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Intensive Culture and Feed Development in *Penaeus japonicus*

Kunihiko Shigueno
Higashimaru Foods, Inc.
2-1-11 Taniyama-cho, Kagoshima City 891-01, Japan

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

Introduction

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

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

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

Intensive culture in tanks

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

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

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

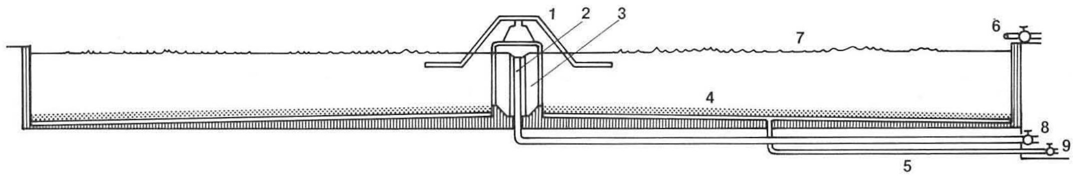

Fig. 1. Round tank (50 m diameter, 2.5 m deep) for intensive culture of *Penaeus japonicus,* side view. 1, water agitator; 2, outlet opening; 3, levelling pipe; 4, sand; 5, outlet pipe; 6, inlet pipe; 7, water level; 8, main outlet pipe; and 9, sand drain.

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

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

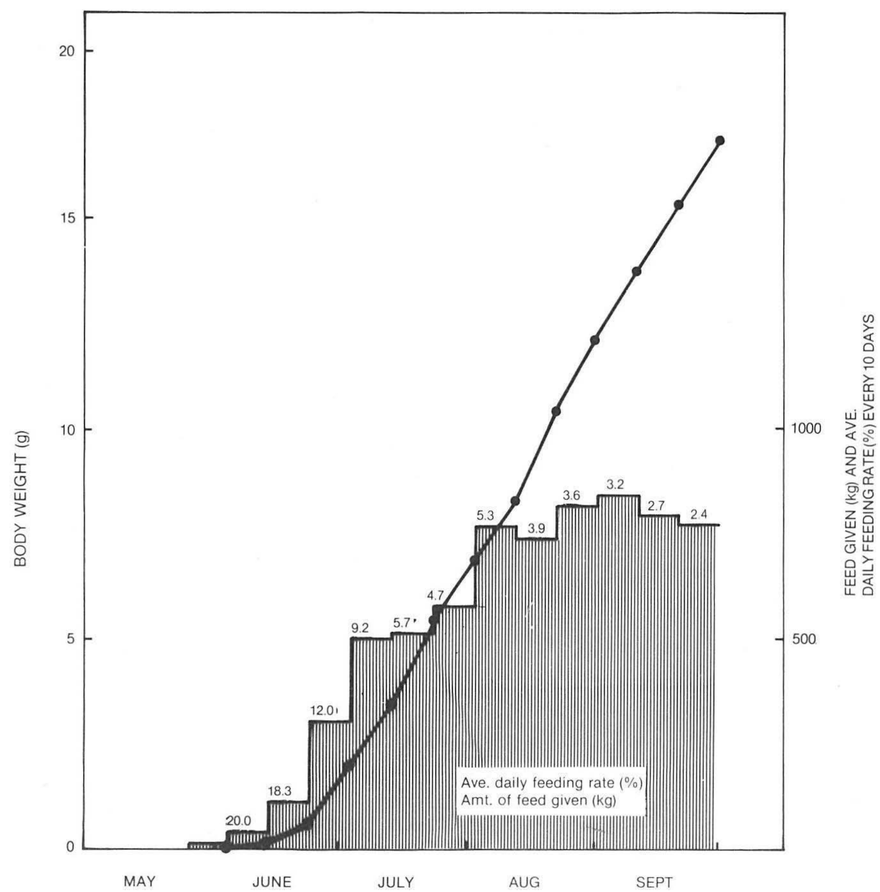

Fig. 2. Growth, amount of feed given and average % daily feeding rate (in figures) every 10 days in an intensive culture operation of *Penaeus japonicus* (1984).

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

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

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

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

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

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

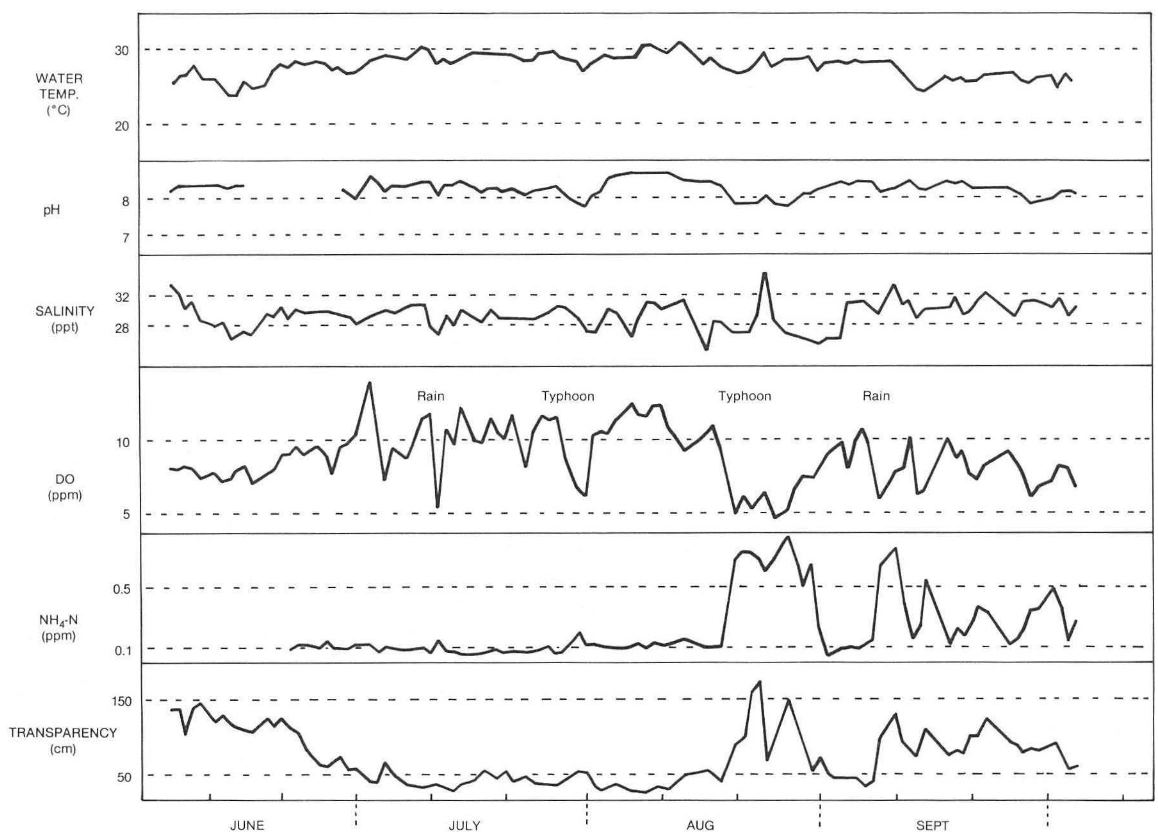

Fig. 3. Water quality (at 1500 hrs) in an intensive culture tank of *Penaeus japonicus* (1984).

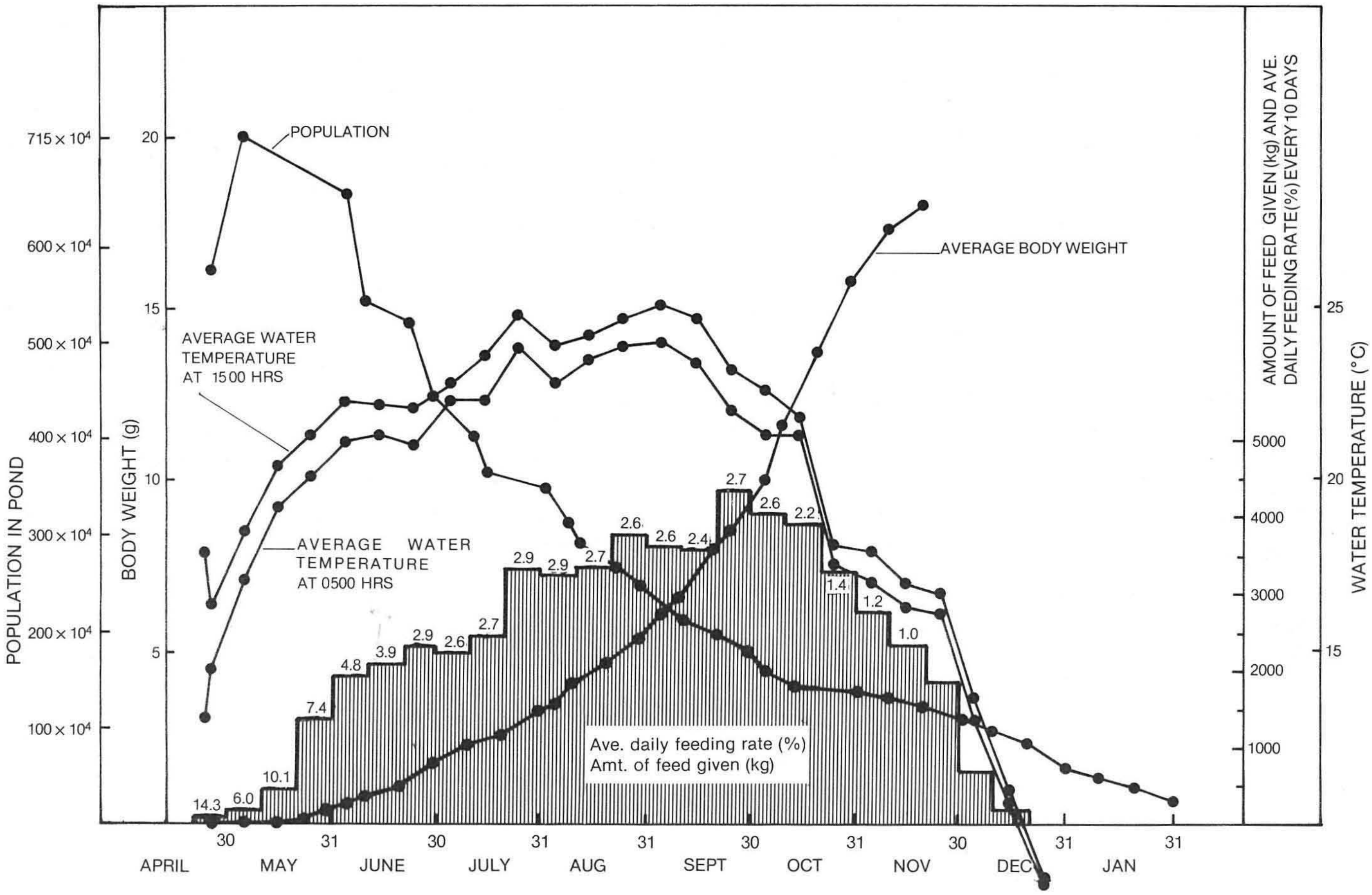

Fig. 4. Population, growth, water temperature, amount of food given, and average % daily feeding rate (in figures) every 10 days in a semi-intensive culture operation of *Penaeus japonicus* (1980). This operation was in a nursing and growing pond (pond 1, see text) of 5.09 ha with survival of 85.94%,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

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

Semi-intensive culture in earthen ponds

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

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

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

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

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

One of the four ponds was first used to nurse the post-larvae to juveniles and then was continuously used as a growing pond (pond 1). The juveniles transferred from pond 1 into newly prepared growing ponds (2-4) were raised to adult size. The remainder of the juveniles in pond 1 were kept and grown to marketable size in the same pond. Figs. 4-7 present existing shrimp population, population density, total feed given every 10 days and growth curve of shrimp in each pond. The postlarvae released from hatchery tanks into pond 1 were nursed to juveniles of around 0.6 g by the beginning of June and repeatedly transferred to growing ponds 2-4 by means of electric shockers. This was continued until October. A remarkable increase in growth of the transferred juveniles in the newly prepared growing ponds as compared with those that were retained in the nursery pond was noticed. The transfer operation ensures an accurate count of the number of existing shrimp. This is very important in determining the production schedule. Partial harvest for marketing usually starts in August. Partial harvest of small shrimp weighing 12-15 g was repeatedly done from one pond to another. It is well established that the repetition of the thinning procedure stimulates the growth of the remaining shrimp and ultimately maximizes total production. Partial harvest is followed by ordinary harvesting of adult shrimps usually by January of the next year. This shrimp farm ultimately recorded a total net production of 98 tons from 17 ha of ponds. This is equivalent to 5.79 ton/ha/year. The food conversion rate throughout the culture period for pond 1 was 1.61, whereas it varied from 2.02 to 2.64 in the three growing ponds. This is a result obtained in one of the typical successful shrimp farms in 1980.

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

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

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

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

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

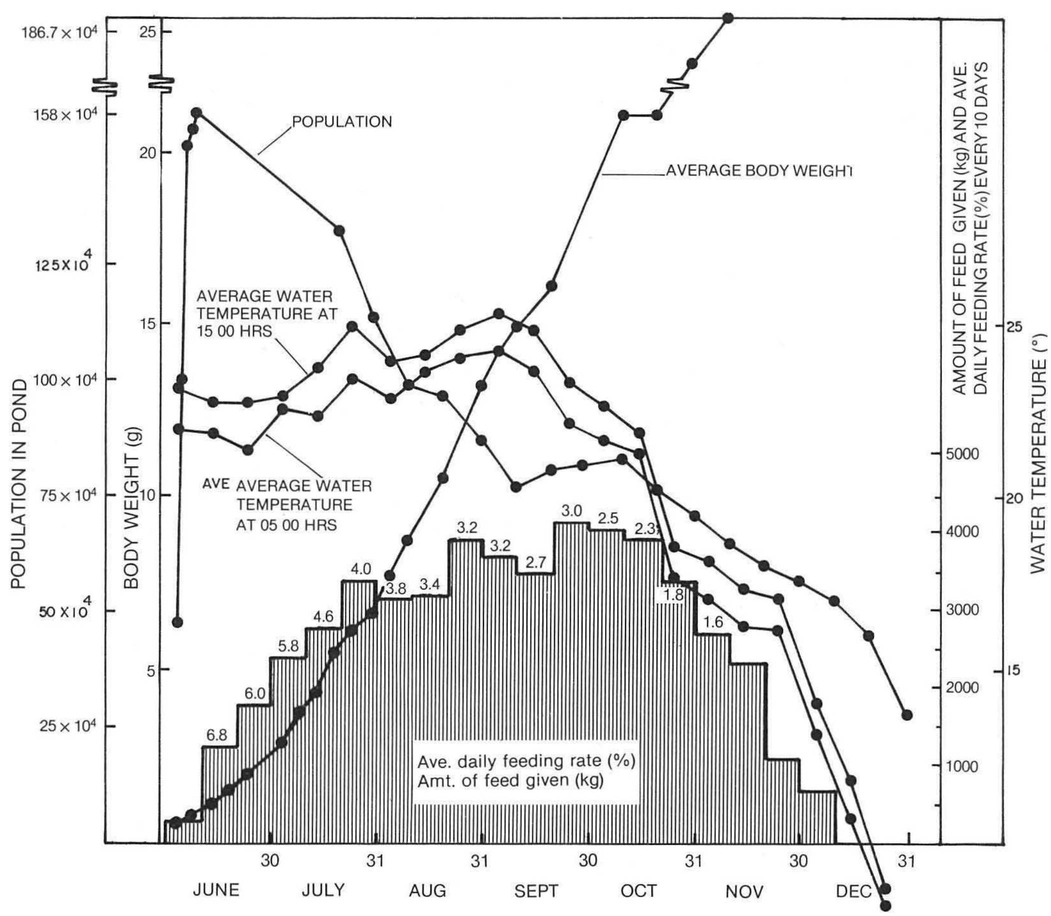

Fig. 5. Population, growth, water temperature, amount of food given, and average % daily feeding rate (in figures) every 10 days in a semi-intensive culture operation of *Penaeus japonicus* (1980). This operation was in a growing pond (pond 2) of 4.10 ha, survival of 88.56%, gross production of 28,425.8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

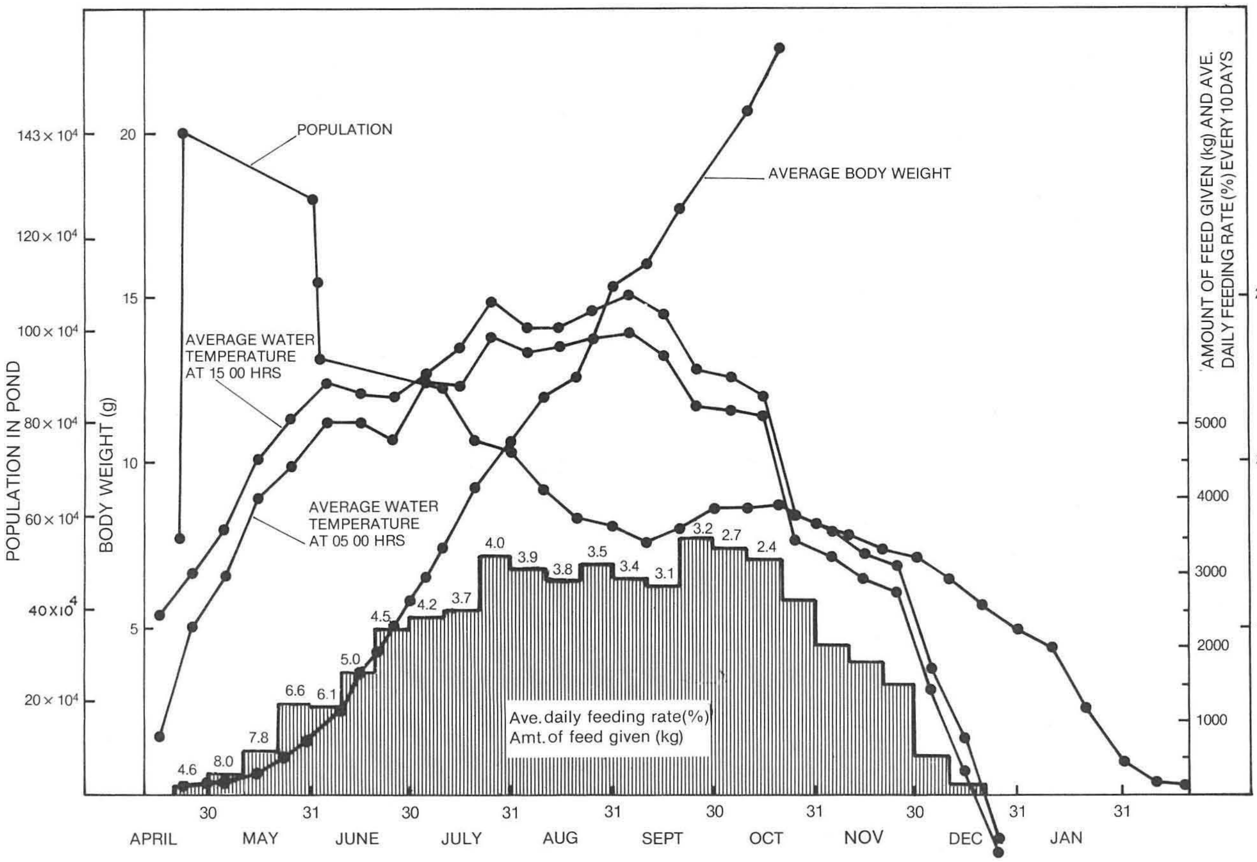

Fig. 6. Population, growth, water temperature, amount of food given, and average % daily feeding rate (in figures) every 10 days in a semi-intensive culture operation of *Penaeus japonicus* (1980). This operation was in a growing pond (pond 3) of 4.15 ha with survival of 90.24%, gross production of 29,405.9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

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

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

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

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

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

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

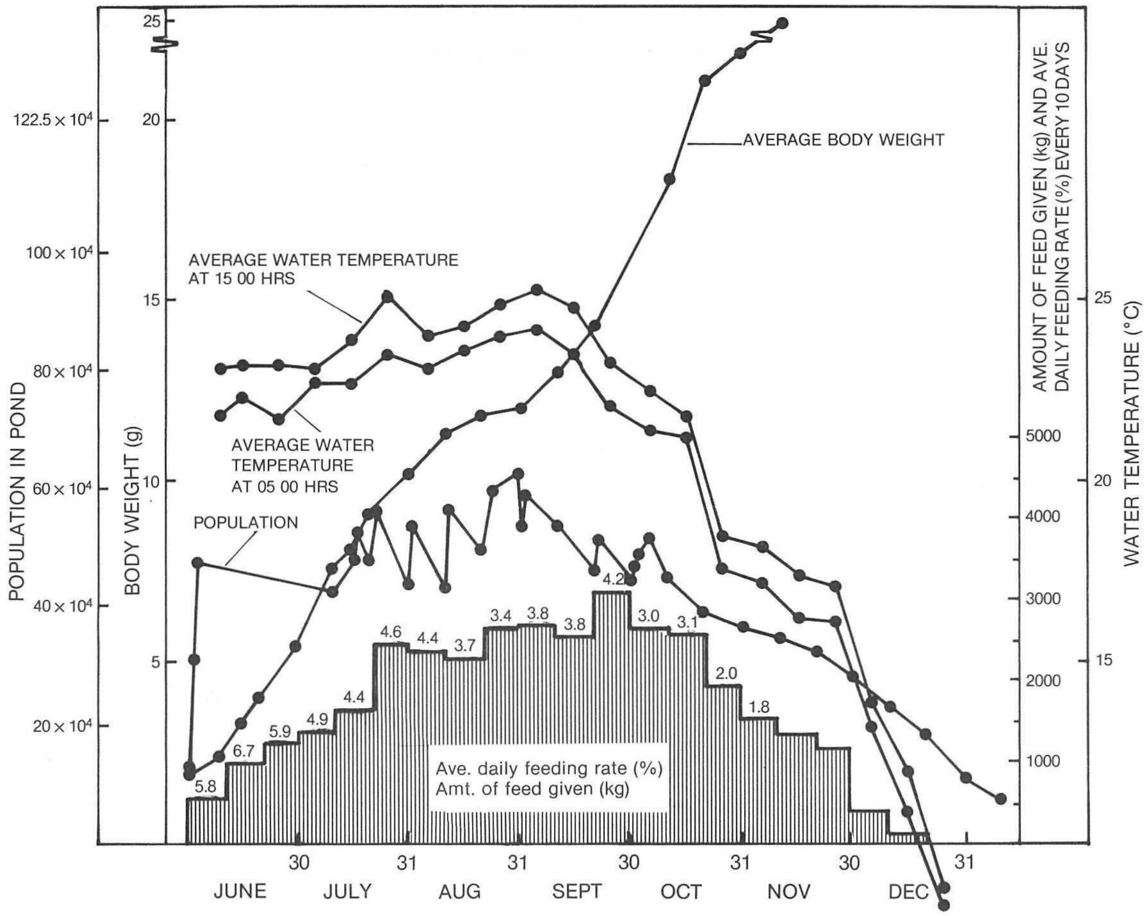

Fig. 7. Population, growth, water temperature, amount of food given and average % daily feeding rate (in figures) every 10 days in a semi-intensive culture operation of *Penaeus japonicus* (1980). This operation was in a growing pond (pond 4) of 3.68 ha, survival of 81.8%, gross production of 18,808.5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

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

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

Feed development

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

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

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

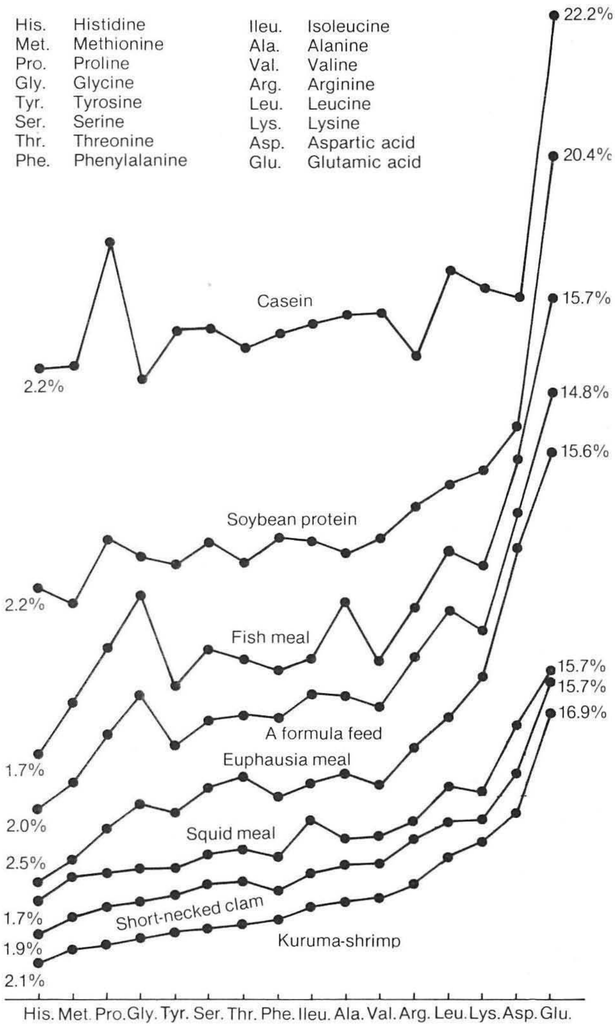

Fig. 8. Amino acid composition in eight kinds of materials and feeds relative to 16 amino acids.

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

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

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

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

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

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

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

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

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