii with *Brachionus.*

The Brachionus were produced in a 0.15 ha pond in which the population could reach a maximum of 2×10^9. They were fed on Chlorella pumped in from an adjacent 0.15 ha pond. The culture in the Chlorella pond was initiated by adding dense cultures produced in nearby 31 t concrete tanks. If Chlorella production proved to be inadequate, baker's yeast was used as a supplementary food source for Brachionus. The problems with this extensive system for Brachionus production were the contamination of the Chlorella pond with Brachionus and adult A. salina and contamination of the Brachionus pond with a predatory copepod Tigriopus.

The hatchery had two sets of larval rearing tanks with only one set supplied with sand filtered seawater. These latter tanks experienced none of the hepatopancreas disease which was rife in the other set which received water that was not sand filtered.

The fibreglass greenhouses which enclosed the hatchery tanks were cleverly designed in that they included sliding windows which aided in internal temperature regulation.

D. Tarumizu Culture Centre, Tarumizu, Kagoshima Prefecture, Japan

This centre (Map 1, position D) was similar to the Nagasaki Prefecture Research Station in that P. japonicus was only one segment of a multi-species rearing programme. However, the P. japonicus larval rearing was quite successful in that only two crops/year from each of 4 x 110 t tanks were necessary to produce 10×10^6 P_{20}. The purpose of the rearing was to provide P_{20} for liberation experiments and to assist local farmers with intensive tank stocking.

The most commonly used method of producing diatoms for zoeae was the same as that used at Fujinaga. However, a relatively pure mass culture of the diatom Chaetoceros was also bloomed but in separate tanks. These cultures could be added to a larval tank if its diatom bloom failed.

The explanation provided for why the Chaetoceros culture would bloom when the larval tank bloom was failing was that the spring diatoms in the larval rearing water were less successful than Chaetoceros at the artificially high water temperatures caused by the greenhouses. If both diatom blooms failed, finely ground artificial diet was fed to the zoeae.

At the centre research was being conducted on replacements for A. salina in the M_1 to P_5 phase. Six alternatives for this phase were being evaluated.

(1) 40×10^6 A. salina nauplii/10^6 M_1 were fed/day with an increase to $120 \times 10^6/10^6$ larvae by the P_5 stage.

(2) No A. salina nauplii were used but 200×10^6 Brachionus were fed/10^6 M_1/day with an increase to 600×10^6/day/10^6 larvae by the P_5 stage.

(3) Brachionus plus A. salina nauplii plus finely ground artificial diet were used. This was the method being used for mass production of P_{20}.

(4) A 1:1 ratio (dry weight basis) of A. salina nauplii and artificial diet was used.

(5) Only artificial diet was used.

(6) Artificial diet plus Brachionus were both added.

Alternatives (1), (3) and (4) were successful but did not eliminate A. salina nauplii. Alternative (5) was not consistently successful with the diet used but alternative (6) was considered to be very promising. Its advantage over alternative (2) was that it reduced the workload in producing sufficient Brachionus.

Most hatcheries that used Brachionus cultured it on a diet of Chlorella and used baker's yeast when Chlorella stocks were low. The centre, however, has experimented with using baker's yeast as the sole food source. The research has shown that Brachionus grown solely on baker's yeast was an equally successful diet as that grown on Chlorella, when fed to P. japonicus larvae.

Chlorella culture has usually required very large culture tank facilities and its elimination would be very valuable. Thus the centre has developed a *Brachionus* tank (Figure 2) containing 2 t of recirculating culture which was passed through a 20 ℓ plastic bead filter 18 times/day. Up to 100×10^6 *Brachionus* were harvested daily when 10% of the culture was replaced with clean seawater. The major problem with the system was contamination by *Tigriopus* but attempts were still being made to scale the system up to 100 t.

The most serious difficulty that was experienced during the mass production of *P. japonicus* P_{20} was a disease characterized by incomplete moultings and death of mysis or young postlarvae. A poor diatom bloom during zoea appeared to often precede an outbreak of the disease. Shigueno (1975) again noted that *Vibrio* bacteria were associated with this disease. A successful treatment was used at the centre and this involved the application of Fazoridon to the rearing at a concentration of 10 ppm. The treatment also killed the diatoms and necessitated the addition of cultured *Chaetoceros*.

The centre used two alternative methods for estimating the harvest of P_{20}. If the harvest was to be used for liberation, numerous 1 ℓ samples were taken from an aerated 1 ℓ holding tank and the P_{20} in each were counted. If an estimate was required for pond stocking, approximately 2,000 P_{20} were counted into a standard dish and uncounted P_{20}'s were added to a similar dish until the densities appeared to match. This procedure was repeated until the desired number had been collected from the numerous matchings of P_{20} densities. The second method was far more accurate than the first and 95% accuracy was claimed when experienced technicians were used.

E. S.I.S.F.F.A. (Seto Inland Sea Fish Farmers Association) Hatchery, Shibushi, Kagoshima Prefecture, Japan

This hatchery was one of a chain of large *P. japonicus* hatcheries operated by S.I.S.F.F.A. for the purpose of liberation to boost the fishery. The Shibushi hatchery was the largest of the chain and featured a 2,400 t larval rearing tank that provided an annual output of 140 x 10^6 P_{20} with a maximum output of 50 x 10^6 for one single rearing. The 2,400 t tank took two days to clean with a 35 atm pressure freshwater hose.

The hatchery (Map 1, position E) had an excellent oceanic aspect with its water supply being drawn from a rocky shoreline. No water filtering or salinity monitoring was considered necessary. The coastal seawater temperatures were higher than would be expected at such a latitude and the elevation was caused by a nearby warm current. No greenhouses or heating were used and the rearing season was largely confined to summer.

The diatom supply was based totally on rearing relatively pure cultures of *Chaetoceros* and adding these to the fertilized larval rearing tank. During zoea the pH was carefully monitored and if it fell outside of the range 8.0-8.6 a large proportion of the rearing water was replaced with fresh seawater.

The addition of *Brachionus* commenced at the relatively early stage of Z_2 but was discontinued at the completion of zoea when brine shrimp nauplii were added to the tank. The feeding rates were very low with *Brachionus* being fed at the rate of 350/larva and brine shrimp nauplii at 150/larva. These figures were totals for the whole rearing period and not rates/day. In 1976 artificial plankton was used but was later considered to be not worthwhile. The *Brachionus* were cultured on a diet of *Chlorella* and baker's yeast in concrete tanks of 100 t or larger. The *Chlorella* growing procedure was highly productive (Figure 3).

Chlorella culture from a 300 t tank was pumped to the top of a large concrete terrace that had 15 interconnecting levels. The culture passed through each of the levels before draining back into the 300 t tank. The terracing also had a volume of 300 t and the advantage of the system was that the culture in the terrace had a maximum depth of 30 cm. This allowed good light penetration through the whole depth and as a result the *Chlorella* density was as high as 50×10^6 cells/mℓ. Ten t of *Chlorella* culture were harvested daily.

The hatchery was located near the Tarumizu Culture Centre and appeared to have a similar disease problem, i.e., incomplete moulting and eventual death of mysis and young postlarvae. The hatchery manager stated that the affected larvae were usually covered by adhesive diatoms arranged in circular clusters. No antibiotics were used but high rates of water exchange were adopted if the disease occurred.

The cost of rearing *P. japonicus* at the hatchery (salaries excluded) was estimated by the manager to be ¥0.2/P_{20}.

F. S.E.A.F.D.E.C. (South East Asian Fisheries Development Centre), Tigbauan, the Philippines

(1) Introduction

S.E.A.F.D.E.C. Aquaculture Division was found to be a quite large organization with a staff of 150 and numerous research stations. It was funded by the cooperative of Asian nations which are members of A.S.E.A.N. and also attracted aid from western nations including Australia. The range of animals being investigated for aquacultural purposes was quite large but the main species were the jumbo tiger prawn *P. monodon* and the milkfish *Chanos chanos*.

(2) Larval Rearing

S.E.A.F.D.E.C. originally utilized the Mindanao State University hatchery at Naawan (see Section 3 G) but in 1975 the hatchery at Tigbauan (Map 2, position A) was commissioned.

The *P. monodon* production record is given below.

Year	*P. monodon* hatchery output
1975	2.0×10^6
1976	2.5×10^6
1977	5.0×10^6 by mid 1977

The hatchery was not well located in that the seawater supply tended to have excessive turbidity and a reduced salinity during periods of heavy rain. The hatchery water was passed through a sophisticated sand filter system but during my stay the turbidity levels were so high that one filter had to be back flushed for five minutes every 20 minutes.

In previous years the *P. monodon* spawners have been purchased from fishermen but in 1977 all spawners were collected from S.E.A.F.D.E.C.'s maturation pens (see Section 6). They were either spawned in large larval tanks as in Japanese hatcheries or in 1 t plastic tanks. This latter method was surprisingly successful.

As indicated in Table II two types of larval rearing tanks were used. The first type was based on the Japanese concrete tank but an epoxy coating on the concrete was used to facilitate cleaning. The volumes of the large tanks ranged from 50 to 200 t and these tanks were situated either within greenhouses or in the open. The nauplius density aimed for was 25,000/t and S.E.A.F.D.E.C. researchers were planning to reduce this figure to 10,000/t to overcome mortality problems. In comparison, the *P. japonicus* nauplius density aimed for at Fujinaga was 15,000-20,000/t. The other type of tank was a 2 t fibreglass or epoxy sealed timber tank with a conical base (Figure 4). The design was based on the tanks used for U.S. species at Galveston, Texas. The nauplius density in the Tigbauan 2 t tanks was usually 65,000/t. The maximum yield/t was much higher in the small tanks (50,000 postlarvae) than in the large ones (10,000). The 2 t tanks were prone to temperature drops and supplementary heating was used to maintain the rearing temperature at 28°C.

The most unusual aspect of the larval rearing method used was the low nutrient levels in the rearing water. In both types of tanks the diatoms were transferred to the rearing tanks from special algal tanks and no fertilizer was added to the rearing water. In the case of the 2 t tanks the diatom bloom was passed through a very fine sand filter that retained the diatoms, which were then washed to remove nutrients before addition to the larval rearing tanks. A diatom population was maintained in the larvae tank until harvest and this food supply was supplemented with Brachionus, brine shrimp nauplii and minced shrimp. This last item was quite expensive but overcame the problem of accumulation of food in the centre of the tank when the motorized bottom stirrer was being used. The larvae became benthic at P_5 and at this stage they were transferred to nursery ponds.

The hatchery had several problems which have strongly limited the production of P. monodon postlarvae. The sudden salinity drops which occurred in the hatchery water supply after heavy rain, e.g., from 30‰ to 28‰, have caused survival problems during nauplius and zoea. The fungus Lagenidium has been a common problem in the larval tanks and the herbicide Trifluralin which has been used with success elsewhere for this fungus has not proved to be a satisfactory treatment. However Furanace was of some value in treating this fungus. Heavy mortalities were sometimes evident in the early postlarval stages but the causes were unknown.

It should be noted that Metapenaeus ensis and P. merguiensis have also been reared at Tigbauan.

(3) Diatom Production

The P. monodon larvae were fed with a locally isolated diatom Chaetoceros calcitrans. Whilst pure stocks were maintained in 250 mℓ conical flasks, S.E.A.F.D.E.C. also used a larger scale system for producing pure cultures of Chaetoceros. White, plastic lined 200 ℓ tanks were lit by 8 x 40 watt fluorescent tubes enclosed in a water tight, clear perspex box that was submerged within the Chaetoceros culture.

A culture with an initial density of 100,000 cells/mℓ would reach a density of 3.5×10^6 cells/mℓ within 24 hours and peak to a maximum density of 5.0×10^6 cells/mℓ.

The dense cultures produced in this manner could be used in three ways:

(a) Continuously cultured by retaining 10% of the previous culture.

(b) Flocculated, for harvesting, by using an alum concentration of 50 mg/ℓ in the 200 ℓ tanks. After flocculation the pH was readjusted to 7 and the concentrated diatoms frozen. An alternative flocculant was lime ($Ca(OH)_2$. During flocculation lime raised the pH to 9.5 whilst alum lowered it to 6.5. These pH levels could be harmful to the diatoms but if carried out quickly the frozen diatom cultures would bloom again after thawing and reculturing. Small scale trials indicated that *Chaetoceros* cells grown from frozen stocks were adequate for the prawn larvae but in the large scale larval rearings this procedure was not as successful.

(c) Used for large scale *Chaetoceros* production. The pure cultures harvested from the 200 ℓ tanks were used to initiate blooms in 1 t plastic tanks within a greenhouse. Ten of these cultures were transferred to 40 t outside tanks or 5 t of the previous 40 t culture were retained. If there was sufficient light the 40 t culture could be harvested at a density of $3\text{-}4 \times 10^6$ cells/mℓ after 2-3 days. If harvesting was delayed contamination by other diatom species became a serious problem. In the larger scale diatom tanks crude agricultural fertilizers were used, i.e., an initial addition of 4 kg of urea and 800 g of 16:20 N:P fertilizer per 40 t tank. To prevent contamination by diatoms in the seawater added to the large diatom tanks, 16 g of Calcium hypochlorite/t of water was added before addition of the pure diatom culture. Neutralization of the hypochlorite was effected by the addition of 40 g of Sodium thiosulphate/t.

Mr. Nukiyama one of the larval rearing experts on loan from the Japanese Government estimated that a P. monodon Z_1 consumed 6,000 diatoms/day. The consumption rate, added to the fact that S.E.A.F.D.E.C. aimed to maintain diatom densities of 10,000 cells/mℓ in Z_1 and 100,000 cells/mℓ in Z_3, necessitated the production of large volumes of Chaetoceros culture.

(4) Chlorella and Brachionus Production

Brachionus has already occupied a major role in S.E.A.F.D.E.C.'s prawn larval rearing programme but its importance should increase in the future. S.E.A.F.D.E.C. staff expressed the belief that a combination of Brachionus and artificial diet would entirely replace the brine shrimp component of the feeding programme. The Brachionus plicatilis used by S.E.A.F.D.E.C. was imported from Japan in egg form. These eggs have often been collected from the bottom deposits within Brachionus tanks. The Chlorella culture was also Japanese but its purity or identity even to the generic level was not clear. However, the culture has been very successful for rearing Brachionus and also has exhibited a satisfactory salinity tolerance in the range 10-60‰.

The Chlorella was cultured in a 360 t tank and was fertilized 1-2 times/month at the following rates:

Fertilizer	Concentration (ppm)
Ammonium sulphate	100
Urea	10-15
16:20 N:P fertilizer	10-15

For initiating a new culture of Chlorella in the 360 t tank 5 t of a 16-20 x 10^6 cells/mℓ culture were added with the total volume being increased daily by seawater addition. A culture of 1 x 10^6 cells/mℓ usually reached a density of 10 x 10^6 cells/mℓ in 4-5 days of clear weather.

The Brachionus was cultured in an adjacent 360 t tank and Chlorella was added when necessary for the maintenance of a Brachionus density of 50-100 individuals/mℓ.

The maximum density that had been attained was 200/mℓ. S.E.A.F.D.E.C. staff attempted to maintain more than 5 *Brachionus* per mℓ of larval rearing water from M_1 to harvest but often could not produce enough *Brachionus*. There were two main problems. Firstly the *Chlorella* and *Brachionus* tanks were adjacent so that *Brachionus* contamination of the *Chlorella* tank was quite common and it necessitated the occasional draining of the *Chlorella* tank. Secondly, the copepod *Tigriopus* was a common inhabitant of the *Brachionus* tank. Whilst this copepod has usually been considered to be a predator Mr. Nukiyama has found that its population has peaked after that of the *Brachionus* has declined. Thus he regarded *Tigriopus* as a competitor with *Brachionus*.

G. Mindanao State University Institute of Fisheries Research and Development (M.S.U. I.F.R.D.), Naawan, the Philippines

Located on Map 2, position B this *P. monodon* hatchery was well placed with a largely oceanic aspect. The water supply had a salinity that was usually greater than 30‰ with a minimum of 28‰. Also no filtering of the rearing water was considered necessary. The ambient temperatures were such that greenhouses were unnecessary for year round operation of the hatchery but shading was being used.

In contrast to S.E.A.F.D.E.C., this hatchery used only spawners collected in traps. Their rostrums and telsons were clipped before being placed in inflated plastic bags for transport to the hatchery. The bags contained approximately 3 ℓ of seawater and 7 ℓ of oxygen. Females collected from the traps had been found to be more successful spawners than those taken from otter trawls. Some maturation work was being initiated to improve the reliability of supply and to reduce the cost of spawners. The spawners were stocked directly into the larval rearing tanks with 3-4 and 10 being stocked into the 16 t and 60 t tanks respectively.

This hatchery used lower diatom densities than S.E.A.F.D.E.C., i.e., 5,000-10,000 cells/mℓ for Z_1 to P_3 and used yeast as a diatom substitute if the bloom failed. The added diatoms came from a multispecies diatom bloom although it did tend to be dominated by Chaetoceros. The main difference was that no brine shrimp whatsoever were used. Brachionus was heavily relied upon. Interestingly tuna meat was used for feeding the postlarvae and apparently replaced the more conventional diets, e.g., squid or bivalves successfully. A high water exchange rate of twice the volume of the larval rearing tank/day was used in mysis and postlarva and from Z_3 to harvest at P_7 the tank bottom was cleaned daily with a siphon.

The hatchery experienced a variety of problems including a shortage of tanks for Brachionus and Chlorella culture. The fungus Lagenidium was again a problem as was an unidentified disease which caused body reddening, immobility and finally death of mysis. Frequent water exchanges sometimes overcame this disease. One problem which was completely solved was that of the protozoan Epistylis. This was found to originate in the Chlorella tank but the use of a low concentration of formalin in this culture, before it was fed to the Brachionus, was found to be effective in killing the Epistylis.

P. indicus has proved to be a much easier species to rear than P. monodon but was not as popular a species with the Filipino prawn farmers because of its lower market value. Thus P. monodon larval rearing has remained the main function of the hatchery.

H. Phuket Fisheries Research Station, Phuket Is., Thailand

This hatchery (Map 3, position A) was ideally placed in terms of salinity, temperature and turbidity. However, it drew its water supply from a small bay which received the effluent from a heavy metal refinery. This fact in combination with the inadequate size of the hatchery site (6.4 ha) has necessitated a search for a new location.

Although rapidly being overtaken by S.E.A.F.D.E.C. this hatchery had the highest *P. monodon* output of any visited. Whilst research was also being undertaken into barramundi (*Lates* sp.) and *Macrobrachium*, its main function was to produce *P. monodon* fry for pond stocking. With a staff of 49, including six biologists, the station was able to utilize low cost but labour intensive rearing methods. However, funding other than for salaries was quite inadequate and during my visit *P. monodon* rearing had temporarily ceased because the station could not afford the spawner costs (Baht 200/prawn). The station's output was also limited by its production of *Brachionus* which was in turn limited by the tank volumes available for growing *Chlorella* and *Brachionus*. Salinity drops in the uncovered *Brachionus* tanks during heavy rain sometimes caused mass mortalities which further reduced output.

The rearing methods were quite conventional (see Table II) but the maximum production of 4,000/t in any one rearing was relatively low. Hatchery staff stated that disease and parasite problems were quite serious. In a bid to reduce spawner costs a maturation programme had been initiated but the larvae resulting from these induced spawnings had proved difficult to rear.

I. Songkhla Marine Fisheries Station, Songkhla, Thailand

This site (Map 3, position B) was only suitable for prawn larval rearing for the eight drier months of the year when the salinity of the water was greater than 30‰ and when a simple settling tank was adequate for controlling turbidity. However, from October to January the salinity had at times dropped to 15‰ because of the overflow of a nearby lake and no rearing was possible during this period. The wet season also corresponded with a period of low spawner availability.

In 1976 the station reared 1.5×10^6 banana prawn (*P. merguiensis*) postlarvae. In 1977 it was anticipated that 3.5×10^6 would be reared in addition to 0.5×10^6 *P. monodon* P_{20}.

Although limited by the supply of spawners, the *P. merguiensis* output exceeded pond stocking requirements and thus the remainder were liberated.

This was the only hatchery visited that used stored seawater for larvae rearing. The seawater was often held for about four days in a settling tank before being used. However, the effects of this storage on the diatoms within it were difficult to evaluate as the rearing water was innoculated with approximately 10 t of *Chaetoceros* culture before it was fertilized.

The *Chaetoceros* was grown as 50 t cultures which were initiated with cultures from 1 t tanks or with 5 t of the previous 50 t culture. The following fertilizers were added.

Nutrient	Amount/t
KNO_3	100 g
K_2HPO_4	10 g
Silicon solution	5 mℓ
EDTA	5 g

In 3-5 days a 50 t culture could be harvested at a density of 30,000-50,000 cells/mℓ. This density was much lower than that achieved at S.E.A.F.D.E.C. For the 1 t tanks a clear plastic cover allowed light to reach the culture but prevented windborne contamination.

One of the problems experienced by the hatchery was that caused by the protozoan *Zoothamnium* which attached to the gills of the larvae. Use of the antibiotic Tetracycline at a concentration of 1 ppm during M_2 to P_{10} proved to be successful as a preventative.

J. Faculty of Fisheries, Kagoshima University, Kagoshima, Japan

This institute did not seem to operate as a large scale hatchery but was involved in research aimed at improving larval rearing procedures. The University had several foreign scientists working with or under the direction of Dr. A. Kanazawa.

(1) Spawning

It had become apparent that spawning tanks should ideally be larger than 2 t in capacity but that good spawnings were possible in smaller tanks. At the time of my visit two P. japonicus spawners had produced a combined total of 1×10^6 nauplii within a 2 t spawning tank.

(2) Diatoms

One of Dr. Kanazawa's co-workers Dr. David Jones, (Dept. Marine Biology, Marine Science Laboratory, Anglesey, U.K.) stated that either chain diatoms or single cell diatoms were adequate for feeding P. japonicus zoeae. Dr. Kanazawa's co-workers considered that there was a strong difference in the optimum diatom density for the larvae of P. japonicus and P. monodon. They considered the optimum densities to be 100×10^3 and 50×10^3 cells/mℓ respectively.

(3) Diatom Substitutes

Dr. Jones had been preparing encapsulated diets for P. japonicus zoeae. For Z_1 the capsules were 5-15 μ in diameter and enclosed a liquid diet. For M_1 they were 30-35 μ with a more solid internal phase. The capsules gave low survival rates but responses to nutritional changes in their internal composition had been demonstrated. Varying the fatty acid composition of the internal phase affected the survival rate. The diatom substitutes used for P. japonicus zoeae, soycake or finely ground artificial diet, usually gave good survival rates when added directly to the larval rearing water. However, when these substitutes were enclosed within capsules they were much less successful. Dr. Jones explanation was that the substitutes work by stimulating a bacterial bloom in the rearing water and that the bacteria probably provide most of the nutrients for the zoeae. When the substitutes were enclosed within the capsules a bacterial bloom did not occur.

SECTION 4

PRAWN FARMING PONDS IN JAPAN

A. Introduction

During my ten week visit to Japan much less time was available for investigating the phase of farming from P_{20} to market size than for the hatchery phase. In contrast to my four week stay at the Fujinaga hatchery (Section 2), it was not possible to actually work at a pond site. However several pond sites were visited and also discussions were held with various industry leaders and academics involved with the grow out phase. These workers included K. Fujinaga who had financial interests in a conventional prawn farm and a prawn feed business, Dr. K. Shigueno who set up the intensive prawn farming industry in Japan and Prof. Y. Hirasawa who had conducted detailed economic comparisons of different types of Japanese prawn farms.

This section of the report deals solely with *P. japonicus* which is the only species of prawn farmed in Japan on a commercial scale. It should be noted however that Dr. J. Kittaka is investigating the suitability of a more temperate species in northern Japan. For a detailed understanding of the grow out phase of prawn farming in Japan, this report should be considered in combination with the works by Shigueno (1975) and Hirasawa and Walford (1976) which are both in English.

B. Historical Aspects

After the late Dr. M. Fujinaga and his staff developed methods for the rearing of *P. japonicus* larvae on a large scale he moved on to the grow out phase and eventually set up a commercial scale farm in 1963 on disused salt farming land in the Seto Inland Sea region (Map 1). Other farms were soon set up and production from ponds slowly grew to approximately 500 t/ annum by 1970.

In the southern regions of Japan fishermen had for many years stocked *P. japonicus* from the fishery into ponds and held them until the colder months when prices were higher.

These areas have subsequently been used for the farming of hatchery reared postlarvae to market size and have allowed the industry to expand rapidly. Thus by 1974 the total production had risen to more than 1000 t/annum. Much of this increase came from the Amakusa Is. region (Map 1, position B).

In 1969 Dr. K. Shigueno set up a large scale intensive prawn farming trial near Kagoshima. This work continued and gave rise to a new type of capital intensive, high density prawn farm several of which were operating on a commercial basis at the time of my visit.

All of the prawn farms supply the lucrative live prawn market in Japan and exist only because of the high prices they obtain for their crops.

C. Farming in the Seto Inland Sea Region

The prawn ponds in this region were found to have quite large (2-5 ha), sandy bottomed ponds which usually had only one screened gateway through which seawater exchanged. In most of the ponds aeration involved intermittent use of mechanical surface agitators. However, more recently constructed ponds have usually been smaller with better water exchange rates and with more effective bottom aeration (Section 4F). P_{20} from hatcheries were usually stocked into nursery ponds in April-May and were transferred to growing ponds after 1-2 months. The stocking density in the larger growing ponds had to be kept at a low level, e.g., 200,000/ha because of the poor aeration and water exchange rates.

K. Fujinaga provided the following approximate growth data for a well managed pond in this region.

Date (Day/Month)	Average individual body wt. (g)
1/5	0.01 (i.e., P_{20})
1/6	0.30
1/7	2.00
1/8	6.00
1/9	16.00
1/10	22.00
1/11	26.00

Most of the harvest was sold in November-December to avoid mortality during winter. In the Seto Inland Sea region winter pond water temperatures have regularly dropped below the lethal lower limit of 6^{o}C.

No fish control was exercised during the time the prawns were in the growing ponds other than for the incoming water to pass through a coarse sieve. Farmers also ensured that no fish were present at the time of stocking. However the use of a nursery pond meant that the time that the prawns were in the growing pond was reduced and thus the opportunities for predators and competitors to reach significant biomasses were limited.

Before being stocked the ponds were drained and dried in the sun. The turning over of the dried surface sand also facilitated the oxidation of the fouled pond bottoms. The importance of this pond bottom maintenance was made apparent during a visit to the Yamaguchi Prefecture Naikai Farming Fisheries Centre at Aio (Map 1, position A). The annual production from a 2 ha pond had steadily dropped from 6.1 t to 2.0 t because of poor pond bottom maintenance.

Many of the farms in this region were built on disused salt fields but such land has become scarce and expensive. K. Fujinaga stated that considerable areas of intertidal land had been reclaimed for rice planting. However, as an oversupply of rice had developed, land could be purchased at a price of ¥2,600,000/ha and used for prawn ponds. Production rates, feeding, profitability and future prospects are discussed in Sections 4F, 4G and 4J.

D. Farming in the Amakusa Is. Region

At the time of my visit this area had 120 ha of ponds which yield a total annual production in excess of 400 t of *P. japonicus*.

The ponds were located on four main islands (Map 1, position B) and received water which was largely oceanic in character, i.e., low turbidity and high salinity. The other major hydrological feature was the 4 m tidal amplitude.

The farmers in this region have adopted an unusual pond design that avoids the high construction cost of building pond walls that exclude such high tides. The design also helped overcome the shortage of land suitable for pond construction. Rock walls high enough to retain a depth of 1.5 m have been constructed out from the shore so that they enclosed intertidal land. Above the rock wall netting, sufficiently fine to retain the prawns, was fixed to a height above maximum spring high water. In exposed positions the netting layer was replaced by more rock and cement. Figure 5 shows both types of wall. Gates were included to aid flushing and also drainage of the pond after harvest.

The high flushing rates, e.g., twice the pond volume/ day, that resulted from the netting walls and high tides helped maintain extremely clean ponds. The pond water was quite clear and the pond bottoms usually remained unfouled, i.e., without a buildup of decaying organic matter. As a result fungal infections in the gills, common in fouled ponds, have rarely occurred in this region. The favourable bottom conditions were enhanced by drying, ploughing and contouring of the pond bottom after harvest. Figure 5 shows the resultant 0.5 m deep pond bottom furrows. Prawns tend to burrow into the sides and tops whilst any waste materials tend to accumulate in the bottom of the furrows. The high flushing rates also had an adverse affect. The high transparency of the pond water has caused heavy growths of the benthic macrophyte _Ulva._ Shigueno (1975) has discussed the adverse effects of this plant on prawn growth and in this region hand netting for _Ulva_ was a daily chore. The algicide RADA (Delrad or Rosin Damine acetate) was also used in the pond when hand collection was inadequate to control _Ulva_.

Hatchery reared P_{20} were stocked into nursery ponds and transferred to growing ponds at an approximate size of 1.0 g. At one farm that was visited there was a 2 ha nursery pond and a 5 ha growing pond. The juveniles were harvested from the nursery pond by a pocket net placed over the drainage outlet.

An alternative method used in Japan was to set up a pound net within the nursery pond (Shigueno 1975). After harvest some of the juveniles were stocked into the growing pond and the remainder left in the nursery pond which thus became a growing pond. This limited system of double cropping was widely used in the Japanese prawn farming industry.

The stocking density in the growing ponds was usually 2,000-250,000/ha but some ponds equipped with bottom aeration supplied by a Rootes blower were stocked at 400,000/ha. Mechanical agitation was intermittently used in the unaerated ponds. Both K. Fujinaga and Prof. Hirasawa considered that aeration was unnecessary in this region.

K. Fujinaga who owned a pond in this region provided the following approximate growth rates for a well managed pond in the Amakusa Is. region.

Date (Day/Month)	Average individual body wt. (g)
1/6	0.01
1/7	0.5
1/8	4.0
1/9	12.0
1/10	20.0
1/11	24.0
1/12	26.0

Stocking occurred later in this region than in the Seto Inland Sea area because relatively high winter water temperatures (minimum 10^{o}C) allowed the retention of much of the crop until February-March when higher prices were obtained. The ponds were completely harvested in April and were ready for stocking in May-June.

Prawn farming in this region appeared to be highly profitable with one farmer who had 10 ha of ponds receiving a gross income of ¥200,000,000 and recording a profit of ¥80,000,000 for the previous year. Both K. Fujinaga and Prof. Hirasawa confirmed the credibility of these figures.

The type of pond construction discussed above eliminated the problem of purchase of land for excavation. However substantial payments had to be made to fishermen's cooperatives to compensate for their alienation from fishing grounds. The average price received for the prawns harvested in this region in the 1976-77 season was approximately ¥7,000/kg. Further details on the farming in this region are given in later parts of Section 4.

E. Intensive Farming in the Kagoshima Region

During a three day trip to this area two commercial, intensive culture, prawn farms were visited and also discussions were held with Dr. K. Shigueno the researcher who initiated this style of farming. The two farms were quite similar, the first being owned by the Bohnotsu company and the second by Mitsui Norin, a part of the Mitsui group of companies (Map 1, position F).

The concrete tanks (Figure 6) were circular with a diameter of 36 m and an approximate floor area of 1000 m^2. Each had a 10 cm thick sandy bottom that was supported above a concrete base to a height of 10 cm. Originally concrete blocks were used beneath the sand but in more recently completed tanks plastic cones replaced the blocks as the supporting structure. A layer of fine mesh was placed between the sand and the supporting materials. The water depths at the centre and edge of each tank were 0.9 m and 1.2 m respectively. Water entered the tank through a 25 cm diameter plastic pipe pierced with numerous holes that acted as angled jets and which caused a circular (in the horizontal plane) flow of water within the tank. Waste food and prawn shells were directed towards the centre of the tanks because of this circular flow and these wastes could be voided by the lifting of a cylinder of plankton mesh that surrounded the central drainage point. The double bottom described earlier allowed exhalent water to flow out through the sand bottom thus maintaining very favourable bottom conditions.

At Bohnotsu the water exchange rate was 4.5 times the tank volume/day. Higher flushing rates than this caused hardening of the sand bottom and much lower rates raised the maximum ammonium ion concentration to 0.9 ppm. The normal daily maximum was 0.2-0.3 ppm and this tended to occur at night. At Mitsui Norin the flushing rate was 3 times/24 hours with the highest rate occurring at night. Neither firm used additional aeration and at Mitsui Norin the normal daily minimum dissolved oxygen concentration was 5 ppm and this occurred around midnight.

The Kagoshima region had the highest water temperatures of all the Japanese prawn farming areas and this characteristic made it highly suitable for prawn farming. The farms had oceanic aspects and despite the high flushing rates the tank water temperatures were as high as 30^{o}C in summer. The average daily tank water temperatures for the winter months of January-February were quite high at 14-15^{o}C. Growth rates in mid summer were 6-7 g/month and in winter approximately 1 g/month. The tanks were neither heated nor enclosed within greenhouses. Growth and survival rates were carefully monitored at both farms with sampling intervals of once/10 days and once/month respectively. Survival rate sampling was accomplished by direct diver observation of the number of prawns that could be disturbed in 5 m^2 of the 1000 m^2 tank bottom.

Initial tank stockings took place in July-September. The stage at which the postlarvae were stocked was ideally P_{20} but these intensive culture farms had their own hatcheries and stocking might be as late as P_{40} if no tanks were available at the P_{20} stage. The normal stocking density was 100-120/m^2, i.e., 1,000,000-1,200,000/ha, but some tanks were stocked at even higher densities, e.g., 300/m^2 until other tanks had been harvested, at which time the densely stocked juveniles were redistributed to two or more tanks. This type of stocking practice allowed the harvest of 1.6 crops/year/tank. Dr. Shigueno's earlier smaller scale trials had suggested that an annual production of 3.5 kg/m^2, i.e., 35,000 kg/ha could be obtained.

The average annual production from the commercial intensive farms had been substantially less at approximately 2 kg/m^2.

The intensive type of prawn farming practised around Kagoshima has required the development of a nutritionally complete diet because little additional food can be provided by the benthos in such heavily stocked ponds. As a result of the nutritional research carried out by Dr. Shigueno and other Japanese nutritionalists (see Section 7), an artificial, pelleted prawn diet has become commercially available. At Mitsui Norin this was the only diet fed to the prawns and despite considerable mortality the overall F.C.R. (Food Conversion Ratio = kg of feed fed/kg of prawn harvested) was a creditable 3.4.

The intensive culture farms in the Kagoshima region harvested most of their crops in April-May, the period of maximum market price. Thus Mitsui Norin in 1977 sold 28 t of live shrimp and 1.5 t of frozen shrimp for an average price of ¥7,300/kg despite the fact that the prawns had an average weight of only 14.1 g.

As Shigueno (1975) noted this type of intensive farming has demonstrated that high survival rates can be achieved despite extremely high stocking densities. Very high yields and high market prices have also been obtained but a variety of problems have been encountered.

(1) Other Species

Before the practice of sieving intake water was adopted a variety of possibly harmful species occurred in the tanks. At Mitsui Norin approximately 2,000 striped catfish were removed from the 13 tanks over a short period of time. Interestingly a few milkfish *Chanos chanos* and jumbo tiger prawns *Penaeus monodon* have also been found in the tanks.

(2) Diet

Difficulties have been experienced with the supply of ingredients for the artificial diet. Also the colour of the prawns fed with the diet has been somewhat pale and this has detracted from their market value.

(3) *Fusarium solani*

This gill fungus has caused considerable mortality in the intensive tanks but when the ammonium ion concentration has been kept to a low level there have been few fungal problems.

(4) Bacterial Disease

Mitsui Norin lost one million prawns from their 1977-1978 crop because of bacterial infection. The antibiotic Chloromycetine which contains Chloramphenicol has proved successful in controlling the disease.

(5) *Ulva*

This benthic macrophyte has been a serious problem in tanks which have a high water transparency. Divers regularly collected the algae from the tank bottoms. In large quantities *Ulva* has lead to wastage of feed. Severe deterioration in bottom condition has also occurred when large quantities of *Ulva* have died.

(6) Water Quality

Pesticides from nearby tea plantations have been held responsible for mass mortalities of prawns at Mitsui Norin. Tissue pesticide concentrations have been approximately 30 times that which occurs in the inlet water. At great expense the oceanic water intake pipe will have to be extended to a greater depth so as to avoid contamination.

Dr. Shigueno has continued to undertake research into intensive culture. He proposes to grow macrophytes on the tank walls so that metabolic wastes and possibly pesticides will be absorbed. Dr. Shigueno did a considerable amount of work on an intensive culture system which used recirculating water but the build up of very high VFA (volatile fatty acids) levels in the tank water inhibited progress.

Additional information on the intensive prawn farms is provided in later parts of this Section.

F. Comparison of Farming Areas

A visit was made to the Tokyo University of Fisheries where discussions were held with Professor Y. Kirasawa who has published a detailed comparative study on the economics of prawn farming in Japan (Hirasawa and Walford, 1976).

Professor Hirasawa has divided Japanese prawn farms into five types.

(1) The older Seto Inland sea region ponds as described in Section 4C.
(2) Smaller Seto Inland Sea region ponds which have been recently constructed or result from the subdivision of type (1) ponds. These ponds have efficient bottom aeration and more water exchange gates than type (1) ponds.
(3) The Amakusa Is. region ponds as described in Section 4D.
(4) Older and less efficient intensive culture farms in the Kagoshima region.
(5) Modern style Kagoshima intensive culture farms as described in Section 4E.

The average annual production/square metre for types (1), (2) and (3) was 300, 580 and 300 g respectively. Type (1) production has been limited by the low stocking densities used because of the poor flushing rate. Type (3) production was expected to improve as the farmers became more experienced and used the higher stocking densities which the high flushing rates that occur there should allow.

The type (2) production figures have been very impressive especially when compared to type (3). The Seto Inland Sea region has lower water temperatures than the Amakusa Is. region and thus the farms should be less productive. Prof. Hirasawa considered the water exchange rates to be the key. In summer only a few critical periods have usually occurred. At these times high temperatures and very still conditions have threatened the crop's survival. In these periods the type (2) farmers have been able to obtain high flushing rates with the extra help of pumps.

Also the pond aeration has helped maintain adequate dissolved oxygen levels. However for the rest of the growing season low flushing rates were used. Prof. Hirasawa believed that this led to greater retention of nutrients in the ponds and allowed a greater component of the prawns' diet to be obtained from the pond benthos in the type (2) ponds than in the type (3) ponds. Hirasawa and Walford (1976) presented data which suggested that feeding costs/kg of prawn produced in the type (3) ponds were 36% higher than those for type (2) ponds.

The aeration system used in type (2) ponds was only seen from a distance but apparently consists of compressed air blown through 5 cm diameter pipes placed on the pond bottom. The air escaped into the pond water through large (5 mm) holes in the pipes.

One of the type (2) ponds investigated by Prof. Hirasawa provided evidence that very high stocking densities were not necessary for high yields. In 1974 the Ube farm used 800,000 seedlings (probably P_{20}) for 2.8 ha of ponds and produced 5,840 kg/ha. Assuming a 90% survival rate in the nursery ponds and also assuming that all nursery ponds were used later as growing ponds a stocking density of approximately 250,000 juveniles/ha appears to have been used. It should also be noted that the lower water exchange rates used in the Seto Inland Sea ponds lead to lower transparency of the pond water and fewer Ulva problems.

G. Feeding

Hirasawa and Walford (1976) have noted that prawn farming began in the Seto Inland Sea region because of the abundance of low cost feed, e.g., short necked clam *Tapes phillipinarum*. This situation has changed drastically as the following data provided by K. Fujinaga shows.

Approximate feeding regime for a Seto Inland Sea region *P. japonicus* pond

Supplementary feed	% of diet	Feed cost ¥/kg	Contribution to total cost of diet ¥/kg
Short necked clam (minus shell)	20	300	60
Euphausid shrimps	30	170	51
Small *Metapenaeus* shrimp	30	110	22
Whole fish	20	60	12
Total	100		156

With a food conversion ratio (F.C.R.) of 14:1, i.e., 14 kg of clam and frozen shrimp and fish/kg of prawn harvested a total feeding cost of approximately ¥2,200/kg harvested could be expected. There has been a strong trend to reduce the amount of clam used because of its great expense. One alternative food item was mussel meat which was inexpensive (¥75/kg) because of its unpopularity for human consumption in Japan. Large amounts of feed were added daily to the ponds and represented a large component of the operating costs. In the Amakusa region fresh and frozen feeds were used and at one farm the daily feed for 600,000 prawns (5 g body weight) in a 3 ha pond was 1,400 kg of frozen shrimp. At another farm in this region the feed costs for 7 ha of ponds containing 5 g *P. japonicus* were a total of ¥400,000/day.

In Section 4E the use of a pelleted diet in the Kagoshima intensive prawn farms (types (4) and (5)) was noted. Such diets have also been used on a smaller scale in prawn ponds (types (1), (2) and (3)). They were often used on weekends when labour was in short supply and some pond owners have largely replaced fresh and frozen feeds with artificial diets.

In the company of Dr. K. Shigueno a visit was paid to the largest manufacturer of artificial prawn feed in Japan, Higashi-Maru Eatables Industry Ltd. (28 Tokushige, 1 Juin-cho, Hi Oki Gun, Kagoshima). In the early 1970's Dr. Shigueno arranged for the company to produce, on a commercial basis, an artificial diet that was largely composed of squid meal. Due to competition for squid as a human food the cost of squid forced the price of the artificial diet up to ¥1,000/kg. This diet was quite adequate nutritionally and the F.C.R. was 2.0-2.5. However the feed costs were excessive with such an expensive diet and more recently the diet has been redesigned and now costs ¥650/kg. The F.C.R. has as a result deteriorated to 3.0-3.5.

Nutritionally the main problem has been the poor body colour exhibited by prawns fed with the diet. The shell colour strongly affects the market value of the prawns and a variety of ingredients have been included to overcome the problem. The composition of the diet has by no means reached finality but some of the obvious ingredients were dried squid, crab shell, shrimp bran, cayenne pepper, seaweed rick in alpha-carotene, fish meal, gluten and brewer's yeast. The manufacturers provided the following composition data.

Item	% of dry diet
Protein	50 - 55
Fat	3 - 4.5
Fibre	0.2
Ash	20 - 23

At the time of my visit the method of preparation was to hammer mill the ingredients, moisten, pass through a noodle extruder and oven dry.

To reduce costs and to take advantage of the improved growth that results from using pastes instead of dry pellets, the company was experimenting with steam heated pastes. To aid stability in the pond water the pastes would have to contain more gluten which in addition to the squid meal was responsible for most of the binding in the dry pellets.

It should be noted that fertilization of the pond and tank water at Japanese prawn farms does not take place other than by adding feed.

H. Pond Construction Costs

The actual cost of excavation was usually not the major cost in the construction of a prawn pond in Japan. In the Seto Inland Sea region a 2-3 m wide gate could cost approximately ¥20 x 10^6. A cheaper alternative was to use a large siphon. One farm in the region had a 12 ha pond fitted with two siphons 1.5-2.0 m in diameter. These siphons could exchange 50% of the pond water/day and were started by a vacuum pump. The cost was approximately ¥5 x 10^6 each.

In the Amakusa Is. region a 2.5 ha rock wall and netting pond could be constructed for ¥40 x 10^6. In an exposed position where the whole wall had to be made of rock and cement the cost was ¥70 x 10^6. A major expense could be the purchase of sand for the pond bottom, e.g., a 10 cm deep layer if the natural bottom was unsuitable for *P. japonicus.* Suitable sand in this region was priced at ¥1,300/m^3.

It appeared that most if not all of the Kagoshima intensive prawn farms were built before the "oil crisis" and the subsequent inflationary period. When it is considered that the economics of these existing farms have been marginal it seems unlikely that new farms could be constructed for a price that would allow profitable operation at least at current costs.

The above details on pond construction costs were provided by K. Fujinaga.

I. Marketing

The prawn farming industry exists in Japan because of the very high prices paid for live prawns. Approximately 30% of the live prawns sold came from prawn farms whilst the remainder came from the fishery. During my stay the peak price for any one shipment of live farmed prawns was ¥14,500/kg. K. Fujinaga provided a general description of price movements for farmed live prawns in the period August, 1976 to July, 1977 (Figure 11). Prices were usually lowest in autumn (¥4,500/kg and highest in spring (¥8,000/kg).

This pattern had strong implications for the marketing of the produce of the various prawn farming areas. Seto Inland Sea farmers had to market their crop before mid winter and thus received poorer prices relative to the other areas. The Amakusa Is. region marketed in winter-spring but could not generally wait for the peak spring prices because of the weakened condition of the over-wintering prawns. The death of prawns during harvest and cooling has quite severe implications as the market value of frozen *P. japonicus* has usually been only a half of that of live *P. japonicus* (Hirasawa and Walford, 1976). The Kagoshima intensive culture farms, with year round growing conditions, could market during the peak prices. The size of the live prawns strongly affected the market prices they received. Figure 12 shows the average wholesale price and size data, for four days during July 1977, taken from Tokyo Fish Market daily reports. Prawns in the size range 14-25 g whole body weight seemed to be preferred.

A visit was made to the Tokyo Fish Market where a large proportion of the prawn farm produce was marketed. The prawns were harvested with the aid of electric nets (Figure 7) or when ponds were finally drained with a hand held electric probe. They were then cooled, packed and transported in the same way that spawners were treated (Section 2D). The boxes of sawdust plus prawns arrived during the evening before the morning auction.

Some of the prawns were repacked by receiving agents or merely opened for an inspection by wholesalers prior to the auction.

J. Future Prospects

K. Fujinaga estimated the annual farmed *P. japonicus* production was in excess of 1000 t/year. Hirasawa and Walford (1976) estimated the 1974 production to be 1300 t and noted that the official statistics (950 t) strongly underestimated production. K. Fujinaga considered that annual production could be expected to rise to 2000 t/year with most of the expansion occurring in the Amakusa Is. region.

The future market value of the farmed prawns is difficult to predict. Hirasawa and Walford (1976) note a relationship between prices for farmed prawns and those for frozen wild prawns. Also farmed prawns, for a limited period each year, compete directly with live wild prawns. Thus future prices will be influenced by the state of the *P. japonicus* fishery which has been resurging strongly.

As noted earlier feed costs form a major part of the running costs of all of the types of Japanese prawn farms. The future appears to lie with artificial feeds as competition with human usage of the frozen feeds (e.g., mussel, shrimp and fish) will probably become too strong in the future. Provided the price of artificial feed is not unfairly elevated nutritional research should bring feed costs down in the future.

Type (1) and (2) farms apparently have little opportunity to expand although some conversion of type (1) farms into (2) farms may occur. Type (4) intensive farms are now outdated and no more of these will be built. Type (3) farms should expand provided intertidal areas remain available for pond construction and yields should increase in type (3) ponds as expertise improves. However feed costs will have to be controlled as food conversion ratios are poorer in type (3) ponds. Type (5) intensive farms apparently have immediate economic problems but if feed costs can be lowered profitability may improve.

However large scale expansion does not seem likely for some time in the Kagoshima region.

One thing remains very clear. There is very strong demand amongst the Japanese people for high quality prawns. Prof. Hirasawa noted that the demand elasticity for farmed *P. japonicus* was 2.18, i.e., for every 10% increase in per capita income a 21.8% increase in demand can be expected. This was extremely high as demand elasticity for food products has generally been less than 0.5 in developed countries. Thus if Japanese prawn farmers can control feed costs, both through nutritional research and by maximizing the contribution of the pond benthos, the future for the industry looks bright.

SECTION 5

PRAWN FARMING PONDS IN THE PHILIPPINES AND THAILAND

A. Introduction

My investigation of the grow out phase of prawn farming in the Philippines and Thailand was similar to my experience in Japan in that it was not based on working at a pond site for any period of time. Visits of approximately half a day were made mostly to experimental ponds and research workers were interviewed. The information obtained was much more fragmentary than that from Japan partly because the prawn farming industries in these countries were undergoing rapid development and change. Also much shorter periods were spent in the Philippines (10 days) and Thailand (10 days) than in Japan (10 weeks).

B. Laguna de Bay (Philippines)

This 90,000 ha shallow lake (Map 2, position C) had numerous freshwater feeder streams and one saltwater inlet from Manila Bay. During the dry season (around January) the lake level had usually dropped and this had allowed the entry of saltwater from Manila Bay thus raising the lake salinity to 2-3‰ depending on distance from saltwater inlet. During the rest of the year salinity was usually around 0.07‰. The long term plan was to use the lake for drinking water but serious industrial and domestic pollution had occurred.

The lake had an interesting mixture of brackish and freshwater species including milkfish (*Chanos chanos*), *Macrobrachium rosenbergii* and *Penaeus monodon*. The occurrence of *P. monodon* in such a low salinity was extremely surprising. At the S.E.A.F.D.E.C. research station on Laguna de Bay *P. monodon* had been grown concurrently from P_{35} (22 mm total length) in a floating cage in the lake and in tanks at a salinity of 8‰. The *P. monodon* grown in the lake water had grown much more rapidly than those in the tanks and had reached 72 mm T.L. (approximately 2 g) after six weeks.

The station's *M. rosenbergii* research will be discussed in a later section. However it was interesting to note that *P. monodon* and *M. rosenbergii* had the same domestic market value ₱45/kg.

C. S.E.A.F.D.E.C., Leganes, the Philippines

S.E.A.F.D.E.C. had 90 ha of ponds for *P. monodon* and milkfish research at Leganes near the Tigbauan hatchery (Section 3F). Most of the *P. monodon* nursery pond research was done in 0.1 ha ponds. S.E.A.F.D.E.C. had been distributing P_{20} to *P. monodon* farmers but had been disappointed with the results, i.e., 10% survival to 50 g body weight. Thus their researcher, F. Apud, had been investigating the feasibility of using nursery ponds to enable larger *P. monodon* to be distributed. Mr. Apud gave details of three nursery pond trials in which P_5 from the Tigbauan hatchery had been grown for one month.

Trial 1

Stocking density P_5/m^2	% survival at harvest	Average body wt. at harvest (g)
86	32	0.3
36	34	-
22	36	0.8

There was no feeding but preparatory fertilization took place. A large percentage of the losses were apparently related to initial handling.

Trial 2

Feeding procedure	% survival ($\bar{X} \pm S$)
mussel 0-2 weeks 100% of biomass/day 2-4 weeks 20% of biomass/day	56.3 ± 7.6
Unfed	20.7 ± 7.4

In this trial there were no handling problems. A 10%/day water exchange rate was maintained by tidal flushing supplemented with pumping at night when oxygen depletion was most likely.

Trial 3

A 1 ha pond stocked with 350,000 P_5 (35/m^2) received a low water exchange rate and a daily feeding with fresh mussel. After 30 days 169,000 juvenile *P. monodon* (48.3% recovery rate) were harvested by netting the drainage pipe.

Further work was planned on aeration which was not used in the above trials and on water exchange rates. However it was estimated that the break even point for a *P. monodon* nursery pond fed with mussel was 34% survival rate.

The value of *P. monodon* seedlings is given below.

Stage	₱/postlarva
P_5	0.08
P_{35}	0.35
Wild (P_5-P_{35})	0.15

Mr. Apud provided the following information on his method for producing a rich benthic growth ("lab-lab") in nursery and growing ponds.

(1) Drain pond and dry to a cracked state.

(2) Apply lime if pH is unfavourable.

(3) Apply 2 t/ha of dry manure or 200 kg/ha of 16:20 N,P fertilizer and add water to a depth of 3-5 cm.

(4) Gradually raise the water level to 15-20 cm over a period of two weeks.

(5) Stock at 25 cm depth and raise to 50 cm by harvest time in a nursery pond. In a growing pond the final depth would be 1 m. For both types of pond the preparation time would be approximately one month but poor weather could extend this.

For growing ponds Mr. Apud recommended a stocking density of 2 P_{35}/m^2 and only $1/m^2$ when 500-1000 milkfish fry/ha were also stocked in the same pond. He also considered that nursery ponds were unnecessary for P. merguiensis.

D. Mindanao State University Institute of Fisheries Research and Development (M.S.U. I.F.R.D.), Naawan, the Philippines

Besides operating as a hatchery (Section 3G) this Institute carried out research into nursery ponds and pond benthos as well as providing an extension service to the expanding prawn farming industry on the large island of Mindanao.

Mr. W. Subang provided information on nursery ponds and the Mindanao industry. The Institute had tried three methods of handling hatchery produced postlarval P. monodon.

(1) Sold P_{25} to farmers for direct stocking into growing ponds.
(2) Stocked P_{5-10} in nursery ponds for 45 days before transferring them into the farmers' growing ponds.
(3) Acclimatized the P_{5-10} for two weeks in fine plankton mesh hopper net, i.e., a staked out netting enclosure with a netting bottom. The hopper net was stocked with 50 postlarvae/m^2 which were fed with mussel. The longer term plan was to set up the hopper nets directly in the farmers' growing ponds. Of the three approaches Mr. Subang had found the third to be the most successful with survival rates of up to 95% being obtained.

The Institute's staff had found that Penaeus indicus could be directly stocked into the growing ponds as P_{20}.

The Mindanao prawn farming industry serviced by the Institute was not visited but Mr. Subang provided detailed information on it. The industry has grown rapidly to 400 ha of ponds and many milkfish farmers were changing over to prawns. A "lab-lab" growth was induced before stocking.

Cost of ponds	₱30,000/ha
Pond size	5-10 ha
Flushing rate	½ the volume/day for 3 days every 2 weeks
Stocking rate	mostly 0.5-1.0/m^2 but up to 3.0/m^2
Survival rate	65%
Harvest size	75/kg, i.e., 33 g
No. of crops/year	2
Growing time	5-6 months
Feed rate	10% of biomass/day with trash fish and mussel
Sale price at pond	₱30/kg
Calculated production/ha/year (1/m^2, 33 g harvest wt., 65% survival and 2 crops/year)	430 kg/ha/year

Mrs. H. Vicente has begun a large benthic sampling programme on P. monodon ponds. The major components of the fauna have proved to be nematodes and polychaetes with the former being much more important. Other common inhabitants have been benthic copepods, bivalves and kinorhynchs. She noted that "lab-lab" was a complex mixture of blue green algae and benthic diatoms, e.g., Navicula and could also contain filamentous algae.

E. Phuket Fisheries Research Station, Phuket Is., Thailand

This P. monodon hatchery (Section 3H) has been providing seedlings for an expanding prawn farming industry in the Chantaburii Province (Map 3, position C) of Thailand as well as providing technical assistance in the grow out phase.

Staff at the research station gave details of the 14 months P. monodon farming that was closely studied at a Chantaburii farm.

The pond was designed in the usual Thai fashion with deeper channels surrounding a feeding plateau. The deeper channels were provided so that the prawns could find cooler water during hot weather. The pond shown in Figure 8 is similar but has more channels. The pond walls of the Chantaburii pond enclosed an area of 1.92 ha and this figure has been used below for the calculation of production/ha. The Thai publication relevant to this project calculated production/ha of floor area of deeper channel. Should this analysis be required the data expressed/ha should be multiplied by 4. Trials A and B were consecutive trials within the same pond. The feeding regime was 10% of biomass/day with trash fish, mussels, crabs and rice bran.

Pond data	Trial A	Trial B
Whole pond area (ha)	1.92	1.92
No. of P_{21} stocked	300,000	100,000
Stocking rate (P_{21}/m^2)	15.6	5.2
Duration of trial (days)	225	165
Average wt. at harvest (g)	40.0	32.0
% survival	21.2	38.2
P. monodon production (kg)	2544.0	1222.0
Other species of prawn		
(a) *P. merguiensis* (kg)	128.5	831.6
(b) *Metapenaeus* sp (kg)	1000.0	279.0
Valuable fish		
(a) Barramundi (*Lates* sp) (kg)	50.0	-
P. monodon wt. (kg/ha)	1325.0	636.5
Total prawn wt. (kg/ha)	1912.8	1214.9

The consecutive trials lasted a total of 14 months with only a two week break between and thus allowed the calculation of a reasonable estimate of annual production. For *P. monodon* alone the result was 1681.3 kg/ha/yr and for the total prawn catch it was 2680.8 kg/ha/yr.

The result could probably have been improved by aeration because oxygen depletion had caused heavy losses. In Thailand P. monodon usually was worth Baht 120/kg to the farmer whilst P. merguiensis was worth Baht 80-100/kg.

The station's staff also gave details of the traditional prawn farming industry near Bangkok (Map 3, position D). There were approximately 10,000 ha of ponds in that region producing well in excess of 1,000 t/yr. The ponds were similar to the one shown in Figure 8 but were managed in quite a primitive manner. Natural recruitment of P. merguiensis was relied upon and achieved by pumping in water when postlarvae of this species was likely to be abundant. The ponds were unfed but fertilized with organic wastes. Consequently production was low with the estimates provided ranging from 200-300 kg/ha/yr. Extension workers were attempting to get these farmers to stock hatchery reared P. monodon a species which was more valuable than P. merguiensis, and grew faster.

F. Songkhla Marine Fisheries Station, Songkhla, Thailand

This station (Map 3, position B) consisted of four substations, one of which functioned as a prawn hatchery (Section 3I). Mr. K. Chaiyakam was conducting P. monodon farming trials in ponds at another of the substations. He provided details of a recent harvest from the 0.32 ha pond shown in Figure 8.

Stocking density (postlarvae/m^2)	1.5
Survival rate %	87.0
P. monodon harvest (kg/ha)	375.0
Miscellaneous shrimp harvest (kg/ha)	6.0
Feed type	Trash fish and rice bran
Feed rates (% of biomass) for various prawn weights	
1 g	0
1-5 g	20
5-10 g	15
10 g	10

The pond was initially fertilized with 125 (kg/ha) of superphosphate and also received 400 (kg/ha) of calcium oxide CaO which acted as a sulphide suppressant. The water exchange rate was 30%/day, five days/week and no aeration was used.

Details were also provided for the P. merguiensis farming industry in the Nakhorn Si Thammarat area (Map 3, position E). There were approximately 480 ha of ponds with a maximum pond size of 56 ha. A combination of naturally recruited and artificially reared larvae were relied upon and harvests were reported to be in excess of 1000 kg/ha/yr in the ponds fed with trash fish and rice bran.

SECTION 6

LIBERATION OF POSTLARVAL PRAWNS IN JAPAN

Hirasawa and Walford (1976) have shown that from 1965 to 1969 the catch of *P. japonicus* dropped steadily from 2,900 t/yr to 1,263 t/yr (Figure 13). The 1970 catch was slightly lower than the 1969 catch but from 1970 to 1974 the catch steadily recovered to approximately 2,900 t/yr. Shigueno (1975) noted that the liberation of postlarval *P. japonicus* began in 1968 and it was widely accepted amongst Japanese research workers that the liberation programme had played a major role in causing the fishery to recover.

A visit was made to the Nagasaki Prefecture Research Station (Map 3, position C) whose *P. japonicus* hatchery work has been discussed earlier (Section 3B). The station was liberating 4×10^6 P_{20}/yr and planned to increase this to 50×10^6 by 1981. The *P. japonicus* catch in the Nagasaki Prefecture had remained very stable during the period 1965-1972 but by 1974 the catch had increased by approximately 300%. The station staff attributed the increase to the liberation of postlarvae but noted that liberation programmes in surrounding prefectures may have contributed to the increase.

Kurata and Shigueno (1976) have provided a detailed review of Japanese liberation work and associated research. The major problem has been that when P_{20} have been released into the shallow inshore areas, where they naturally occur, they have tended to suffer heavy mortality within the first 24 hours. A high proportion of this mortality can be attributed to predation, mostly by fish, e.g., the goby *Gobius gymnauchen.* The most common method used to reduce this mortality was to liberate the P_{20} into large netting enclosures and hold them there for several days before the netting was removed. K. Fujinaga (Section 2) considered this method to be the most successful but heavy mortality could still occur. It was not possible to inspect these enclosures but a detailed description of them can be found in Shigueno (1975).

Several weeks were spent with Dr. H. Kurata who has developed an artificial tideland as an alternative to the netting enclosures. Figure 9 shows Dr. Kurata's tideland. The top portion was a 1 ha stocking zone which was located at the mean high water neap tide level near Aio (Map 1, position A). This upper part of the beach would normally have been uncovered for most of the day but a minimum depth of 5 cm of water was maintained by pumping seawater to the top of the beach and letting it flow over low retaining walls. A fish net helped exclude fish and a concrete wall sheltered the tideland from wave action. During an inspection of the tideland no fish were apparent but there were numerous gastropods and crab burrows. Apparently these invertebrates were only serious predators of the P. japonicus postlarvae during periods of low salinities or high temperatures. Despite the fact that the tide was quite high the water in the tideland was unusually warm. Dr. Kurata stated that the flow rate was such that water temperatures above 35°C should not occur and that the postlarvae could tolerate 35°C.

There were three major problems with the tideland other than the cost of construction and operation. Firstly the macrophyte Ulva tended to accumulate and decay on the tideland. Secondly the postlarvae (juveniles) did not disperse quickly enough after growing well on the tideland and thus prevented maximum usage being made of the facilities. Finally food may have been the factor limiting the optimum stocking density for P_{20}. Dr. Kurata provided the following growth data for P_{20} on the artificial tideland.

Stocking density P_{20}/m^2	Growth rate Increase in total length (mm)/day
30-50	1-1.5
100	0.5-0.7

Kurata and Shigueno (1976) noted that stocking at densities above 100 P_{20}/m^2 was a waste of postlarvae.

The major research problem posed by the whole liberation project has been the evaluation of its contribution to the resurgence of the P. japonicus fishery. The P_{20} were of course too small to allow simple tagging methods. The approach taken has been to tag juveniles larger than 1 g and release them in nursery areas. For the growth phase up to 1 g size frequency distribution analyses have been used but not with great confidence. Kurata and Shigueno (1976) presented estimates from various authors who attempted to find the percentage of liberated P_{20} which were caught by inshore fishermen in the commercial catch. These ranged from 0.7-5.7% and if calculated as the percentage of P_{20} which survived the period of initial mortality the proportion caught in the commercial catch was 8.8-29.3%.

Dr. Kurata stated that the P. japonicus were subject to heavy fishing pressure from tangle net fishermen both in nursery areas and in deeper waters in the Seto Inland Sea. Furthermore after spawning within this sea at an approximate age of one year, the prawns migrated out of the Inland Sea and could spawn again during their second year. In these deep spawning areas between Kyushu and Shikoku they were subject to further fishing pressure. The catches in these deeper areas were not included in the recapture rates for liberated P_{20} and thus the above figures may underestimate the value of liberation. However it should be obvious that recapture rate has been very difficult to estimate accurately. Dr. Kurata's general conclusion was that liberation has made a contribution but that it may have been only one of a number of influences which could include the general improvement of the Japanese aquatic environment during the 1970's.

Liberation of postlarvae may increase the catch in a fishery if recruitment of postlarvae is the limiting factor. This limitation may be caused by physical problems, e.g., by strong currents especially in a localized area or an inadequate reproductive output from the adult population.

This latter alternative could again be caused by physical conditions, e.g., abnormal water temperatures but could also be the result of excessive fishing pressure reducing the number of reproducing females to inadequate levels. This last alternative seems unlikely for a highly fecund species such as *P. japonicus.* However Dr. H. Kurata estimated fishing mortality near the nursery areas to be approximately 50% with a similar percentage of prawns in the deeper fishing grounds within the Seto Inland Sea also being caught by fishermen.

Clearly the data necessary for Japanese fisheries scientists to totally explain the changes in the *P. japonicus* catch since 1965 was not available. They apparently cannot be explained on the basis of changes in effort. In theory liberation of postlarvae could be particularly useful as a fisheries management method for a species whose reproductive stock has been over exploited because the liberated postlarvae could augment both the fishing catch and the reproductive stock.

SECTION 7

INDUCED MATURATION OF FEMALE PRAWNS IN THE PHILIPPINES

One of the major biological problems in prawn farming has been the supply of eggs for prawn larval rearing as female penaeid prawns, unlike males, generally do not mature in ponds. The most common approach has been to collect females with ripe ovaries from the commercial catch and to allow these to spawn in the hatchery. Whilst this approach has been quite successful in Japan (Section 2), the procedure has generally been quite costly and highly dependent on weather conditions being suitable for fishing and also on ripe females occurring in the catch. To overcome these problems S.E.A.F.D.E.C. (Section 3F) initiated a *P. monodon* maturation project in the Philippines. Several of their maturation facilities were visited and discussions were held with relevant researchers.

A. Igang Facilities on Guimaras Is.

Igang was located near Tigbauan (Map 2, position A) in a maze of islands which had an oceanic aspect. The salinity at a depth of one metre was usually in the range 30-34‰ but could drop to 22‰. Two types of maturation enclosures have been tried with the first being a series of fixed bamboo pens (Figure 10) lined with netting (1.5 cm knot to knot) that was in contact with the muddy bottom. Each pen enclosed 250 m^2 and the depth was approximately 3.5 m. The second type of enclosure was a floating pen containing four compartments each with the same type of netting, floor area and depth as the fixed pens. The floating pens usually did not sit on the sea bottom. Santiago (1977) has described the fixed pens and the early research at Igang which resulted in 6% of female prawns maturing after one eye stalk had been ablated. The success rate has not improved significantly since this early work possibly because of the low quality of the salted mussel diet that was used. In this context it was interesting to note that the success rate was less in the floating pens which did not allow the prawns access to benthic food organisms.

Another factor which may have been significant was the fencing off of the cove containing the maturation enclosures. This would have strongly reduced the flushing rate.

B. Batan Bay Maturation Station

Batan Bay has become the major S.E.A.F.D.E.C. *P. monodon* maturation site. It was not visited but discussions were held with the relevant biologist Dr. L. Rodriquez and with a visiting oceanographer who had inspected both the Igang and Batan sites. This latter site was situated at the northern end of the Panay Is. (Map 2, position D) and was apparently much more estuarine than the Igang site. However, S.E.A.F.D.E.C. staff have collected wild *P. monodon* spawners from turbid water of lower salinity as well as from clean, high salinity oceanic waters. The Batan station had both floating and fixed pens but has relied more on the latter type because the floating pens have been susceptible to damage during rough weather. The success rate was similar in both enclosures and it was worth noting that the diet was freshly opened mussel.

The stocking rate in the Batan pens was 100-200 females/pen with an equal number of males. There were six maturation pens plus two others for holding prawns to be used for the replacement of mature or dead prawns in the maturation pens. The pens were managed in the following manner. The netting which lined the pens was lifted four times/month on the first or last day of any phase of the moon. Mature females were removed for transport to the Tigbauan hatchery and replaced with females which were ablated before stocking. Mortality was stated to be only a minor problem and although very variable the percentage of females removed at each lifting was usually in excess of 20%. The Batan station sent 400-600 mature females/ month to the Tigbauan hatchery and the average time from ablation to removal was two weeks.

Clearly the Batan site has proved to be far more successful than the Igang site and a variety of hydrological and biological factors could have been important in this improvement. Igang staff attributed it to the availability of fresh mussel at Batan. Interestingly some unablated spawners have been collected from pens at Batan.

C. Tigbauan Hatchery Tank Maturation Trials

After the discovery of a spawning with subsequent development of larvae in a hatchery tank being used for the holding of immature P. monodon, Dr. J. Primavera began a maturation project in hatchery tanks. Her work in a 50 t concrete tank (Primavera 1978) stocked with 47 females and an equal number of males, resulted in nine reaching stage III and three reaching stage IV. This staging scheme involved a I-IV scale.

Stage	Characteristics
I	Immature stage.
II	Early maturation stage with yellow ovaries.
III	Late maturation stage with light green ovaries and most of the ovary developed.
IV	Mature stage with dark green fully developed ovaries.
V	Spent stage after spawning.

Her staff stated that ablated females with body weights greater than 100 g gave a 15% maturation rate within 3 weeks in 120 t tanks. The tanks were located within a fibreglass greenhouse and no other light control was used. Mussel meat was the diet and it was priced at ₱1/kg. Dr. Primavera's staff stated that the hatch rate for the eggs of spawners from the hatchery tank trials was the same as for those from unablated females but that the fecundity was usually only 100,000-150,000 eggs/spawning as opposed to approximately 300,000 for the unablated ones.

D. Hatchery Success with Batan Spawners

A Japanese hatchery expert at S.E.A.F.D.E.C., Mr. Nukiyama provided the following data on hatchery success with spawners from Batan. The last batch they had received was comprised of 50 females, ten of which spawned fully and 22 partially. They produced 7×10^6 eggs and 5×10^6 nauplii. The hatch rate was usually 80-90% but in this case was lower. Mr. Nukiyama attributed this to the depressed salinity of the hatchery water supply (28‰). The hatchery used a figure of 100,000 eggs/induced female for working out the required stocking density of potential spawners sent from Batan.

S.E.A.F.D.E.C. staff have done histological examinations of the ovaries of ablated female *P. monodon* and have found that the degree of ripeness of oocytes within an ovary was more variable than for unablated mature females. Furthermore ablated females with ovaries at stage II or III have sometimes spawned. This information suggested that the I-V ovarian staging system may not be as accurate for determining the hatchery value of ablated females as it is for wild females.

E. Tagging and Ablation Methods

Primavera (1978) briefly described the eyestalk ablation method which involved making an incision across the eyeball and squeezing the eyestalk. Care must be taken to not rip out the optic nerve. The above paper also showed the eyestalk tag used which consisted of a simple numbered brass ring closed around the unablated eyestalk. These tags have been very useful for studying the rematuration of stage V spawners in captivity.

F. Information from other Regions

The staff at M.S.U.I.F.R.D. at Naawan, Philippines (Section 3G) noted that unablated *P. indicus* spawners could be obtained from ponds but that this was only very rarely the case with *P. monodon.*

SECTION 8

PRAWN NUTRITION

A. Introduction

Some details of the major artificial diet used at Japanese prawn farms have been mentioned earlier in this report (Section 4G). Research into the basic nutritional requirements of *P. japonicus* has continued in the hope of both improving the quality and reducing the cost of artificial feeds for this species. Summaries of discussions with two leading researchers in the field of *P. japonicus* nutrition are presented below. Research into *P. monodon* nutrition has begun in the Philippines and brief details of this project are also included. All levels of dietary components are expressed below as a percentage of dry weight.

B. Discussions with Dr. A. Kanazawa

The larval nutrition studies carried out by Dr. Kanazawa's research team have been discussed in Section 3J. Dr. Kanazawa has also been researching the nutrition of juvenile *P. japonicus* at the Faculty of Fisheries, Kagoshima University, Kagoshima (Map 1).

(1) Binding of Experimental Diets

Dr. Kanazawa steam heated, for 20 minutes, the moist mixture of dietary ingredients which included agar. The resultant gel was then bagged and sterilized by a second period of steaming. Very good water stability had been achieved with this method.

(2) Protein

He agreed that the protein content of the commercial artificial diet was in excess of that required for the supply of essential amino acids. He hoped that the excess protein which was presumably used for energy could be spared by carbohydrate. In his experimental diets a dietary protein level of 50% was used.

(3) Soluble Carbohydrates

A 5.5% glucose component was included in his diets and this had been found to have no inhibitory effects on growth when used in combination with sucrose and starch. However his coworker Mr. Soliman found that 60% of the sucrose contained in the diet was lost by leaching to the surrounding seawater.

(4) Glucosamine

Dr. Kanazawa agreed that the prawn could synthesize glucosamine, a key building block of the major shell component chitin. However he felt that its rate of synthesis was inadequate during some parts of the moult cycle and that this could explain why a growth response was recorded when it was included in experimental diets.

(5) Lipids

He has published in Japanese a paper which showed that the incorporation of phospholipids, e.g., lecithin, into a *P. japonicus* diet caused improved growth.

(6) Organic Acids

Dr. Kanazawa's diets were highly unusual in that succinic and citric acids were added. He noted that they occurred at high levels in *Tapes* sp. (short necked clam), a successful fresh diet, and thus may have useful metabolic roles within *P. japonicus*.

(7) Minerals

Dr. Kanazawa's coworker Dr. Sasaki Mitsuru had established the following optimum mineral levels for *P. japonicus* diets.

Mineral	Optimum level in diet (% of dry wt.)
Ca	1.0
P	1.0
K	0.9
Mg	0.3
Cu	0.006

Iron (Fe) and manganese (Mn) were growth inhibiting at all levels of supplementation and should not be added.

C. Discussions with Mr. O. Deshimaru

Mr. Deshimaru, a coworker of Dr. Shigueno, was employed by the Kagoshima Prefecture at Kagoshima. He has published numerous papers on the nutrition of *P. japonicus* juveniles and provided the following information.

(1) Binding of Experimental Diets

Mr. Deshimaru used mannan, a polysaccharide of the sugar mannose as the binder. He noted that leaching of added amino acids to the surrounding seawater had not been a problem.

(2) Form of Diet

Better growth rates had been obtained when the diet was fed as a moist paste rather than as an oven dried pellet.

(3) Cellulose

It had become apparent that the addition of cellulose to *P. japonicus* diets had slowed down the rate of passage in the gut and thus increased the overall efficiency of absorption of nutrients.

(4) Protein

Mr. Deshimaru also agreed that much of the protein used in the high protein *P. japonicus* diets was being metabolized for energy purposes. With regard to protein sources he noted that the addition of yeast to artificial diets generally improved prawn growth rates.

(5) Calcium

He noted that as a 1 g *P. japonicus* could absorb 8.0×10^{-4} g Ca/day from seawater the prawn should be able to obtain enough calcium from the surrounding water. However he felt the level of other nutrients may have an effect on the procurement of an adequate calcium supply.

(6) Cholesterol

Although he noted that other researchers had found a 0.5% component of cholesterol to be adequate in *P. japonicus* diets, his research had indicated an optimum level of 1.4-2.2% on a dry weight basis.

(7) Miscellaneous Ingredients

Mr. Deshimaru no longer included taurine, betaine and RNA in his diets.

D. Discussions with Dr. F. Pascual

Dr. Pascual was initiating a *P. monodon* nutrition project at the S.E.A.F.D.E.C. laboratories at Tigbauan (Section 3F) in the Philippines (Map 2, position A). Her approach was different from that of the above Japanese researchers in that she was attempting to find how much supplementation fertilized *P. monodon* ponds required. The Japanese workers were testing diets in aquaria tanks where few if any benthic food organisms were available and thus were investigating total nutritional requirements. Dr. Pascual was planning to test diets in 500 m^2 ponds. She hoped to design diets which were composed largely of locally available feed sources. The proposed ingredients included fish meal, prawn head meal, Ipil meal, which was made from the plant *Leucana glauca* and contained more than 20% protein, soycake (14% protein), rice bran and wheat starch.

SECTION 9

AQUACULTURE OF OTHER SPECIES

A. Introduction

Most of the Japanese aquaculture establishments that were visited carried out research into more than one species. Thus whilst investigating a research station's *P. japonicus* programme it was possible to briefly inspect aquaculture facilities for red sea bream (*Pagrus major*), yellowtail (*Seriola* sp.), abalone, seaweeds and various molluscs. In the Philippines and Thailand brief information was obtained on the aquaculture of milkfish (*Chanos chanos*), oysters and barramundi (*Lates* sp.). Details on these species have not been included in this report but could be made available. However, very detailed information was obtained on crab larval rearing and to a lesser extent on the freshwater prawn *Macrobrachium rosenbergii*. This information has been included as the aquaculture of these species has much in common with that of marine prawns and may prove relevant to the Australian situation.

B. Hiroshima Prefecture Fisheries Experimental Station, Ondo Is., Japan (*Portunus trituberculatus*)

A visit was made to this station which was located at the south-eastern end of Hiroshima Bay (Map 1, position G). The station had a large crab larval rearing programme involving the crab *Portunus trituberculatus*. This species was similar to the Australian "blue swimmer" or "sand crab" *Portunus pelagicus* but dominated more estuarine areas whilst in Japan *Portunus pelagicus* was largely restricted to more oceanic waters. The larval history of *P. trituberculatus* and crabs in general differed from that of penaeid prawns in that the larvae hatch out as zoeae. After having passed through four zoeal stages (Z_{1-4}) the megalopa stage was reached and this could be considered to be the equivalent of mysis. After megalopa the $Crab_1$ stage was reached and this was the beginning of the postlarval phase. The following information on *P. trituberculatus* aquaculture was provided by three of the station's staff, Dr. Sato, Mr. Oda and Mr. Inoko.

(1) Spawning

Female *P. trituberculatus* carrying eggs under their abdominal flaps were caught in oceanic waters and held in concrete tanks deeper than 1 m until ready to spawn. At this stage they were placed in individual 1 t plastic tanks the sides of which were covered by black plastic. The tanks were located in a relatively dark greenhouse made of coloured fibreglass sheets. Excessive light apparently inhibited spawning. No temperature or salinity controls were exercised, and despite a temperature range of 16-27^{o}C within the spawning tanks during the spawning season these variables were not considered to be problems. The female crabs generally released all of the eggs held under the abdominal flap at each spawning. The first spawning could produce up to 1.5 x 10^6 zoeae and after being transferred back to the deep concrete tanks a female would generally be ready to spawn a second batch of eggs 2-3 weeks after the first spawning. Up to four spawnings/female had occurred during a season but the number of eggs declined for spawnings after the first and the larvae from the third and fourth spawnings were usually difficult to rear.

(2) Larval Rearing Tank and Management

A 60 t concrete larval rearing tank with a sloping bottom of depth 1.0-1.5 m was used. At the deeper end a drainage system allowed collection of the tank contents in a deeper outside concrete well. The tank was located in the open but during periods of excessively high water temperatures a shading cloth was used to cover the tank. Tanks located within greenhouses had given poor results.

Seawater was pumped directly out of the Seto Inland Sea and was added to the tank without filtration. At the time of addition of approximately 1.5 x 10^6 Z_1 from the spawning tank in which they had hatched, a *Chlorella* bloom of approximately 200,000 cells/mℓ was initiated in the larval tank. No water changes were applied until 10 days after the stocking of the Z_1 when megalopa appeared.

A daily water exchange rate of 20% was used until harvest at $Crab_1$ stage. The _Chlorella_ bloom was naturally succeeded by a diatom bloom and both were considered desirable for maintaining suitable water quality conditions. The blooms would also have reduced the light intensity within the tanks.

(3) _Feeding_

A summary of the feeding methods used for _P. trituberculatus_ larvae at Hiroshima is given below.

Larval stage	Duration (days)	Diet fed
Z_1	5	_Brachionus_
Z_{2-4}	10	_Brachionus_ and brine shrimp nauplii
Megalopa	10	Brine shrimp nauplii and mascerated shellfish
$Crab_1$	-	(Harvest)

An alternative approach to feeding Z_1 was to use molluscan trocophore larvae, e.g., those resulting from mascerating oyster gonads. In this approach it was necessary to begin the feeding of brine shrimp nauplii before Z_2.

(4) _Harvest_

After 25 days in the larval tank the Z_1 had passed through the megalopa stage and had become $Crab_1$. At this stage they were harvested by the addition and later removal of clinging materials to which the $Crab_1$ postlarvae attached. The maximum survival rate from Z_1 to $Crab_1$ was 30% with an approximate average of 10%.

(5) _Liberation of Crab Postlarvae_

The _P. trituberculatus_ fishery in Hiroshima Bay had been relatively stable over a period of some 20 years with a maximum annual catch of 160 t. However a period of steep decline ensued and by 1971 the catch was negligible.

A liberation programme for $Crab_1$ stage P. trituberculatus was begun in 1973 and the subsequent annual release rate has been 1.0-1.5 x 10^6. The fishery has recovered to an annual catch rate of 70 t by 1976.

Crab liberation programmes have experienced the same problem as those for P. japonicus in that the liberated postlarvae have been too small to tag for the purpose of estimating recovery rates. The staff of the Hiroshima Prefecture Fisheries Experimental Station partially overcame this problem by liberating a known number of $Crab_1$ into a small bay which had no natural P. trituberculatus population. The recapture rate within the bay for these postlarvae was 5% but not all were of commercial size. Some emigration could also have occurred.

(6) Broodstock Production

Egg-carrying female P. trituberculatus were often difficult to obtain for larval rearing work and thus the station was carrying out a maturation programme. $Crab_1$ postlarvae were stocked into 8 m^2 concrete tanks at a rate of 3,000/tank. Upon reaching 5-6 cm Carapace Width (C.W.) they would be transferred to an outside pond. The anticipated maturation schedule was:

Rearing	June-July, 1977
Mating	November, 1977 at 12 cm C.W.
Spawning	May, 1978.

A total of 100 mature crabs/3,000 $Crab_1$ was expected to be harvested.

C. Yamaquchi Prefecture Naikai Fisheries Experimental Station, Japan (P. trituberculatus)

This station was located close to the Fujinaga Penaeid Shrimp Institute (Map 1, position A) and the relevant researcher was Mr. Inoue.

(1) Larval Rearing

The larval rearing method used was very similar to that of the Hiroshima Prefecture Fisheries Experimental Station and the published research work of the Yamaguchi staff strongly supported the feeding procedure used. The following conclusions were taken from Iwamoto et al. (1973).

(a) *Brachionus* is superior to *A. salina* as a diet for Z_1.
(b) For older zoeae (Z_2) *A. salina* nauplii are superior to *Brachionus*.
(c) *Brachionus* are of little value to megalopa.
(d) *A. salina* by itself is not adequate for megalopa.
(e) Clam meat plus *A. salina* appears to be better than clam meat alone for megalopa.
(f) Clam meat is of little value to zoeae.

The major difference in rearing methods was the use of vertically hung screens of synthetic mesh in the Yamaguchi larval rearing tanks during megalopa. This was to increase surface area and thus reduce cannibalism. It was apparently successful as survival rates were as high as 80%. The normal stocking density was 30-40 Z_1/ℓ which was higher than that used at Hiroshima (1.5×10^6 $Z_1/60$ t = 25 Z_1/ℓ).

(2) Broodstock Production

This station also had a maturation programme involving ponds stocked directly with $Crab_1$ stage *P. trituberculatus*. The maturation schedule that was anticipated was:

$Crab_1$ stocked at 40,000/0.11 ha pond	late May, 1977
At time of inspection estimated survival rate 3,000/pond at 9-10 cm C.W.	August, 1977
Expected mating time at 200 g body weight (12.5 cm C.W.)	September, 1977
Spawning	April, 1978

A total of 200-300 egg-carrying females were expected to be harvested from each pond. The diet used in the broodstock ponds was an unprocessed mixture of frozen trash fish, clam and shrimp.

(3) Pond Trials

The station's staff had carried out farming trials to market size in ponds and had published the results of these trials. They found that dividing the pond floor into 1 m^2 sections with low and incomplete divisions made of corrugated fibreglass allowed a harvest density of approximately one crab/m^2 as opposed to a harvest of 0.2 crabs/m^2 in ponds without divisions. The divisions would have provided a visual and tactile barrier to the crabs. Dr. Kurata (Section 6) who accompanied me on the visit to the Hiroshima Prefecture Fisheries Experimental Station noted that stocking ponds at densities higher than that required to give a yield of 10,000 crabs/ha, i.e., one crab/m^2, did not greatly increase the number of crabs harvested. It appeared that for this highly aggressive species social behaviour limited the degree to which crabs could be successfully crowded together but that sensory barriers may have partially overcome this by reducing aggressive interaction.

The Yamaguchi research team had attempted to grow *P. trituberculatus* in individual cages but had only obtained slow growth rates. The above results on farming crabs to market size resulted from experimental work as there was little or no commercial farming of crabs in Japan. Fishermen in the Amakusa Is. region (Map 1, position B) did however hold *P. trituberculatus* in ponds from summer when prices were low until winter to obtain peak prices. Average winter prices for males was ¥1,800/kg but was higher for females ¥2,500/kg, because crab eggs were considered a delicacy. Commercially marketed crabs usually weighed more than 200 g.

D. S.E.A.F.D.E.C., Tigbauan, the Philippines (Scylla serrata)

Some of the other projects carried out at this research establishment (Map 2, position B) have been discussed in Sections 3F and 9C. A mud crab (*Scylla serrata*) larval rearing project had been initiated by Ms. A. Lavina.

In the Philippines there was a small scale Scylla serrata farming industry conducted by milkfish (Chanos chanos) farmers but the industry was limited by the supply of juveniles for pond stocking (pers. comm. G. L. Escritor, World Bank consultant). The larval rearing of the mud crab at Tigbauan had been relatively unsuccessful despite a good supply of spawners and the use of diatoms, Brachionus and brine shrimp nauplii as larval feeds. However the larvae had shown good salinity tolerance down to levels of 15‰.

E. Songkhla Marine Fisheries Research Station, Songkhla, Thailand (S. serrata)

Other research at this group of research stations (Map 3, position B) has been discussed in Section 3I. Staff at Songkhla had successfully grown their own broodstock of S. serrata. Small juveniles of approximately 4 cm C.W. had been stocked into 100 m^2 bamboo walled pens at 2-3/m^2 and had reached 150 g body weight in 3 months on a diet of trash fish. Egg-carrying females were greater than 100 g in body weight. The survival rates within these pens were unavailable because of escape of crabs by burrowing under the pen walls. The larvae resulting from the spawning of the broodstock were reared through the larval stages but cannibalism had been a problem in megalopa stage. The staff at Songkhla noted that the larvae of the crab Portunus pelagicus had been successfully reared at another Thai Government research station at Rayong (Map 3).

F. S.E.A.F.D.E.C., Laguna de Bay, the Philippines (Macrobrachium rosenbergii)

Other research activities of this station have been discussed in Section 5B as has the hydrology of Laguna de Bay. S.E.A.F.D.E.C. staff had achieved considerable success with rearing M. rosenbergii larvae on a moderately large scale with inexpensive diets. M. rosenbergii have usually been farmed in freshwater ponds but the larvae tend to survive better in brackish water. Female M. rosenbergii were spawned in plastic washing basins (approximately 20 ℓ capacity) and yielded an average of 35,000 eggs/spawning. The actual larval rearing was carried out in squat 2 t wooden tanks sealed with fibreglass.

The salinity of the tank water was 12-14‰ and the survival rate over the 45 day larval rearing period was 50% when an initial density of 30 larvae/ℓ was used. *M. rosenbergii* have generally been reared in other parts of the world on a diet of brine shrimp nauplii (*A. salina*). S.E.A.F.D.E.C. staff were using a mixture of egg yolk and strained liver baby food over the whole rearing period and supplemented this with daphnia (*Moina* sp.) after day 20. This type of feeding was very much less expensive than using brine shrimp. The long term plan was to liberate the *M. rosenbergii* into Laguna de Bay to boost the local fishery for this valuable species.

G. Songkhla Marine Fisheries Research Station, Songkhla, Thailand (*M. rosenbergii*)

The work of one of the Songkhla substations on *P. monodon* and *P. merguiensis* was discussed in Section 3I. This substation also functioned as a *M. rosenbergii* hatchery as well as producing 500,000-700,000 barramundi (*Lates* sp.) fingerlings/year. The *M. rosenbergii* techniques were very similar to those developed by the Hawaiian researcher Dr. T. Fujimura (Fujimura 1966, Fujimura and Okamoto 1970). The tanks used at the substation were 16 t and could yield a maximum of 100,000 postlarvae/tank. Brine shrimp nauplii remained the major diet as attempts to spare it with *Brachionus* had not been successful. *M. rosenbergii* farming was a rapidly expanding industry in Thailand and a government hatchery had been constructed north of Bangkok to produce 20 x 10^6 postlarvae/year. Private hatcheries were also operating and charging Baht 1.50/seedling.

SECTION 10

A GENERAL SUMMARY WITH RELEVANCE TO THE AUSTRALIAN SITUATION

A. Introduction

The prawn farming industries of Japan, the Philippines and Thailand should not be viewed as complete models on which the Australian prawn farming industry can be based. There may be very significant biological, economic and sociological differences between their situations and the Australian situation. Japanese hatcheries can place much more reliance on the supply of spawners from the commercial fishery because their fishermen specifically attempt to market their catch alive. Many of the costly Japanese grow out techniques are not applicable to Australia where the value of the crop would be very much lower. The low labour costs in the Philippines and Thailand allow labour intensive methods that would be quite uneconomical in Australia. Both of these Asian countries themselves have experienced considerable difficulty with directly transferring Japanese techniques to the farming of their own species even with aid of Japanese technicians. Whilst keeping these limitations in mind it should be possible to utilize many of the techniques used in these three countries. Furthermore some of the problems they have experienced will probably plague the Australian industry. An attempt has been made below to summarise the major findings which could be relevant to the Australian industry.

This section of the report will hopefully be of value to many readers including those who do not already have a detailed knowledge of prawn farming. Table III gives a summary of a common approach to prawn farming and includes a classification of the larval stages of penaeid prawns. It should be read in conjunction with the following text.

B. Prawn Larval Rearing

(1) Type of Tank

Clearly there are two main approaches to larval rearing. The first, which is very common in Japan, involves very large (up to 2500 t) concrete tanks in which relatively low density larval rearing is carried out.

This approach is already being used in Australia at the Racovolis Prawn Culture Centre at Port Broughton (Map 4, position A). The second approach is to use much smaller tanks, e.g., 2 t which have been copied from those used in Galveston, Texas, U.S.A. A much higher larval density is used and it became apparent during my trip that this type of tank was being used in Taiwan, the Philippines, Tahiti and in Panama. This approach is similar to that which is used at the Brackish Water Fish Culture Research Station at Port Stephens (Map 4, position B).

It was quite obvious that both approaches can be highly successful with the larger tanks being particularly useful for producing the huge numbers required when postlarvae are liberated into existing fisheries to boost the catch. The smaller tanks require a much lower capital investment and are very useful for experimental purposes and for providing postlarvae for pond stocking. These smaller tanks can be made from fibreglass or epoxy sealed timber.

(2) Tank Cleaning

The painting of concrete tanks with epoxy paint greatly facilitated their cleaning whilst scrubbing of the tanks with a bleach solution was a necessary precaution against disease. However, it is not a total protection and disease can be expected to occur in Australian hatcheries.

(3) Water Temperature

When postlarvae are required for pond stocking it is preferable that the larvae be reared in spring so that the growing period in ponds will be maximized. In temperate Australian areas, e.g., New South Wales, supplementary heating will be required but this may not be necessary in more northern areas of Australia. Summer larval rearing should require no heating and even greenhouses may not be necessary. However, the summer postlarvae may have to overwinter before being marketed as large adults unless the species is farmed at the northern end of its geographical range.

Some consideration should be given to the theory that high water temperatures increase disease risks. This can be because of increased microbial activity and the reduced efficiency of body defences, e.g., blood cell phagocytosis. Greenhouses should not be necessary in northern parts of Australia and even in N.S.W. their efficiency during summer should at times be limited, e.g., by the use of windows.

(4) Salinity

Several of the hatcheries visited experienced problems with sudden drops in salinity. Salinities as low as 28‰ may be inadequate for *P. monodon* nauplii and transported *P. japonicus* spawners are apparently very susceptible to reduced salinities. The best sites for Australian hatcheries are those with oceanic aspects. Reliance on transporting water during periods of low salinity at estuarine sites will only allow low production levels. Oceanic sites also provide fewer turbidity problems, although sand filtering of rearing water may still be useful for reducing disease risks even if turbidity is not a problem.

(5) Spawning

One major problem that has already become apparent in Australia is that of obtaining an adequate supply of spawning females. This was a problem for almost all of the hatcheries visited but there are two major ways of alleviating it. If the females are to be supplied by existing fisheries then the hatchery should be located close to a suitable stock. It should also be recognised that commercial otter trawling is not the ideal method for providing a supply of spawners in good condition. The tangle nets used in Japan are better but it would be difficult to introduce this type of net into established fisheries. The other approach is to set up a maturation facility that will provide a more reliable supply of spawners than can be obtained from weather-dependent, commercial, ocean fisheries.

It became apparent from visiting the Philippines and from discussions in Japan with a researcher from the AQUACOP group in Tahiti that it is feasible to produce captive broodstock. The maturation technique of ablating one eyestalk from spawning size females and providing these prawns with a high quality diet and environment should be very thoroughly investigated in Australia. It is clear that a wide range of prawn species can be matured in captivity and thus it is likely that a maturation facility would successfully overcome the problem of irregular supply of spawners in Australia. Costs however will have to be carefully controlled with labour saving designs and locations which require little heating.

Female prawns have frequently spawned poorly in Australia after transportation to the hatchery. A popular technique in Japan is to transport the females in chilled sawdust. Higher survival rates could probably be obtained by transporting the females in water but the Japanese method reduces transport costs and the chilled sawdust technique may provide a spawning stimulus. It should be noted that transport of spawners in water has been routinely and successfully carried out in the Philippines and Thailand. However the Japanese method should be investigated in cases where the spawner source is quite distant from the hatchery. One surprising finding was that female prawns will spawn quite successfully in smaller tanks, e.g., 2 t and thus tank size has probably not been a factor in poor spawning success in Australia.

(6) Diatoms

There are two methods of providing prawn larvae with the diatoms that are important food sources for zoeae and mysis. The larval rearing tank can be directly fertilized so that the diatoms and larvae grow together. This is the approach used in Japan and at the Racovolis Prawn Culture Centre whilst the second method is used at Port Stephens.

This method involves growing the diatoms in a separate tank and transferring them to the larval rearing tank as required. Clearly both methods can be quite successful. If the first method is used the diatom bloom must be carefully controlled so that the diatom density and pH of the water do not become too high. At the Fujinaga hatchery in Japan the rearing water was surprisingly transparent whilst the larvae were in the zoeal stage. Daily counts of diatom density must be made and shading materials must be available for limiting the diatom bloom. The second method usually involves the monoculture of large volumes of one diatom species. Chaetoceros appears to be a very useful diatom for this purpose. If this method is used in tropical areas, temperate species or cultures should not be used and there is much value in isolating local species and mass culturing these. If a monoculture is required on a large scale the diatom tanks should be carefully located to prevent excessive contamination by diatoms in sea spray. It should be noted that agricultural grade fertilizers can be used for large scale cultures of Chaetoceros.

Diatom blooms will sometimes fail during overcast weather and two solutions to this problem are apparent. A diatom substitute, e.g., finely ground artificial diet or soycake can be added to stimulate a bacterial bloom or frozen diatoms can be added. It is possible to freeze diatoms successfully and indeed thawed diatoms can even be used for initiating a new bloom.

(7) Brine Shrimp and Alternative Diets

The most radical change that will have to be made to the Australian prawn larval rearing methods is to reduce the reliance on brine shrimp nauplii as a food for mysis and postlarvae. The massive escalation in cost of brine shrimp will make large scale rearing of prawn larvae excessively expensive if current Australian usage rates are maintained.

The most commonly used substitute is the rotifer Brachionus and the techniques required for the efficient production of this larval food should be mastered in Australia. Brachionus will also prove to be valuable for the rearing of various crab and fish larvae when these seedlings are required on a large scale. The labour costs in producing Brachionus can be quite high and research into a suitable artificial diet, to be used in conjunction with Brachionus, will reduce the requirement for Brachionus.

It will probably be necessary to grow the flagellate Chlorella but maximum use of baker's yeast as a feed for Brachionus should also be made. Chlorella-fed Brachionus are definitely required for some fish larvae but this is not necessarily the case for prawn larvae.

(8) Postlarval Feeds

For the first five days of the postlarval phase a live planktonic food, e.g., brine shrimp or an artificial diet of neutral buoyancy will be required. After this period the postlarvae change from a planktonic mode to a benthic one and often a mascerated shellfish is then fed. Commonly available fresh shellfish are quite expensive in Australia and substitutes should be considered. Thai scientists successfully use tuna meat. Alternatively, successful diets for adult prawns could be presented in a crumbled, water stable form.

(9) Choice of Species

The choice of species will be largely determined by their relative success during the grow out phase in ponds. However other considerations should be taken into account. In temperate areas it must be possible to either collect or produce spawners in spring if overwintering of the crop is to be avoided. There is of course more leeway in tropical areas because of more seasonally stable water temperatures and faster growth rates. Also it appears that some species are more difficult to rear than others at least with existing techniques.

C. The Pond Phase of Prawn Farming

(1) Pond Design and Location

There are three major types of prawn farming ponds or culture units in use in the three countries visited and it is from these types that the best Australian designs will probably be drawn. The major type is the intertidal earthen pond whose construction involves either excavation or erection of pond walls or more commonly both (Figure 8). This is the type of pond which will probably be used in an Australian industry and is already in use at Port Stephens and at Port Broughton although at this latter site the ponds are mostly quite elevated and pumping is heavily relied upon. There are clear running cost advantages in having a large tidal amplitude where a pond is located. However, high flushing rates may only be intermittently required and thus large tidal amplitudes may not be obligatory. Furthermore elevated sites are often cheaper to excavate because the use of conventional earthmoving equipment may be feasible.

The second type involves the enclosure of an existing area of waterway. This can be achieved by building rock and netting walls out from the shore (Figure 5). However this design may produce higher flushing rates than are desirable unless expensive, non porous walls are constructed. Alternatives include the construction of fixed pens (Figure 10) or floating cages. All of these alternatives which involve enclosing existing waterways may alienate inshore areas from other uses and as such may be unacceptable to regulatory authorities.

The third type of design that can be used for growing postlarvae or small juveniles to market size involves the construction of sophisticated and highly intensive prawn culture units similar to those used in Japan (Figure 6). These units are only marginally profitable in Japan where the value of farmed prawns is extremely high and thus they would probably be unprofitable in Australia.

Ponds should be located at the warmer end of a species geographical range as this allows higher growth rates and longer growing seasons than at the cooler end. These growth features allow much greater flexibility in marketing with the possibility of selling at peak prices when supplies of prawns from conventional fisheries are low. The higher prices received by Japanese prawn farmers in the southern regions as opposed to those further north illustrate this advantage very well. If ponds are built in more tropical areas some consideration should be given to using the Thai design which incorporates deep channels in the pond bottom (Figure 8). Strong aeration would however make the temperature distribution within the pond more uniform and thus reduce the value of the channels as refuge areas during very hot weather.

The siting of ponds, with respect to salinity, depends greatly on the species involved. P. japonicus farms are usually in areas of high salinity whilst many of the Filipino and Thai P. monodon and P. merguiensis farms are in very estuarine areas.

(2) Pond Preparation

An important feature of pond preparation for almost all of the ponds I visited is the requirement that the pond be dried before restocking. This helps ensure that the chemical reduction in pond bottom sediments does not become excessive as the drying, especially if accompanied by ploughing of the bottom, aids oxidation. The more unusual practices of furrowing the bottom of some Japanese ponds and using a sulphide inhibitor, calcium oxide, in the bottom of some Thai ponds warrant investigation in Australia.

(3) Pond Stocking

The most common approach in the countries visited is to stock postlarvae into a nursery pond before transferring them to a growing pond.

One reason for using a nursery pond is that it allows predators and competitors a shorter time to reach harmful population levels before the growing pond is harvested. The necessity for using nursery ponds may vary from species to species and their value should be investigated using Australian species. The strategy of using heavily stocked nursery ponds and converting these to growing ponds after transferring most of the juveniles to other ponds appears to be very logical. Alternatively it may also be useful to retain a high density of prawns in the nursery pond until growing ponds have been harvested as this would allow a limited system of double cropping.

Little quantitative research on optimum stocking density for Japanese growing ponds seems to have been done. However stocking at a density of 200,000-250,000 1.0 g juvenile P. japonicus/ha seems to give high yields. Dr. Shigueno's intensive culture system would not be profitable in Australia but proves that at least one Japanese species can be stocked at extremely high densities (more than 1×10^6/ha) without serious cannibalism. Relatively high stocking densities will be necessary in Australia to recover capital investment.

(4) Pond Management

The major finding from the investigation of the pond phase of the Japanese industry is that water exchange rates should be kept at low levels so that nutrients are retained within the pond. This apparently maximizes the contribution of the pond benthos to the food budget of the prawn. Crisis periods will occur during summer in heavily stocked ponds and thus high water exchange rates will occasionally be necessary. Aeration is necessary in ponds with lower flushing rates but is not required for those with continuously high rates of water exchange, e.g., twice the pond volume/day. The choice of an aeration device is very important.

Surface agitators are popular in Japan but the production levels from ponds fitted with bottom aeration are very impressive and this type of aeration should be thoroughly investigated for Australian ponds. Another advantage of lower flushing rates is that they seem to reduce the transparency of the pond water and hence limit the growth of the benthic macrophyte Ulva which can cause very serious deterioration in pond bottom conditions.

For heavily stocked ponds the ammonium ion concentration should be monitored even if aeration is used. The Japanese intensive culture farm owners have found high ammonium ion concentrations to be a problem.

(5) Feeding and Fertilization

There is a clear lesson to be learnt from the Japanese industry. Reliance on the use of fresh or frozen feeds should be limited if there is any likely competition for these feeds from direct human consumption. Feed costs are of crucial importance to the profitability of prawn farms and if possible even the use of artificial diets specially designed for prawns should be avoided. The tonnage that will be required for such diets will be small and thus prices will be high. Hopefully, currently available mass-produced artificial diets will be adequate if the food obtained from the pond benthos can make up for nutritional deficiencies in the artificial diet. If specialized prawn diets are found to be necessary the production of water stable pastes should be investigated. Specialized diets may be necessary if high stocking densities are used.

No fertilization is used in the heavily stocked and fed Japanese ponds but there may still be some value in fertilizing Australian growing ponds. However the Thai and Filipino techniques of inducing a rich growth of benthic algae by fertilization may have some risk attached to them. Serious deterioration of bottom conditions could occur as they do with rich Ulva growths. Prawns may have difficulty consuming all of the pelleted food added if it falls amongst benthic algae.

(6) Potential Yields

In more temperate areas, e.g., Japan and New South Wales, Australia it is not feasible to farm two crops of postlarvae through to market size/year. However with suitable manipulation of pond stockings some limited double cropping would be possible as discussed in Section 10C (3). The production rates in the Seto Inland Sea region of Japan, which has an equivalent latitude to Port Stephens, are very impressive. In the smaller better managed ponds annual production was in excess of 5,000 kg/ha/yr. Once a suitable species is chosen and experience gained in managing ponds it seems quite likely that similar yields could eventually be obtained in temperate areas of Australia.

Only a vague guide to the prospects for tropical Australian prawn farms can be obtained from Thai and Filipino results. These Asian industries are undergoing a period of change in which more sophisticated farming methods are being introduced, e.g., hatchery reared larvae, higher stocking densities and more intensive feeding. Thus it is not possible to say what their longer term yields will be. However it is clear that two or more crops can be farmed each year. These tropical ponds should eventually be more productive than the temperate Japanese ponds and already a Thai farmer has produced more than 2,600 kg/ha/yr with a mixture of prawn species.

(7) Choice of Species

Some of the species discussed in this report do not naturally occur in Australia. However the Thai conclusion that *P. merguiensis* (banana prawn) is not as suited to pond culture as *P. monodon* is relevant as both species do occur in northern waters. An alternative tropical species for Australian farmers could be the tiger prawn *P. esculentus*. Further south the eastern king prawn *P. plebejus*, and the western king prawn *P. latisulcatus*, the latter in areas of high salinity, would be more suitable.

Perhaps the school prawn, M. macleayi, is the most suited to New South Wales waters although it would not be large enough for export. It seems unnecessary and may indeed be unwise, in terms of disease risks, to import foreign species to Australia.

(8) Marketing and Economics

Australian prawn farmers should locate their ponds so that they can harvest and market their crops at the most lucrative time. In contrast to Japan there will only be a very small domestic demand for live prawns. However the Japanese approach of farming to satisfy a more valuable market that demands high quality should be the aim of Australian farmers. It is still unlikely that Australian farmers will be able to obtain very much higher prices than those that are obtained for prawns from Australian commercial fisheries. Thus the expensive Japanese techniques will require substantial modification but feeding costs in Australia should be much lower than in Japan. A worthwhile approach to estimating the viability of an Australian industry would be to use Japanese production figures and estimates of Australian costs in a detailed feasibility study. A considerable amount of research would however be required before this would be possible.

(9) Polyculture

The Japanese industry is strictly based on monoculture and a similar approach is used in Thailand. Whilst some polyculture with milkfish Chanos chanos is practised in the Philippines this species would not be a viable secondary crop in Australia. In temperate areas large mullet (Mugil cephalus) biomasses do occur in prawn ponds but these are of low value. The Australian industry may not be able to recover its costs by farming prawns alone and an original approach such as polyculture in which oysters utilize the water column within the pond may be necessary.

D. Other Aspects

(1) Liberation of Postlarvae to Boost Fisheries

Although this practice was found to be in operation in Thailand and apparently in the Peoples Republic of China, its major application to prawn fisheries was in Japan. In the Australian situation it would be preferable to prevent a persistent decline in catch by good fisheries management and environmental protection than to attempt to repair a fishery by liberating postlarvae. However if areas exist where natural recruitment is a continual limiting factor that is not related to fishing pressure, e.g., in lakes, some consideration could be given to the use of liberation. One of the reasons why liberation may have been successful in the Inland Sea is that it is a relatively enclosed body of water that allows high fishing pressure.

(2) Maturation of Broodstock in Captivity

The value of producing broodstock in captivity has been discussed in Section 10A (5). The maturation pens used in the Philippines may be too costly in terms of labour for an Australian industry. Their other approach of ablating one eyestalk and subsequently holding females in hatchery tanks has not proved to be very successful in the past at Port Stephens but Filipino results show promise. The third approach which the Philippines plan to investigate is to use land based flowthrough tanks copied from a Tahitian project. Research should be carried out into spawner production and eyestalk ablation should be used but the holding enclosures, whether they be cages or pens mounted on the sea bottom or land based tanks, should be at an oceanic location. This problem of location may have been the reason for unsatisfactory maturation results at Port Stephens. A high quality diet, e.g., fresh mussel will also be necessary for rapid gonad development.

(3) Nutrition

If specialized artificial diets are to be used, e.g., for larval rearing, broodstock production or feeding in ponds, the expensive protein content will have to be minimized and care taken with the level of trace elements, some of which were found by Japanese nutritionalists to be growth inhibitory.

(4) Other Species

The Japanese research into the larval rearing of *Portunus trituberculatus* should be very useful if large scale rearings of Australian crab species are attempted. Whilst *P. trituberculatus* may be an unusually aggressive species it seems likely that in ponds the sensory or physical barriers found to be useful for this species will be necessary for farming Australian species.

The freshwater prawn *Macrobrachium rosenbergii* occurs in northern Australia and is a promising species for aquaculture. During the larval rearing of this species some attempt will have to be made to spare the amount of brine shrimp nauplii used. The larvae however have been reared successfully in Australia and pond trials with this species should be initiated.

SECTION 11

REFERENCES, MAPS, FIGURES AND TABLES

A. References

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B. Maps

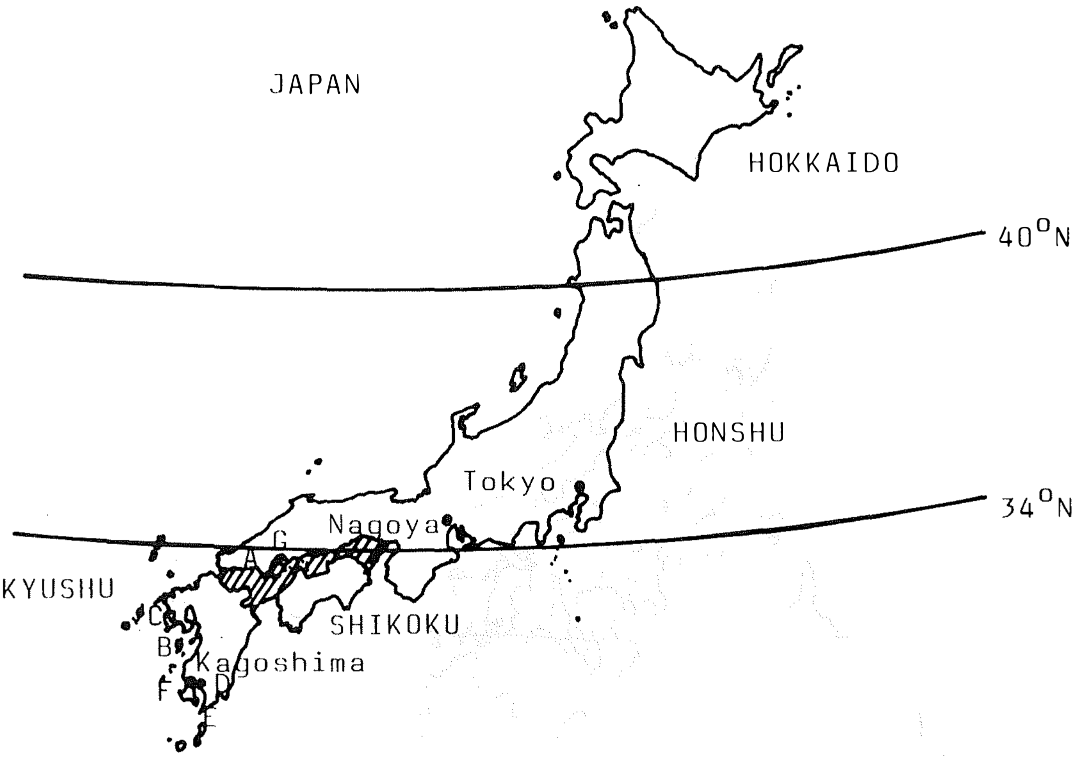
Maps 1 - 4.

C. Figures

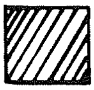
Figures 1 - 13.

D. Tables

Tables I - III.



Map 1



Seto Inland Sea

A Fujinaga Penaeid Shrimp Institute, Aio. Yamaguchi Pref.
Naikai Fisheries Farming Centre, Aio.

B Fujinaga Penaeid Shrimp Institute, Amakusa Islands.
Commercial prawn farming area, Amakusa Islands.

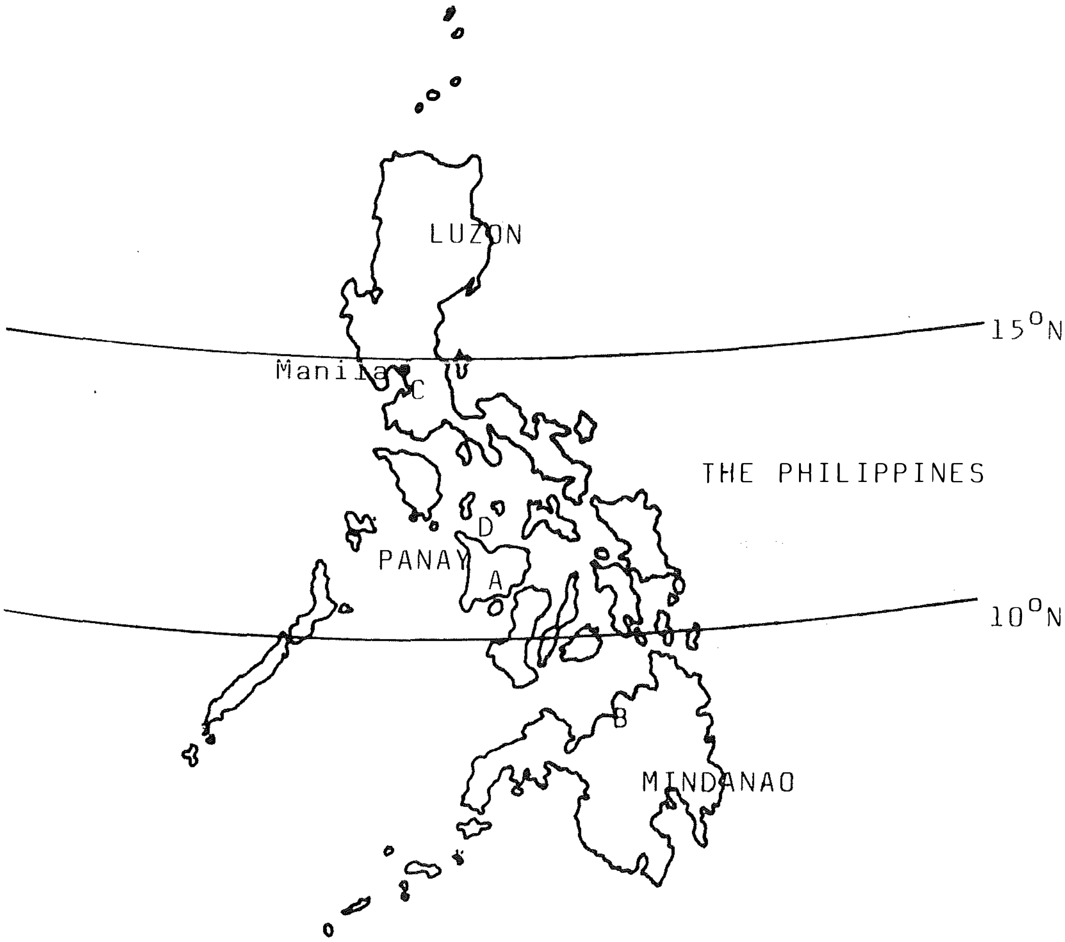
C Nagasaki Pref. Research Station, Nagasaki Pref.

D Tarumizu Culture Centre, Tarumizu, Kagoshima Pref.

E Seto Inland Sea Fish Farmers Association (S.I.S.F.F.A.)
hatchery, Shibushi, Kagoshima Pref.

F Mitsui and Bohnotsu commercial, intensive prawn farms,
Kagoshima Pref.

G Hiroshima Pref. Fisheries Experimental Station, Ondo Is.,
Hiroshima Pref.



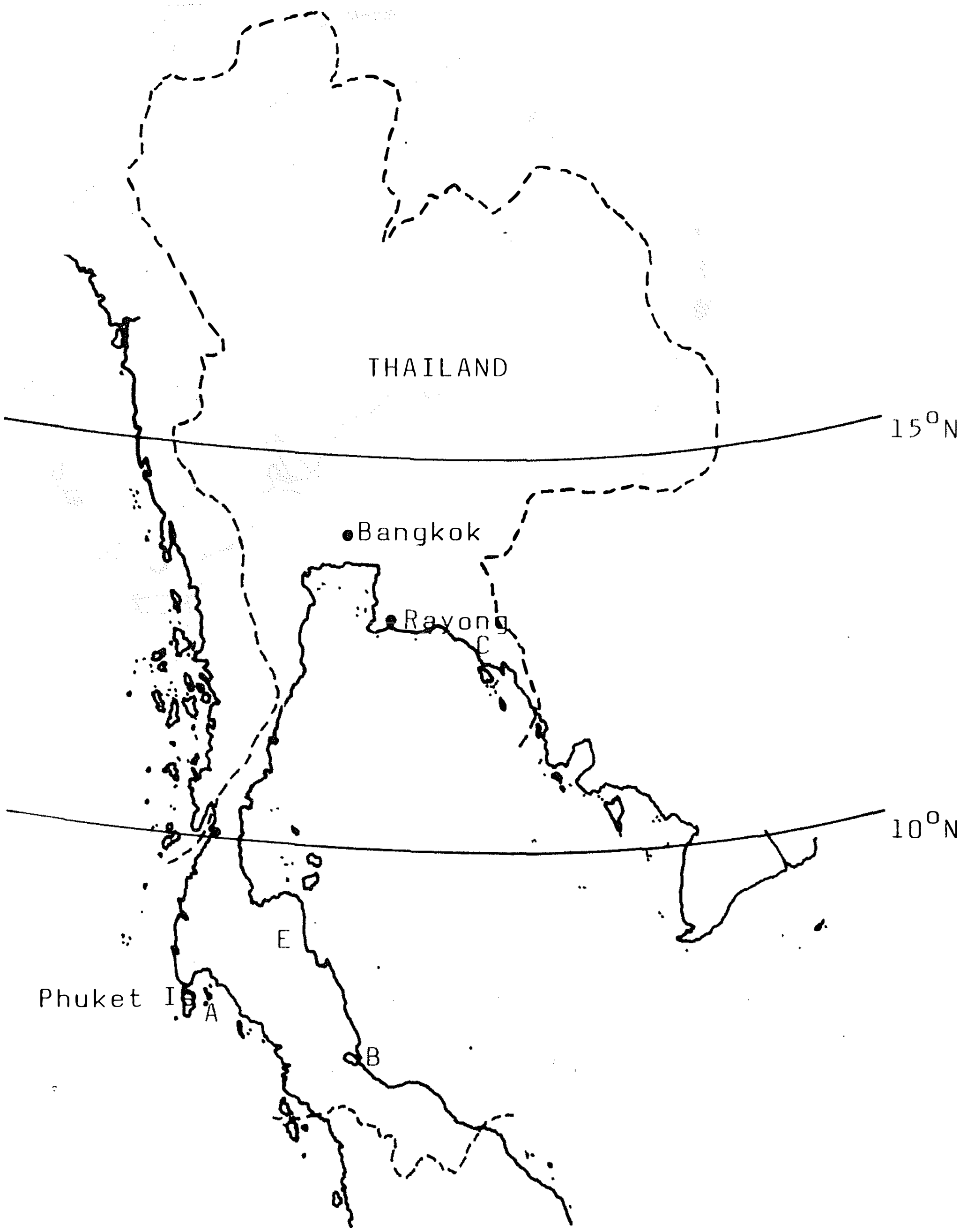
Map 2

A South East Asian Fisheries Development Centre (S.E.A.F.D.E.C.) research stations at Tigbauan and Leganes, Panay Is. and Igang, Guimaras Is.

B Mindanao State University Institute of Fisheries Research and Development (M.S.U. I.F.R.D.), Naawan, Mindanao Is.

C Laguna de Bay, Luzon Is.

D S.E.A.F.D.E.C. maturation station, Batan Bay, Panay Is.



Map 3

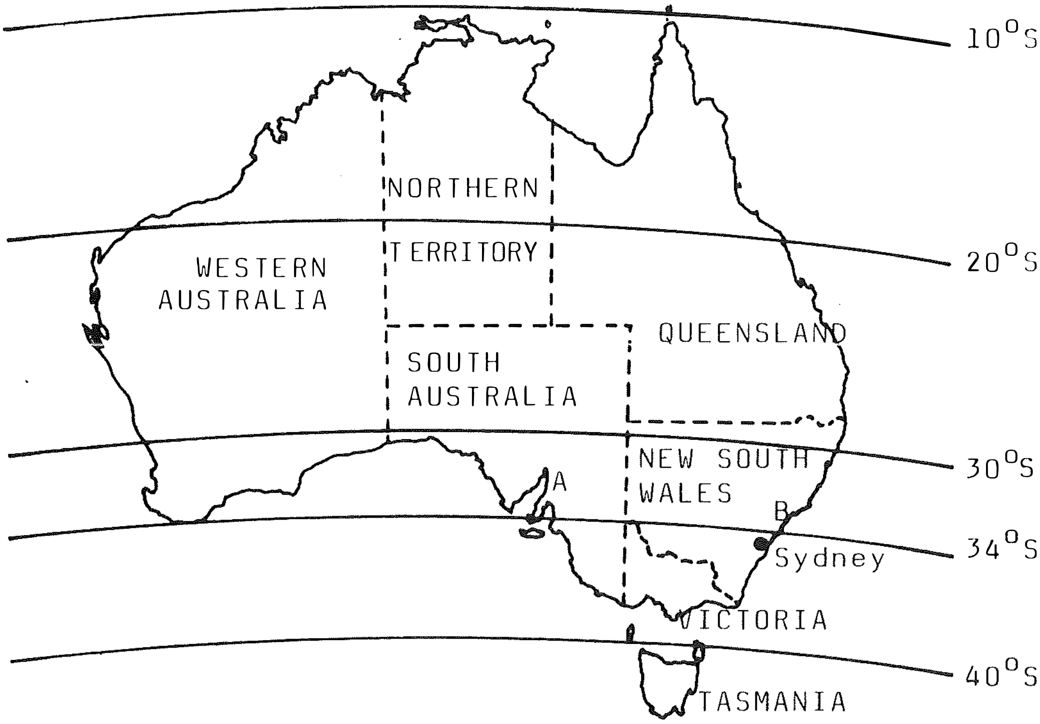
A Phuket Fisheries Research Station, Phuket Is.

B Songkhla Marine Fisheries Station, Songkhla.

C Commercial prawn farming area, Chantaburii.

D Commercial prawn farming area, Samut Songkhram.

E Commercial prawn farming area, Nakhorn Si Thammarat.



AUSTRALIA

Map 4

A Racovolis Prawn Culture Centre, Port Broughton, South Australia.

B Brackish Water Fish Culture Research station, Port Stephens, New South Wales.

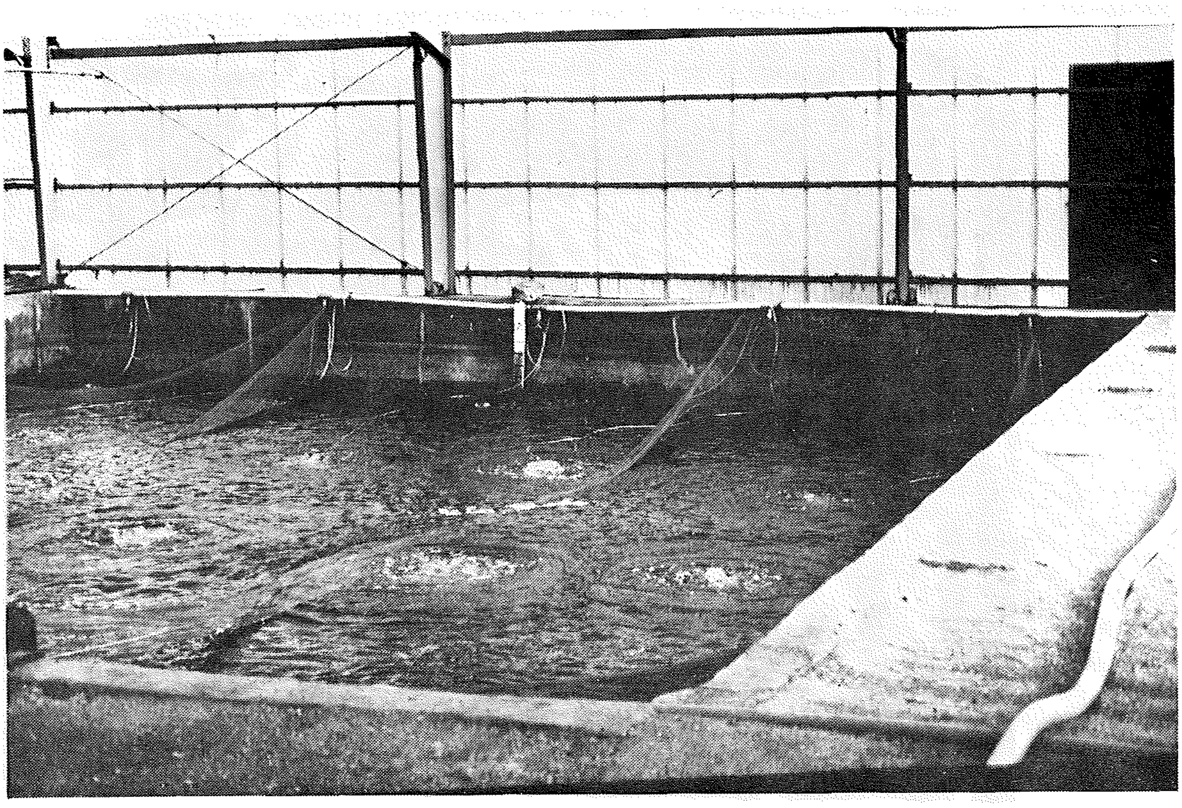


Figure 1
A 200 t capacity Penaeus japonicus larval rearing tank at the Fujinaga Shrimp Institute, Aio, Japan. The surface netting is set for the collection of hydrozoans and the tank is located within a fibreglass greenhouse.

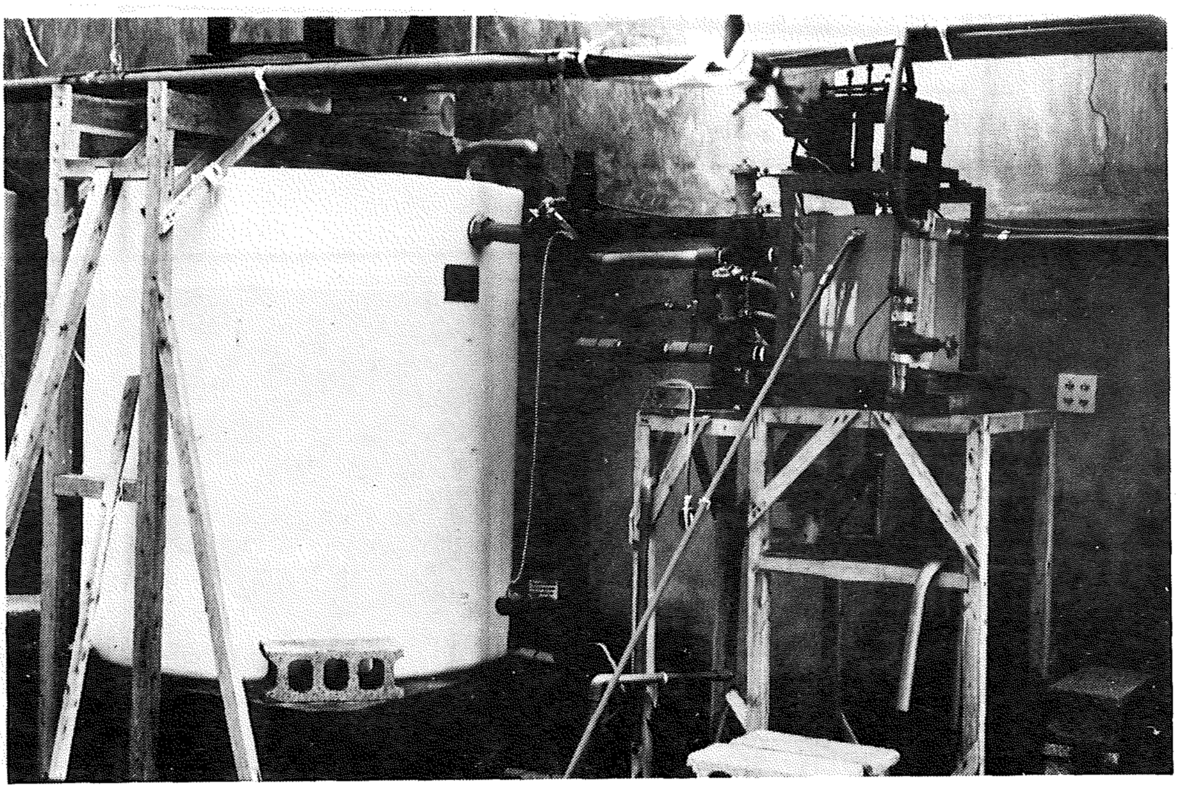


Figure 2
A rotifer (*Brachionus plicatilis*) production system at the Tarumizu Culture Centre, Kagoshima, Japan. The culture continually recirculates from the 2 t fibreglass tank through the 20 ℓ filter which removes *Brachionus* faeces. Yeast is added regularly to the culture tank to act as food for the *Brachionus*.

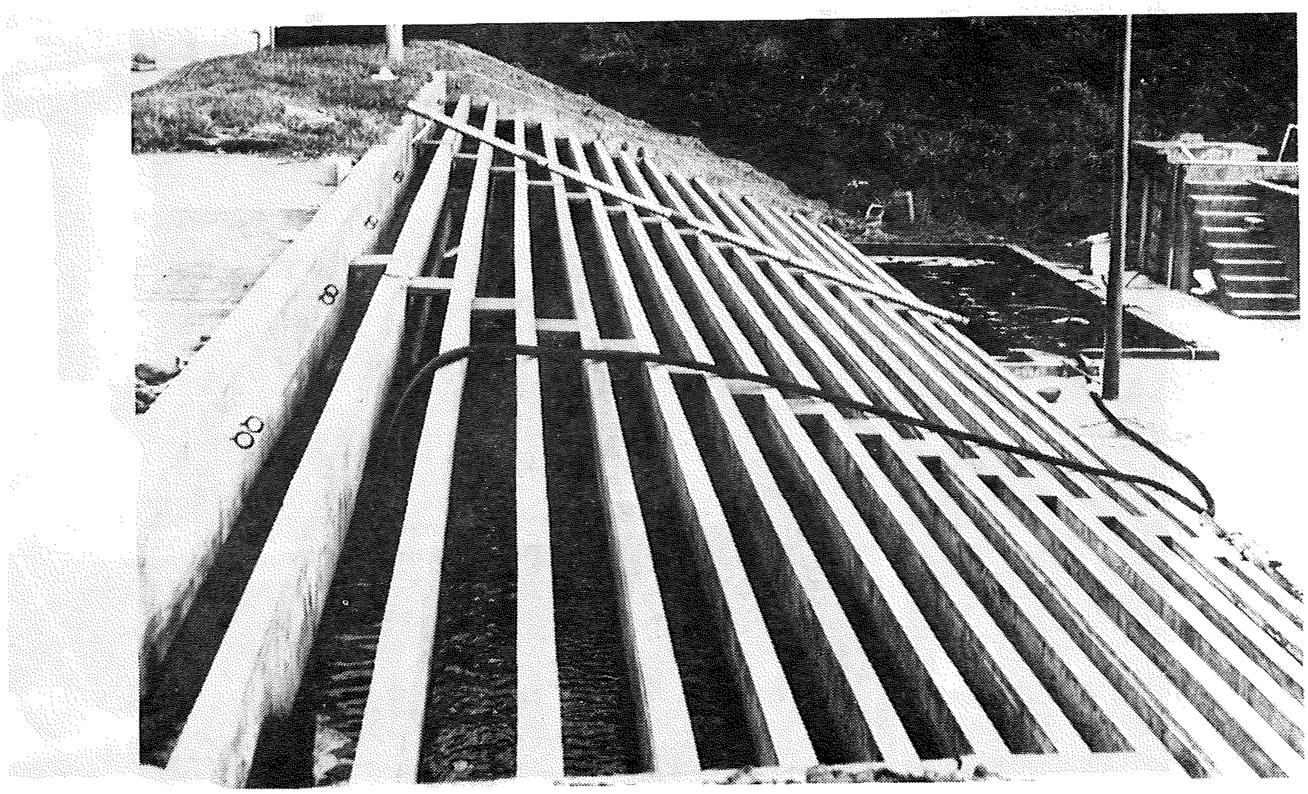


Figure 3
A Chlorella production system at the Seto Inland Sea Fish Farmers Association hatchery at Shibushi, Japan. Culture is pumped from the fertilized 300 t Chlorella tank at the base of the 300 t capacity terrace to the top from where it returns to the tank by traversing each level of the terrace. This shot shows the system at less than full capacity because the total volume of the terrace is not being utilized.

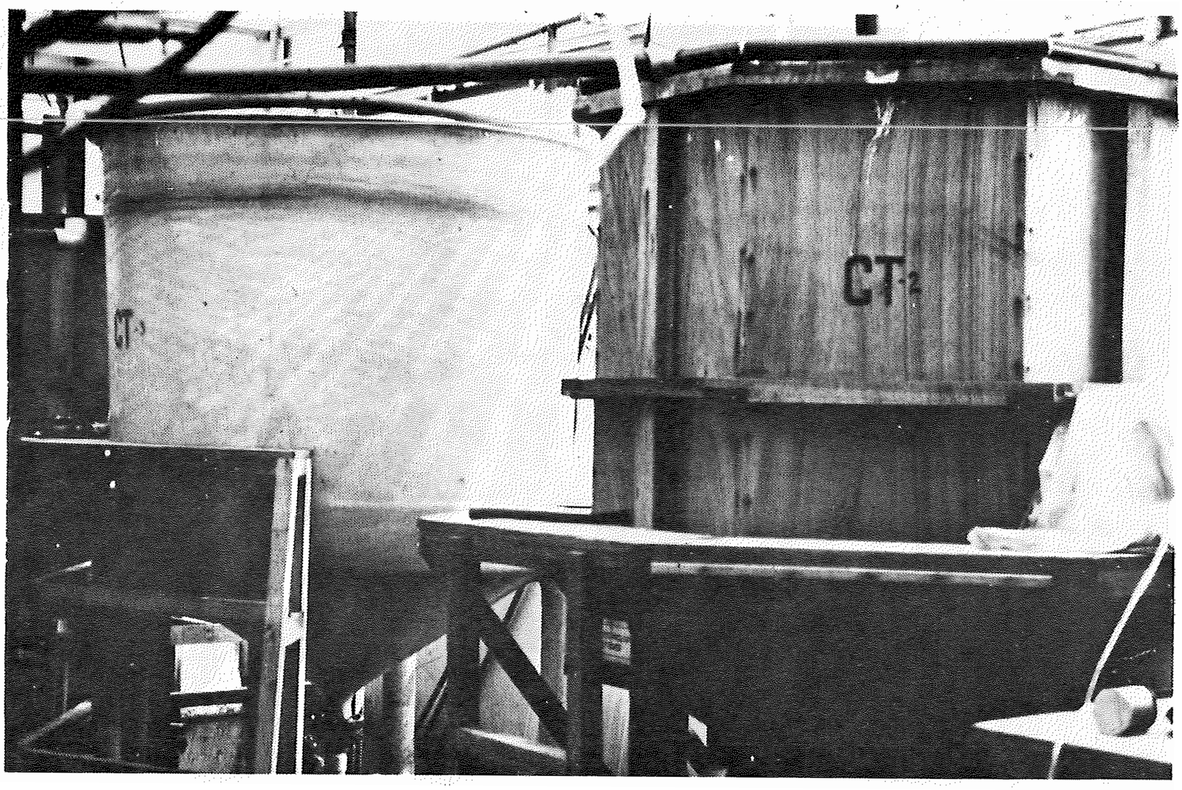


Figure 4
Two 2 t high density, Penaeus monodon larval rearing tanks at the South East Asian Fisheries Development Centre (S.E.A.F.D.E.C.), Tigbauan, the Philippines. The tanks are either made from fibreglass (left) or timber (right).

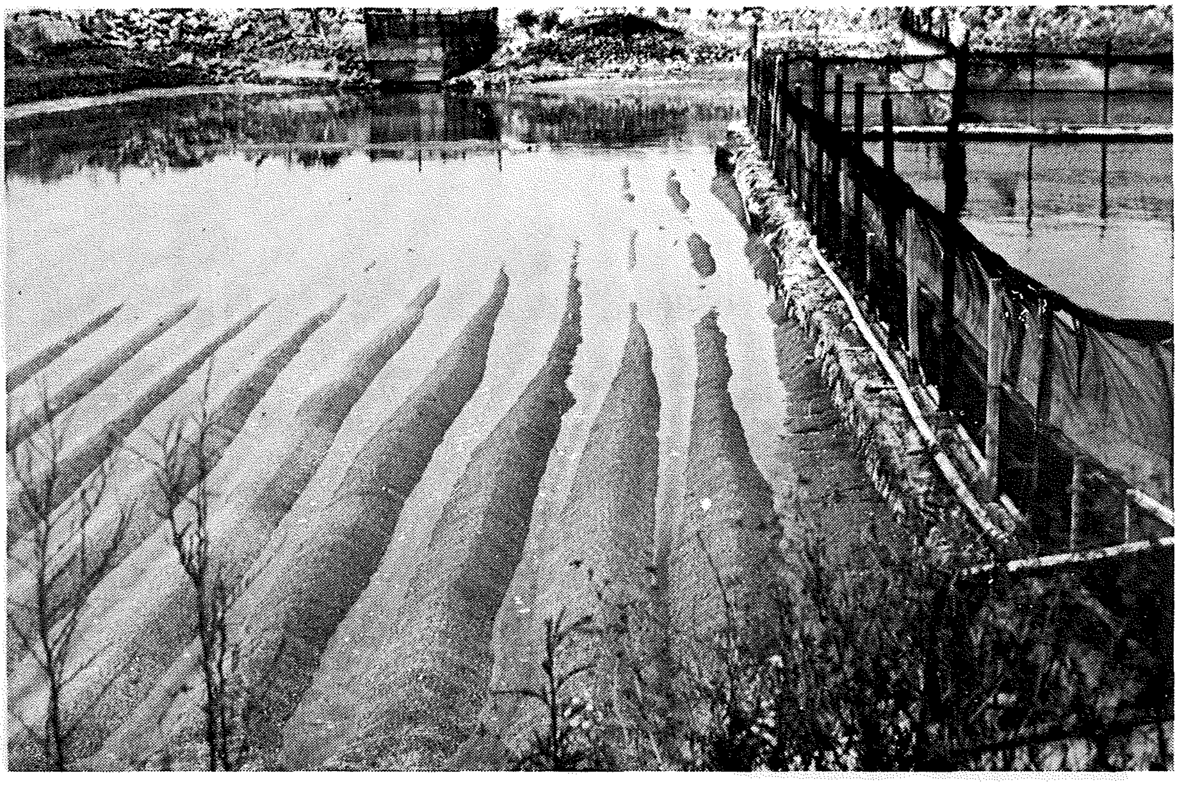


Figure 5

A drained Penaeus japonicus farming pond in the Amakusa Islands, Japan. The contoured pond bottom and the rock and netting pond walls can be clearly seen as can the slope of the pond bottom. The netting section of the pond wall allows a high, tidal flushing rate.

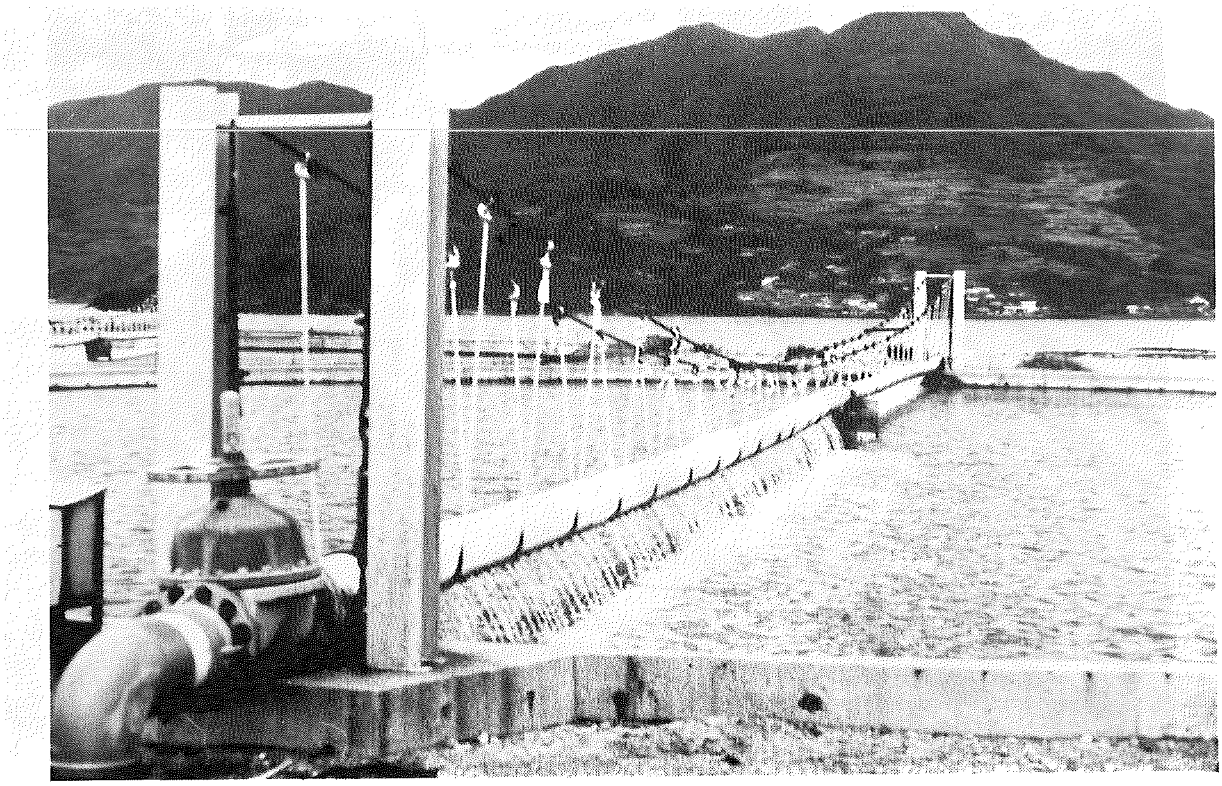


Figure 6
A 0.1 ha intensive farming tank for Penaeus japonicus near Kagoshima, Japan. The angled water jets cause a circular flow within the tank. There is an exhalent flow, through the sandy bottom, which helps maintain favourable bottom conditions.

Figure 7
An electric net for harvesting live <u>Penaeus japonicus</u> from Japanese ponds and intensive culture units. The current flows from a 12V power source through to the sandy bottom via the four probes located between the two metal skis.

Figure 8
A 0.32 ha Penaeus monodon farming pond near Songkhla, Thailand. The pond is drained to reveal feeding plateaus and also channels for avoiding excessively high water temperatures. The feeding plateaus are usually covered by 0.5 m of water and the channels by 1.0 m. A fine mesh screen which helps prevent escape of prawns and entry of predators and competitors is shown in the foreground.

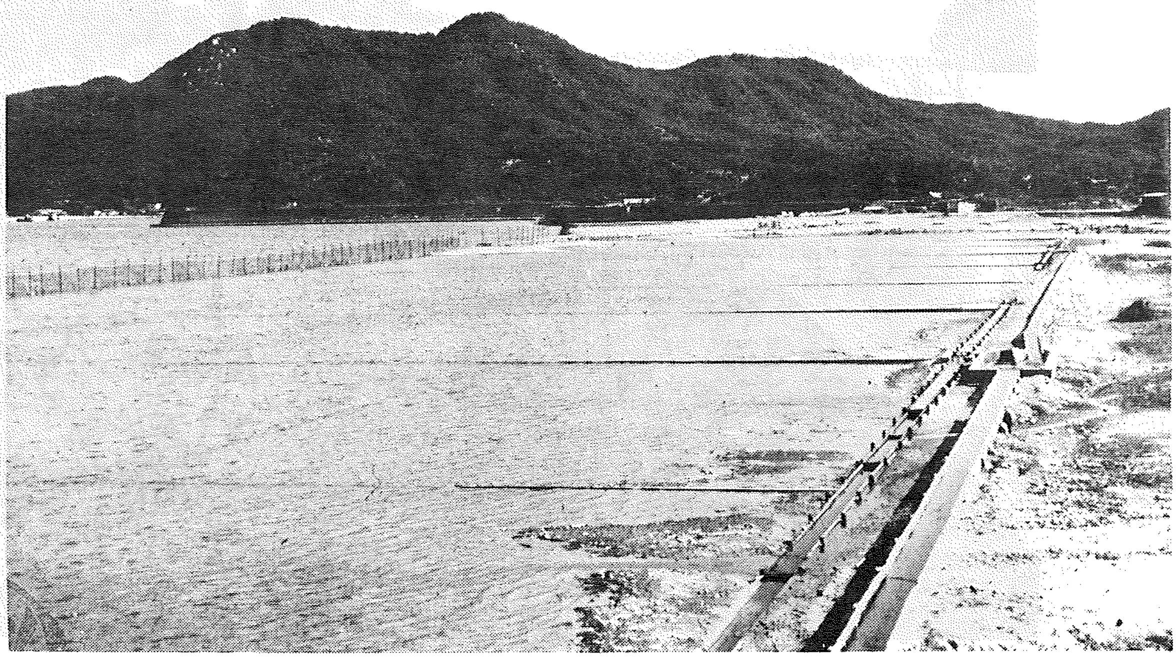


Figure 9
An artificial beach for the liberation of hatchery reared <u>Penaeus japonicus</u> postlarvae near Aio, Japan. The upper beach area is kept covered by seawater which is continuously pumped to the top of the beach. A network of low retaining walls and a fence that excludes fish can be seen.

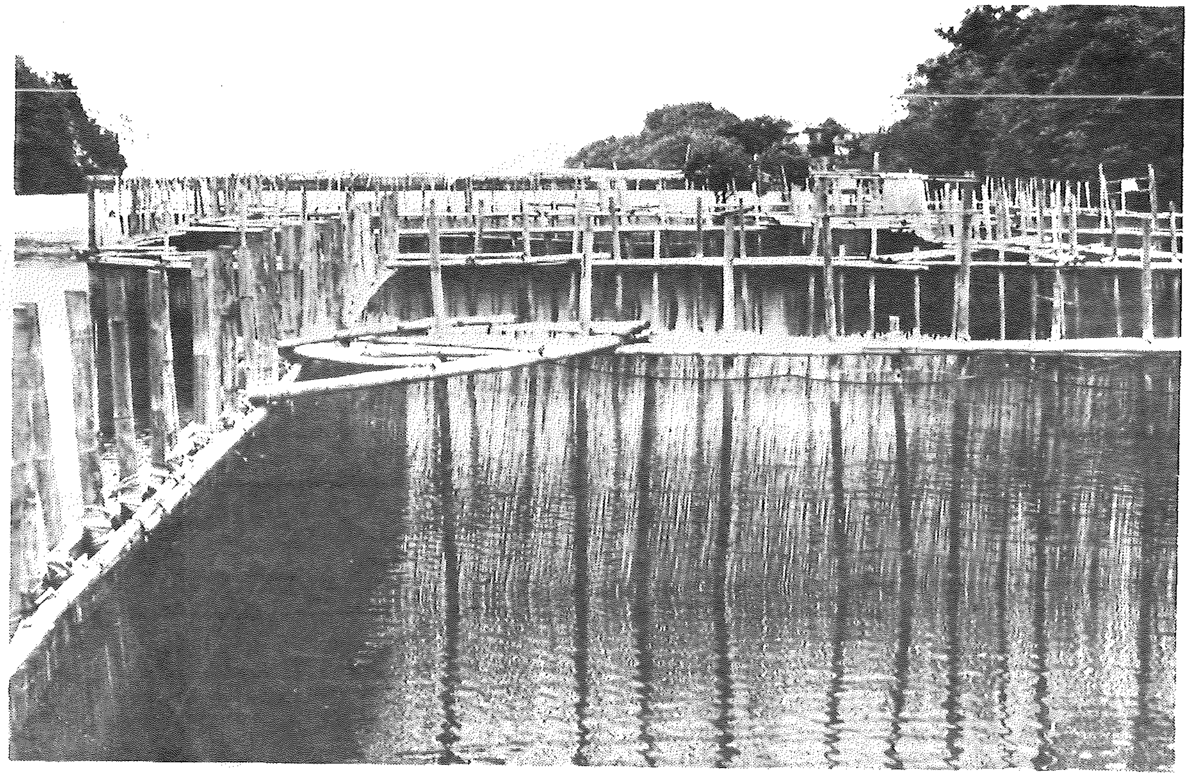


Figure 10
Several 250 m^2 bamboo and netting pens used for maturing Penaeus monodon at Guimaras Island, the Philippines. The netting bottom sits in contact with the muddy bottom at a depth of approximately 3.5 m and can be lifted to allow removal of mature female prawns.

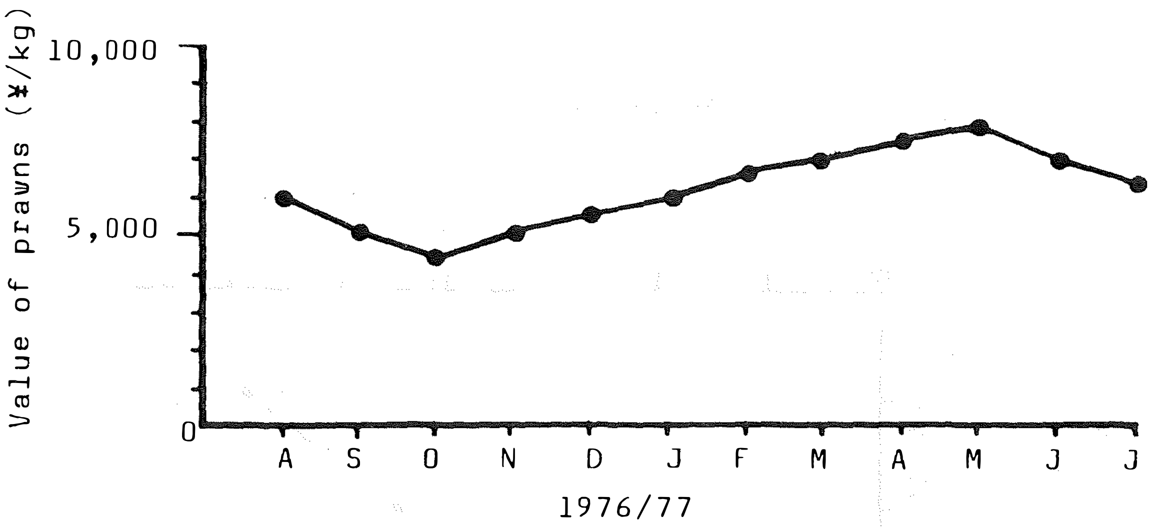


Figure 11. Approximate monthly average price (¥/kg of live Penaeus japonicus) paid to prawn farmers at the Tokyo Fish Market during 1976/77. (Information supplied by K. Fujinaga.)

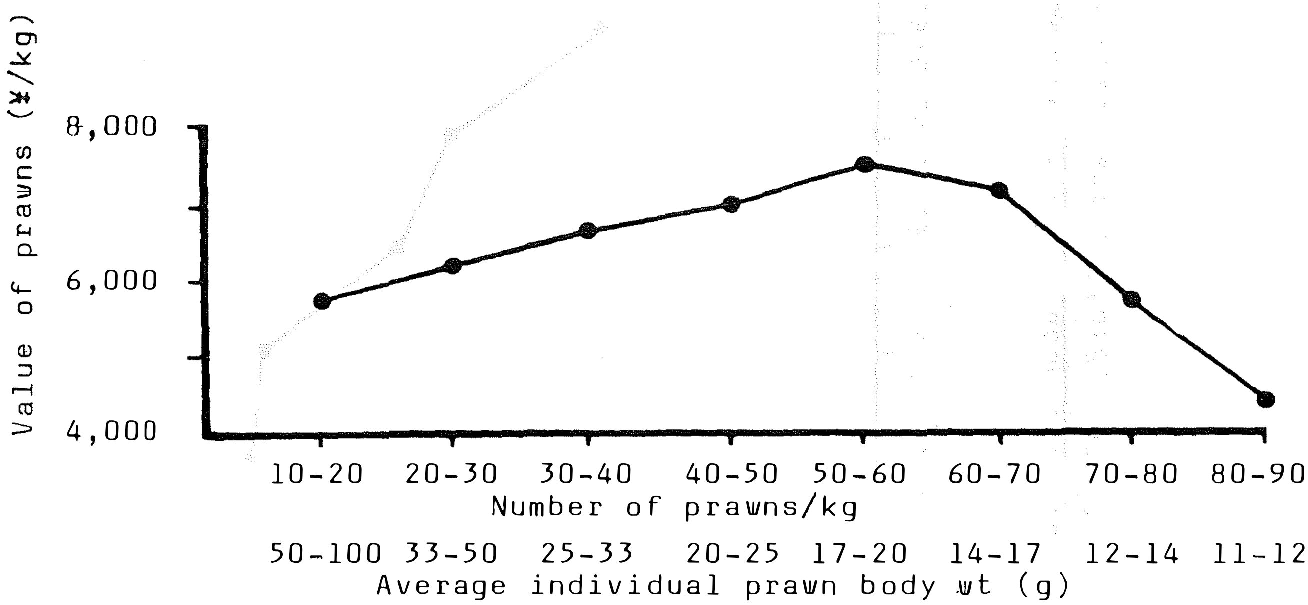


Figure 12. Relationship between size and average wholesale price (¥/kg) paid for live Penaeus japonicus at the Tokyo Fish Market on 4 days during July 1977. (Data for wild and farmed prawns pooled.)

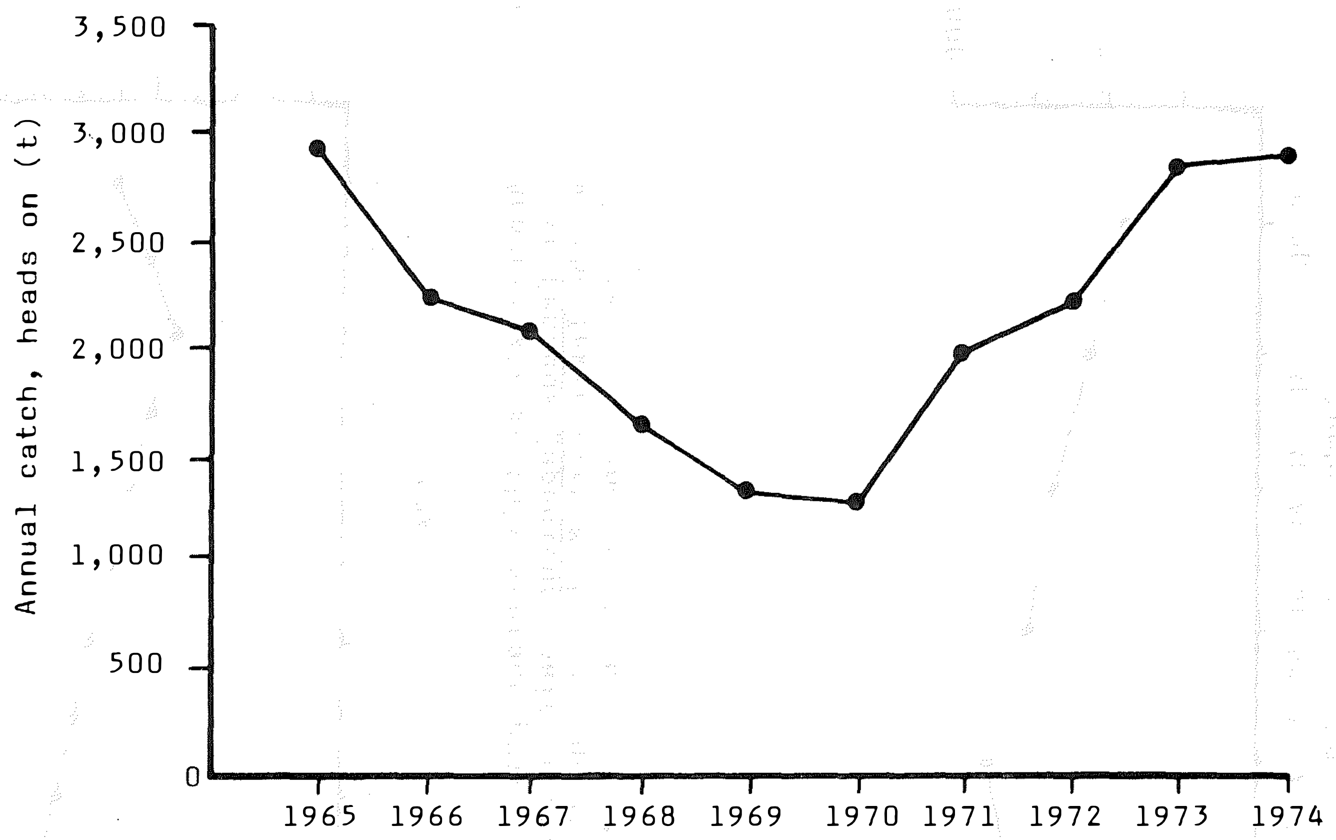


Figure 13. The annual catch for the Japanese *Penaeus japonicus* fishery, 1965 - 1974. (Taken from Hirasawa and Walford, 1976.)

TABLE I An example data sheet for a 200 t concrete tank used for rearing *Penaeus japonicus* larvae at the Fujinaga penaeid shrimp institute, Aio, Japan. (First batch of females stocked on 15.6.1977.)

Stage (Day)	No. of larvae x 10^3 and stage	Water T °C 0800 hr 1500 hr	Water change (t)	Daily final volume	Wt. of fertilizer added (NS g/day)*	Wt. of brine shrimp eggs added (g/day)	Wt. of artificial plankton added (g/day)	Wt. and size of artificial diet added (g/day): Sieve size (meshes/inch)	Wt. and size of artificial diet added (g/day): Total (g/day)	Diatom density (cells/mℓ)	Comments
A_1		21.0 (p.m.)	+60F	60							54 females from another tank added
A_2	eggs	24.8 26.0									36 females from another tank added
A_3,N	1010N	25.9 25.5	+10F	70						220	4 dead females. pH = 8.07
A_4	2020N	25.7 26.2	+10F	80						3860	Removed all females. 6 dead, 45 spawned
Z_1,N	1520N 1100Z	25.6 26.3	+10F	90						20000	
Z_2,N		25.4 25.7	+10F	100							pH = 8.53. Applied shade cloth
Z_3	2200Z	25.3 25.8	+10F	110	200					18000	pH = 8.46. Removed shade cloth
Z_4	2280Z	25.3 24.7	+10F	120	500						A few dead zoea in sample
M_1,Z_5	2560	25.3 25.4	+10F	130		300					Unusually high diversity of larval stages
M_2,Z_6	2420	24.9 24.6	+10F	140		300	300				
M_3	1620	24.6 25.5	+10F	150		300	400				
M_4	2100	25.4 26.4	+10F	160			400	60	100		A few postlarvae present
M_5,P_1		26.0 26.6	+10F	170		400	400	60	240		
P_2		26.4 26.1	+10F	180		200	400	60	280		
P_3		25.7 26.3	+10	190			400	60 40	240 120		Stirred tank bottom daily (P_{3-14})
P_4		26.1 25.0	+10 -20	180			400	40	360		
P_5		24.9 26.2	±40	180			400	40	400		
P_6		26.1 26.9	±40	180				40	360		
P_7		27.0 26.6	±40	180				40	320		
P_8		- 26.5	±40	180				40	320		
P_9		26.6 26.2	±40	180				40	550		
P_{10}		26.1 25.3	±40	180				40	480		Average P_{10} wt. = 1.96×10^{-3} g
P_{11}		25.2 25.8	±50	180				40	560		Changed drainage sieve to 508μ from 345μ
P_{12}		25.5 25.8	±40	180				40	690		
P_{13}		25.6 26.0	±40	180				30	740		
P_{14}		25.3 25.4	±40	180				30	920		
P_{15}		25.4 25.8	±40	180				30	1000		
P_{16}		25.6 26.7	±50	180				30	1140		
P_{17}		26.0 26.1	±50	180				30 No. 2	1020 300		
P_{18}		26.0 27.0	±50	180				30 No. 2	800 600		Cleaned tank bottom with a siphon
P_{19}		26.2 26.6	±50	180				30 No. 2	680 680		
P_{20}		26.8 27.9	±50	180				30 No. 2	680 680		Average P_{20} wt. = 6.2×10^{-3} g
P_{21}		27.3 27.4	±50	180				No. 2	1490		
P_{22}		- 27.0	±50	180				No. 2	1680		
P_{23}		26.3 25.5	±50	180				No. 2	1820		
P_{24}		25.5 26.1	±50	180				No. 2	2040		
P_{25}	Harvest 2300	26.2 27.0	±50	180				No. 2	1710		Average P_{25} wt. = 11.5×10^{-3} g 2.3×10^6 P_{25} was a very good harvest

LEGEND A = adult Z = zoea F = sand filtered seawater

N = nauplius M = mysis P = postlarva Z_5 = 5th day of zoea

* See Page 6 of text.

TABLE II   A comparison of data from all prawn hatcheries visited.

Hatchery and location	Text section code	Larval tank volume (t)	Maximum harvest /t	Annual production x 10^6	Harvest size	Rearing time to P_1 (days)	Feeding regime: Food item
Nagasaki Pref.Res.Stn. Japan	3B	100	10,000	4	P. japonicus P_{20}	10	Diatoms A. salina nauplii Artificial diet
Fujinaga Penaeid Shrimp Inst. Aio, Japan	2	200	15,000	60	P. japonicus P_{20} #	10 (summer) 13 (spring)	Diatoms A. salina nauplii Artificial plankton ~~Artificial~~ diet
Yamaguchi Pref., Naikai Fisheries Farming Centre, Aio Japan	3C	100-250		40	P. japonicus P_{20}		Diatoms Brachionus plicatilis A. salina nauplii Artificial diet
Tarumizu Culture Centre, Kagoshima, Japan	3D	110	13,500	10	P. japonicus P_{20}		Diatoms Brachionus plicatilis A. salina nauplii Artificial diet
SISFFA Hatchery, Shibushi, Japan	3E	2,400	21,000	140	P. japonicus P_{20}		Diatoms Brachionus plicatilis A. salina nauplii Euphausia + Tapes
SEAFDEC, Tigbauan, the Philippines	3F	50-200 and 2	10,000 (large tanks) 50,000 (2t tanks)	>5 (all tanks)	P. monodon P_5	11 *	Diatoms Brachionus plicatilis A. salina nauplii Minced shrimp
Mindanao State Uni IFRD, Naawan, the Philippines	3G	16-60	7,500	3	P. monodon P_7		Diatoms Brachionus plicatilis Tuna meat
Phuket Fish. Res. Stn., Phuket Is., Thailand	3H	40-100	4,000	6	P. monodon P_{20}	10-13	Diatoms Brachionus plicatilis A. salina nauplii Clam meat
Songkhla Marine Fish. Station, Songkhla, Thailand	3I	50	12,000	1.5 P. merguiensis 0.5 P. monodon	P_{20}		Diatoms Brachionus plicatilis A. salina nauplii Squid + shellfish

Stage (inclusive): Z_1 Z_2 Z_3 M_1 M_2 M_3 P_1 P_2 P_3 P_4 P_5 P_6 P_7 P_8 P_9 10//20

For export P_7

* P. merguiensis 9 days

Z1 Z2 Z3 M1 M2 M3 P1 P2 P3 P4 P5 P6 P7 P8 P9 10//20

Table II (Cont.) A comparison of data from all prawn hatcheries visited.

Hatchery and location	Text section code	Diatom production method	Spawner source	Filtering method for rearing water	Problems	Comments
Nagasaki Pref. Res. Stn., Japan	3B	A	Tangle nets	150 µ mesh	None	No heating or greenhouse. Summer rearing only.
Fujinaga Penaeid Shrimp Inst., Aio, Japan	2	A	Tangle nets	Sand filter and 350 µ mesh	Hepatopancreas disease in early postlarva. Salinity drops. Supply of spawners. Copepods and hydrozoans in the larval tanks.	In spring spawners may not spawn until 4-5 days after stocking in larval tank. Spring heating and greenhouses.
Yamaguchi Pref., Naikai Fisheries Farming Centre, Aio, Japan	3C	A	Tangle nets	Sand filter or no filter	Hepatopancreas disease of young postlarvae in tanks supplied with unfiltered seawater.	Interpreter problems. Spring heating and greenhouses.
Tarumizu Culture Centre, Kagoshima, Japan	3D	A (summer) B (spring)	Tangle nets		Disease of mysis and postlarvae which inhibits moulting.	In spring, in heated tanks Chaetoceros blooms more successful than the dominant spring diatoms.
SISFFA Hatchery, Shibushi, Japan	3E	B	Tangle nets	No filter	"	No heating or greenhouses. Summer rearing only. Use of artificial plankton discontinued.
SEAFDEC, Tigbauan, the Philippines	3F	C (large tanks) D (2 t tanks)	Induced spawners	Sand filter	Salinity drops. Turbidity of rearing water. Fungal disease. Postlarval mortality.	Large tanks either in open or in greenhouses. Some heating used in 2 t tanks in greenhouses.
Mindanao State Uni. IFRD, Naawan, the Philippines	3G	E	Fish traps	No filter	Fungal disease. Unidentified mysis disease. Epistylis (protozoan).	No heating or greenhouses. P. indicus much easier to rear than P. monodon.
Phuket Fish. Res. Stn., Phuket Is., Thailand	3H	B	Tangle nets and rematured spawners	Filter	Inadequate Chlorella and Brachionus production. Unidentified parasite and diseases.	Cost of spawners excessive. No greenhouses or heating.
Songkhla Marine Fish. Station, Songkhla, Thailand	3I	B	Tangle nets	Settling tank and 200 µ mesh filter	Poor siting (low salinity and high turbidity) prevents larval rearing for 4 months/year.	Tetracycline used routinely during M_2 - P_{10} to control. Zoothamnium. No heating or greenhouses.

Diatom Production Methods

A Mixed algal population induced by larval tank fertilization.

B Cultures of Chaetoceros added to the fertilized larval tank.

C Cultures of Chaetoceros added to unfertilized larval tanks.

D Washed Chaetoceros cells added to unfertilized larval tanks.

E A mixed algal culture (dominated by Chaetoceros) added to unfertilized larval tanks.

TABLE III A summary of a widely used approach to prawn farming.

Stage in life cycle	Duration of stage	Type of artificial environment used	Diet supplied
Fertilized egg	Less than 24 hours	Hatchery tank	None
Nauplius	Less than 2 days	Hatchery tank	None
Zoea	4-6 days	Hatchery tank	Diatoms
Mysis	3-4 days	Hatchery tank	Diatoms, brine shrimp nauplii
Early Postlarva (planktonic)	5-7 days	Hatchery tank	Diatoms, brine shrimp nauplii
Older Postlarva (benthic)	15-20 days	Hatchery tank	Diatoms, mascerated shellfish
Small juvenile	1-2 months	Nursery pond	Shellfish or artificial diet
Juvenile to market size prawn	Approx. 6 months	Growing pond	Shellfish or artificial diet