CHAPTER III

GROWTH AND PRODUCTION OF SHRIMP

Introduction

The study of the growth of an organism is important in understanding the conditions under which optimum growth occurs. It is also important in getting an insight into the various factors that influence growth. Studies on the growth pattern of commercially important species of shrimp and of the factors that influence their growth rate are essential for the successful cultivation of shrimps.

The length-weight relations of cultured organisms is useful to culturists in estimating the number of organisms in bulk-weighed samples, in setting feeding rates based on the percentage of body weight and in determining the time of harvest of organisms of market size. Length-weight data can also be used as a basis of comparison in calculating the relative condition factor (LeCren, 1951; Swingle and Shell, 1971; Grover and Juliano, 1976). Anderson and Linder (1958), Chin (1960), Kutkuhn (1962), McCoy (1968) and Fontaine and Neal (1971) have reported on the length-weight relations of several species of penaeid shrimps in the natural populations. Hutchins et al. (1979) studied the length-weight relations of different species of shrimps in culture systems.
Lee and Shleser (1984) reported on rapid growth of shrimp in ponds fertilized with cattle manure. Some workers have, on the other hand, found a negative growth response to fertilization (Rubright et al., 1981; Garson et al., 1986). Wyban et al. (1987a) studied the growth of *P. vannamei* in manure-fertilized ponds; they reported negative correlation between stocking density and growth. Further, there was no correlation between shrimp growth and water quality. Furness and Aldrich (1979) found positive correlation between shrimp growth and pond bottom softness. They also found that there was no correlation between shrimp growth and chlorophyll-a levels, dissolved oxygen or pH. Rubright et al. (1981) attributed the increase in shrimp production in fertilized ponds with supplementary feeding to the abundant occurrence of polychaetes, copepods and nematodes. This was implicitly corroborated by Anderson et al. (1987), who showed that when natural foods are abundant, 53 to 77% of the growth of *P. vannamei* were because of grazing on pond biota, whereas 23 to 47% were due to supplementary feed.

Several workers have studied the growth rate of different species of shrimps in culture (Delmondo and Rabanal, 1956; Kubo, 1956; Poernomo, 1968; Subrahmanyam, 1973; Forster and Beard, 1974; Verghese et al., 1975; Kungvankij et al., 1976; Gundermann and Popper, 1977; Liao, 1977; Sundararajan et al., 1979; Sebastian et al., 1980; Liu and Mancebo, 1983; Chakraborti et al., 1985, 1986; Tiro et al., 1986; Chen et al., 1989a, b; Haran et al., 1992). The correlation between growth
(daily or monthly weight gain/mean final weight) and factors such as stocking density, fertilization, aeration, and salinity has been worked out by some of these workers, but they have come up with proof either in support of or against the influence of the factors on the growth of shrimps. The major general conclusion that may be deduced from the results of these studies is that, in semi-intensive monoculture systems, P. monodon reaches marketable size, with a body weight of about 30 g, in about 120 days of rearing.

Biomass increase in cultured shrimps is more or less positively correlated with survival rate, as evidenced from the results of the studies conducted by Deshimaru and Shigueno (1972), Sick et al. (1972), Sick and Andrews (1973). Other relevant contributions on this aspect have come from Gundermann and Popper (1977), Eldani and Primavera (1981), Lee et al. (1986), Sandifer et al. (1987), Wyban et al. (1987a) and Subosa (1992).

Survival rate of shrimps in culture is highly variable; from 10 to 90% (Delmondo and Rabanal, 1956; Caces-Borja and Rasalan, 1958; Eldani and Primavera, 1981; Badapanda et al., 1985; Chakraborti et al., 1986; Pillai et al., 1987; Chen et al., 1989a, b; Trino et al., 1992). On an average, the survival rate of cultured shrimps is as low as about 50%. Factors such as DO, pH, salinity changes, physiological stress, disease, pollution, transportation stress etc., are responsible for this low survival rate of shrimps. Notwithstanding this, survival rate as high as 92% (Deshimaru and Shigueno, 1972) and 100% (Subosa, 1992)
are also reported in literature. Generally, survival rate in culture systems is inversely related to stocking density (Chamberlain et al., 1981). However, several workers have reported that there is no significant correlation between stocking density and survival rate of shrimps (Garson et al., 1986; Wyban et al., 1987a; Goxe et al., 1988; Sivakami, 1988; Chen and Wang, 1990; Allan and Maguire, 1992; Hernandez-Llamas et al., 1992). As Cuzon et al. (1994) has rightly pointed out, the bearing of stocking density on the survival of shrimp is but a matter of conjecture yet.

The growth and production of farmed fish and shrimp are dependent on 40 or more essential dietary nutrients, derivable from either endoganeously produced live food organisms or exogeneously supplied artificially compounded diets (Tacon, 1993). Supplementary feed is highly necessary in shrimp culture because the natural food supply in a small pond is very inadequate to support the high density of shrimp stocked in mariculture ponds. Supplemental feed is commercially formulated in most cases to satisfy the nutritional requirements of shrimp. The importance of supplementary feed in shrimp culture systems has already been established (Sick et al., 1972; Balazs et al., 1973; Rajyalakshmi et al., 1979, 1982; Sedgewick, 1979; Ali, 1982, 1988; Liu and Mancebo, 1983; Gosh et al., 1987; Cruz-Suarez et al., 1992).

Natural diets based on Tapes philippinarum or Mytilus crassitida are successful for the culture of P. japonicus (Shigueno, 1979), but procurement of large quantities of fresh molluscs has obvious
constraints. Dietary requirements of penaeid shrimps, particularly *P. japonicus*, have been well studied by Japanese workers (Kanazawa et al., 1970, 1984; Kitabayashi et al., 1971; Deshimaru and Shigueno, 1972; Deshimaru and Yone, 1978; Deshimaru et al., 1985). In recent years, researchers in the United States have carried out nutritional studies on *P. vannamei* and *P. stylirostris* (Chamberlain and Lawrence, 1981; Wilkinson et al., 1984). Yet, only relatively little is known of the nutritional requirements of shrimps (Courtney, 1989). With a view to finding out a diet which could be used to study the nutritional requirements of shrimps, Kanazawa et al. (1970) formulated four artificial feeds and compared their effect on growth with the results of the studies on shrimps fed on fresh mollusc, *Tapes philippinarum*. These artificial diets were derived from silk worms, chinook salmon and brine shrimp. The average growth rates for all the four diets ranged from 20 to 72% of the growth rate of shrimps fed the short-necked clam, *T. philippinarum*.

Protein requirements not only differ between penaeid species, but also within species, at different stages of development. Post-larvae appear to require more protein than juveniles and juveniles require more protein than the older stages (Bhaskar and Ali, 1981). Bages and Sloane (1981) have found that the growth of post-larvae of *P. monodon* was proportional to the level of protein in the diet (ranging from 25 to 55%). Smith et al. (1985) concluded that small *P. vannamei* appeared to be more influenced by protein level in the diet, whereas growth of
medium-sized and large *P. vannamei* appeared to be more influenced by
the protein source.

Protein being the most important ingredient in formulated diets, there has been much interest in ensuring its correct proportion in manufactured feeds. Although there is a lot known of the optimum protein levels and growth rates of penaeids, Wickins (1976a) pointed out that comparisons cannot be made because of the differences in the source of proteins used. It is generally accepted that dietary proteins with an aminoacid composition similar to that of the shrimp are of better nutritional value (Deshimaru and Shigueno, 1972; Wickins, 1976a; Tseng and Cheng, 1981). In a feeding experiment on *P. japonicus*, Deshimaru and Shigueno (1972) found that the highest growth rate was achieved with shrimp fed on short-necked clam, *Tapes philippinarum*, and also that this food had the greatest similarity, both in the quantity and profile of aminoacids, with those in brown shrimp.

Food conversion of shrimps is a fairly well studied area in shrimp culture. The early grow out trials carried out in the mid 1960s in Japan on *P. japonicus* yielded feed conversion ratios in the order of 12 : 1, with feed combinations of clam, fish and non-commercial red shrimps (Shigueno, 1979). In earlier experiments juveniles yielded feed conversions of about 5 : 1. Deshimaru and Shigueno (1972) showed that younger *P. japonicus* were more efficient feeders than the older. Smith *et al.* (1985) found that younger shrimps grew at a faster rate than older ones. Not only do the younger shrimps utilise food more
efficiently, but their higher growth rate demands that they also feed more frequently than older shrimps.

Compounded diets, presented in different forms (gels, pastes, steam-compressed pellets, flakes, capsules, and dried, spaghetti-like extrusions), are acceptable to shrimp (New, 1976).

A perusal of the literature revealed that a fairly large quantum of information is available on the various aspects of the biology and culture of the common penaeid shrimps of India. But, quite noticeably, information on the growth of shrimps in field conditions is much restricted and is based mainly on length frequency studies. Information on the combined effect of fertilization and supplementary feeding on shrimp growth in semi-intensive systems is also scant, except that from the preliminary studies by Rajyalakshmi et al. (1982), Chakraborti et al. (1986), Pillai et al. (1987), Chakrabarti and Das (1988), Sivakami (1988) and Haran et al. (1992). This chapter deals with the results of the studies on the growth of P. monodon, in fertilized farming systems of Kerala, fed three different supplementary feeds: clam meat, compounded feed (dough ball) and farm-made pelleted feed.

Materials and Methods

It was practically impossible to procure post-larvae for length and weight measurements at the time of stocking. To circumvent this, 120 P. monodon post-larvae (PL20) were collected from a hatchery and
their mean length and weight were determined. These were reckoned as the size at stocking for all culture operations. On the 30th day of stocking, and thereafter, after every 15 days, specimens were collected from the ponds with small-meshed (ca. 5 mm) castnet; 40 specimens were collected at random and placed in a plastic bucket or basin containing pond water. Average length and weight after blotting off as much water from the shell as possible, were found out. All live specimens were returned to the ponds after the measurements.

The average growth (average weight at harvest), and the average production in relation to the stocking density, survival rate and three different feed types (clam meat alone, clam meat + dough ball and pelleted feed) were estimated. The other relevant parameters analysed are the following.

1. Average daily weight/length gain

\[
\text{Average daily weight gain} = \frac{W_f - W_i}{d} \text{ g/day}
\]

where, \( W_f \) = average final weight (g)

\( W_i \) = average initial weight (g)

\( d \) = length of the culture period (days)

\[
\text{Average daily length gain} = \frac{L_f - L_i}{d} \text{ cm/day}
\]

where, \( L_f \) = average final length (cm)

\( L_i \) = average initial length (cm)

\( d \) = length of the culture period (days)
2. Instantaneous growth

It was calculated by using the following formula, as suggested by Hopkins (1992).

\[ G = \frac{(\ln W_t - \ln W_0)}{t} \]

where,  
\( G \) = instantaneous growth  
\( \ln W_t \) = natural logarithm of the weight at time \( t \) and  
\( \ln W_0 \) = natural logarithm of the initial weight

3. Biomass increase per day (g/m²/day)

Biomass increase per day was calculated following New (1976), as

\[ \frac{c}{x} \]

where,  
\( c \) = biomass increase (g/m²) and  
\( x \) = length of the culture period (days)

\[ c = \frac{a z y}{100} - b z \]

where,  
\( a \) = average final weight (g)  
\( z \) = initial stocking density (No./m²)  
\( y \) = survival rate (%)  
\( b \) = average initial weight (g)

4. Apparent Feed Conversion Ratio (AFCR)*

AFCR was estimated by using the following formula (New, 1987).

\[ \text{AFCR} = \frac{\text{Total amount of feed given (kg dry wt.)}}{\text{Total production (kg wet wt. of heads on shrimps)}} \]

* According to New (1987), feed conversion ratio under natural and farming conditions is more appropriately designated as Apparent Feed Conversion Ratio (AFCR), rather than Feed Conversion Ratio (FCR), to indicate the interference of natural foods. Some of the earlier workers who have actually determined the AFCR in their studies, have inadvertently designated it as FCR in their publications. In this text, on all such occasions including those in previous works cited herein, the usage AFCR is adopted.
(The ratio of wet weight to dry weight of fresh clam meat was 4 : 1, and of dough ball, 2 : 1)

5. Feed Conversion Efficiency (FCE)

FCE was calculated by using the formula suggested by New (1987)

\[
FCE = \frac{\text{Total production (wet wt. of heads-on shrimps)}}{\text{Total amount of feed given (kg dry wt.)}}
\]

6. Survival Rate

The mean shrimp weight at harvest was determined from a random sample of 40 shrimps. Survival rate was then calculated by using the following formula (Rubright et al., 1981)

\[
s = \frac{h}{gb} \times 100
\]

where,  
- \( s \) = survival rate (%)  
- \( h \) = total harvest (g)  
- \( g \) = mean weight of shrimp (g) at harvest and  
- \( b \) = initial number stocked

Correlations of average final weight, biomass increase per day and average total production with stocking density and survival rate, were analysed by simple linear correlation analysis. Bearing of feed types on the final weight and total production was analysed employing one-way ANOVA. When in this analysis, ANOVA implied significant difference, Newman-Keuls multiple range test (SNK) was done to find out which of the three treatments (feed types) was significantly different from the others in realising better final weight/production.
Length-weight relation of shrimp in relation to the three feed types were worked out by using the simple linear regression. Significant differences if any, between the regression lines were tested by analysis of covariance procedure. For length-weight studies, the linear form of the relation \( W \propto L^n \) was used.

\[
\log W = \log a + n \log L
\]

where \( W \) = weight (g), \( L \) = length (cm) and \( a \) and \( n \) = calculated constants. Relevant statistical methods were adopted from Zar (1974).

The protein, fat and carbohydrate contents of the three feeds were estimated based on the methods of AOAC (1975). From these results the gross energy and the protein to energy ratio (P/E ratio) were computed following the procedure suggested by ADCP (1983).

Results

The overall results of the study on shrimp culture in 36 culture operations during 1991-92, each extending for 120 days, in three ponds each from Pallithode in Alleppey district and Chellanam and Kannamaly in Ernakulam district are consolidated in Table 7. The mean length of PL 20 at stocking was 1.40 cm and the mean weight, 0.060g

General Features

The stocking density ranged from 4 to 10 PL/m\(^2\) (mean = 6.31 PL/m\(^2\)). The average survival rate was 50.21% (range: 38-58%). The shrimps registered a mean final length of 15.10 cm and a mean final
weight of 30.23 g. Average final length ranged from 14.20 to 16.40 cm and final weight, from 26 to 34 g. The mean length gain per day was 0.128 cm and the mean daily weight gain, 0.252 g. Biomass increase per day registered a mean of 0.795 g/m²/day (range: 0.478–1.275 g/m²/day). The total production in the 36 ponds ranged from 560 to 1,536 kg/ha, with an average of 959.20 kg/ha.

The survival rate and the average final weight were not correlated with stocking density. But, biomass increase per day (r = 0.884; P < 0.001) and total production (r = 0.459; P < 0.01) registered significant positive correlation with stocking density. The average final weight of shrimps was not correlated with survival rate. Similarly, total production also was not correlated with survival rate.

Culture Operation in the Three Regions

As noticeable from Table 4, the major difference in the culture operations in the three regions was in regard to the supplementary feed. In each region, two types of feed were used: fresh clam meat (F1) and clam meat + dough ball (F2) in Chellanam and Kannamaly and fresh clam meat and pelleted feed (F3) in Pallithode. In Pallithode, for eight culture operations fresh clam meat and for four, pelleted feed were used. In Chellanam fresh clam meat was used for four cultures and clam meat + dough ball for the remaining eight cultures. In Kannamaly clam meat + dough ball was used in four cultures, whereas fresh clam meat was used for the rest eight cultures. In spite of the said difference, the average final weight, biomass increase per day and the
total production of the three regions did not show any significant differences.

Feed Types and Growth of Shrimps

The three feeds used for the culture operations had the following composition.

Feed - 1 : Fresh meat of *Vellorita cyprenoides* var. *cochinensis*

Feed - 2 : Feed-1 + Dough ball

Composition of the dough ball was the following.

<table>
<thead>
<tr>
<th>Ingredients</th>
<th>Parts per hundred</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground nut oil cake</td>
<td>45</td>
</tr>
<tr>
<td>Wheat flour</td>
<td>25</td>
</tr>
<tr>
<td>Rice bran</td>
<td>20</td>
</tr>
<tr>
<td>Tapioca flour</td>
<td>10</td>
</tr>
<tr>
<td>Fish oil</td>
<td>2 ml/kg</td>
</tr>
</tbody>
</table>

All the ingredients, except fish oil, were mixed thoroughly and cooked well in an aluminium container. After cooling, fish oil was added and mixed well.

Feed - 3 : Pelleted feed

This feed contained the following ingredients.
Ingredients | Parts per hundred
---|---
Squilla powder | 54
Rice bran | 10
Shrimp head waste | 10
Ground nut oil cake | 10
Wheat flour | 10
Tapioca flour | 5
Vitamin mix + mineral mix | 1
Cod liver oil | 2 ml/kg
Palm oil | 2 ml/kg

All the ingredients, except oils and vitamin mix were ground and mixed in a mixer/mincer machine and steam cooked. After cooling, oils and vitamin mix were added and mixed well. The mixture was pelleted with a hand pelletiser. The pellets were sun-dried to less than 10% moisture.

The quantity of the feeds used in the culture operations is shown in Table 8. Feed-1 (clam meat alone) was fed at 8-10% body weight/day. In Feed-2 clam meat and dough ball were mixed in proportions ranging from about 1:1 to 8:1 and fed at 5-6% body weight/day. Pelleted feed (Feed-3) was given at 3-4% body weight/day. The exact feeding schedule was as described earlier (page 15; Chapter I).

The protein, fat and carbohydrate contents of the three feed types are given in Table 9. The nutritional indices of the three feeding systems are shown in Table 10.
Apparent feed conversion ratio for Feed-1 ranged from 1.49 to 2.55 (mean = 1.70) in the 20 culture operations in which it was used. AFCR of Feed-2 ranged from 1.29 to 2.62 (mean = 1.59; in eight cultures) and of Feed-3 ranged from 1.52 to 1.56 (mean = 1.55; in four cultures) (Table 8). The AFCRs of the three feed types did not differ significantly. The growth of shrimp (g body wt. vs days of culture) achieved with the three feed types is shown in Table 11; Fig. 11. As noticeable from the results, with pelleted feed the growth was greater than with the other two feeds; with Feed-1 and Feed-2, the growth was more or less the same.

The mean total production with the three feed types did not differ significantly. Biomass increase/day was also not significantly influenced by the feed types. However, the final average weight of shrimps for the three feed types differed significantly ($F = 3.817; P < 0.05$). SNK multiple range test (modified for unequal group sizes; Zar, 1974) to test the differences between mean final weight of shrimps with the three feed types gave the following results.
Feed type

<table>
<thead>
<tr>
<th></th>
<th>F1</th>
<th>F2</th>
<th>F3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean final body weight (g)</td>
<td>30.00</td>
<td>30.18</td>
<td>31.60</td>
</tr>
<tr>
<td>Rank of means</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

Comparison | Difference in mean | SE  | q  | p  | q  | Conclusion |
-----------|-------------------|-----|----|----|----|------------|
3 vs 1     | 1.60              | 0.4117 | 3.886 | 3 | 3.566 | \( \mu_3 \neq \mu_1 \) |
3 vs 2     | 1.42              | 0.4367 | 3.252 | 2 | 2.942 | \( \mu_3 \neq \mu_2 \) |
2 vs 1     | 0.18              | 0.3255 | 0.553 | 2 | 2.942 | \( \mu_2 = \mu_1 \) |

Overall conclusion: \( \mu_1 = \mu_2 \neq \mu_3 \)

i.e., mean final weight with feed types F1, F2 and F3 \( F_1 = F_2 \neq F_3 \)

The results show that with pelleted feed (F3) a higher mean final weight of shrimp is possible or that pelleted feed is superior to both fresh clam meat (F1) and clam meat + dough ball (F2) in realising growth of shrimps.

Length-weight Relations of Shrimps

The length-weight relations of shrimps raised using the three feed types were worked out (simple linear regression analysis; \( \log W = \log a + n \log L \)).

Fresh clam meat was used in all the three regions studied and hence, the length-weight relations of shrimps fed this feed were worked out for the three regions separately. The regression equations derived are the following.
Pallithode: $\log W = \log 0.0332 + 2.4573 \log L$ (t = 36.833; P < 0.001)
Chellanam: $\log W = \log 0.0183 + 2.7172 \log L$ (t = 38.253; P < 0.001)
Kannamaly: $\log W = \log 0.0061 + 3.0311 \log L$ (t = 21.940; P < 0.001)

The slopes of the three regression lines differed significantly (analysis of covariance: $F = 7.604; P < 0.001$). The results of multiple range test (SNK) showed that the length-weight relations of shrimps fed clam meat alone in the three regions were significantly different from each other.

Fresh clam meat + dough ball was used both in Chellanam and Kannamaly. The regression equations derived for these two regions are the following,
Chellanam: $\log W = \log 0.0216 + 2.6531 \log L$ (t = 56.242; P < 0.001)
Kannamaly: $\log W = \log 0.0040 + 3.2234 \log L$ (t = 14.902; P < 0.001)
The slopes of these two regression lines were significantly different ($F = 2665.879; P < 0.001$).

Pelleted feed was used in Pallithode only. The length-weight relation of shrimps fed this feed is,

$\log W = \log 0.0159 + 2.7664 \log L$ (t = 44.322; P < 0.001)

In all the foregoing six cases, the dependence of weight on length was statistically highly significant.

Since three different supplementary feeds were used by the shrimp farmers, an attempt was made to study the length-weight relations of shrimps fed the three feeds, ignoring the regional differences within the treatments (feed types). Multiple range test (SNK) revealed that
the slopes of the three population regression lines were similar; their elevations were also not significantly different. Since the three regression lines were coincident, the common or weighted regression coefficient \( b_c \) was calculated; \( b_c = 2.7387 \).

If the regional differences in the length–weight relations within the feed types are ignored, the common regression equation for the length–weight relation of the shrimps cultured in the small-scale, semi-intensive, monoculture systems of Kerala is,

\[
\log W = \log 0.0154 + 2.7399 \log L \quad (t = 53.586; P < 0.001)
\]

This relation is illustrated in Fig. 12.

The 95% confidence interval for the regression coefficient was 2.7399 ± 0.1006 and the standard error for the Y intercept was, \( \log 0.0154 ± \log 0.0523 \).
<table>
<thead>
<tr>
<th>Region</th>
<th>Pond number</th>
<th>Culture number/year</th>
<th>Average initial length (cm)</th>
<th>Average length gain (cm)</th>
<th>Average weight (g)</th>
<th>Average daily weight gain (g)</th>
<th>Instantaneous growth (%/d)</th>
<th>Stocking rate (kg/ha)</th>
<th>Survival rate (%)</th>
<th>Biomass increase per day (g)</th>
<th>Production per ha (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P = Pallithode</td>
<td>1/91</td>
<td>16.20</td>
<td>14.80</td>
<td>0.135</td>
<td>32.00</td>
<td>31.94</td>
<td>0.266</td>
<td>0.052</td>
<td>6.00</td>
<td>40.00</td>
<td>37.44</td>
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<td>1/95</td>
<td>15.60</td>
<td>14.20</td>
<td>0.130</td>
<td>30.00</td>
<td>29.94</td>
<td>0.250</td>
<td>0.052</td>
<td>10.00</td>
<td>38.00</td>
<td>31.92</td>
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<tr>
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<td>0.137</td>
<td>30.40</td>
<td>30.34</td>
<td>0.253</td>
<td>0.052</td>
<td>10.00</td>
<td>38.00</td>
<td>31.92</td>
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<tr>
<td>C = Chellanan</td>
<td>1/91</td>
<td>15.20</td>
<td>13.80</td>
<td>0.127</td>
<td>30.00</td>
<td>29.94</td>
<td>0.250</td>
<td>0.052</td>
<td>5.00</td>
<td>45.00</td>
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<tr>
<td>K = Kannanal</td>
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<td>29.94</td>
<td>0.250</td>
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<td>5.00</td>
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<td>45.00</td>
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<td>0.130</td>
<td>30.00</td>
<td>29.94</td>
<td>0.250</td>
<td>0.052</td>
<td>4.00</td>
<td>40.00</td>
<td>37.36</td>
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TABLE I

<table>
<thead>
<tr>
<th>Region, Pond number, Culture number/year</th>
</tr>
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<tbody>
<tr>
<td>P = Pallithode; C = Chellanan; K = Kannanal</td>
</tr>
<tr>
<td>F1 = Clam meat; F2 = Clam meat + Dough ball; F3 = Pelleted feed</td>
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### TABLE 8

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Feed type</th>
<th>Feed type (wet weight-kg)</th>
<th>Total dry weight (kg/ha)</th>
<th>Production (kg/ha)</th>
<th>AFCR</th>
<th>FCE</th>
<th>Culture number</th>
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<td>Clam meat + Dough ball</td>
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</tr>
<tr>
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<td>1.55</td>
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TABLE 9

The protein, fat and carbohydrate contents (%) of the three feed types

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<th>Feed type</th>
<th>Protein</th>
<th>Fat</th>
<th>Carbohydrate</th>
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<td>52.60</td>
<td>10.63</td>
<td>28.46</td>
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<tr>
<td>Clam meat + *</td>
<td>40.75-49.79</td>
<td>8.61-10.17</td>
<td>25.47-27.77</td>
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<tr>
<td>Dough ball</td>
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<td></td>
<td></td>
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<tr>
<td>Pelleted feed</td>
<td>35.27</td>
<td>6.79</td>
<td>9.79</td>
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</table>

* Represent values for clam meat to dough ball ratios ranging 1 : 1 to 8 : 1
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<th>Indices</th>
<th>Feed types</th>
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<td>Crude protein (%)</td>
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<td>Gross energy * (kcal/100g feed)</td>
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<td>P/E ratio # (mg protein/kcal)</td>
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<tr>
<td>AFCR</td>
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<tr>
<td>FCE</td>
<td>59.40</td>
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</table>

* Calculated based on 4.1 kcal/g for carbohydrates, 9.1 kcal/g for fat and 5.5 kcal/g for protein (ADCP 1983)

# Protein to energy ratio

@ Represent values for clam meat + dough ball ratios ranging 1:1 to 8:1
<table>
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<td>Weight</td>
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<tr>
<td>Weight</td>
<td>2.03</td>
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</table>

### Table 11

Mean length (cm) and weight (g) of shrimps raised using three different feed types, at 15 days interval from 30 days post-stocking.
Fig. 11 Mean final weight of tiger shrimps fed the three feed types—clam meat alone, clam meat + compounded feed (dough ball) and pelleted feed—at 15 days interval from 30 days post-stocking to end of culture period (120 days)

(mean weight of PL 20 at stocking = 0.060 g)
Fig. 11

- Clam meat
- Pelleted feed

Days Post-stocking: 0, 5, 10, 15, 20, 25, 30

Weight (g): 35, 30, 25, 20, 15, 10, 5, 0
Fig. 12 Regression line showing the length–weight relation of tiger shrimp in small-scale, semi-intensive, monoculture systems on the backwaters of Kerala State
Fig. 12

\[ \log W = \log 0.0154 + 2.799 + \log L \]
Discussion

It is well documented that *Penaeus monodon* and *P. japonicus* can be cultured at high densities (Liao, 1977; Liu and Mancebo, 1983; Shigueno, 1985). However, various factors such as salinity, temperature, oxygen, food supply, disease, physiological stress, density of population and consequent availability of space for individuals and competition for the same ecological resources, all influence the growth of shrimps.

Sriraman et al. (1989) reported that the growth rate of *P. monodon* is high; this shrimp attains larger size in culture systems than in natural conditions. For this species, Subrahmanyan (1973) reported a growth rate of 25 to 30 mm/month in the natural conditions and 5 to 26 mm/month in aquaria and tanks. Forster and Beard (1974) reported fast growth rates for *P. monodon* and *P. orientalis*; at low stocking density they reach the mean live weights of 25.43 and 22.80 g, respectively, in 16 weeks rearing. These workers concluded that "both species grew very quickly, and at the low stocking density, reached an acceptable market size within eight weeks from an initial weight of 150 mg."

In the present study, the average daily increment in length was 1.28 mm and in weight, 0.252 g at an average stocking density of 6.31 PL/m². Gundermann and Popper (1977) reported a growth rate of 0.300 g/day for *P. monodon*, which is slightly higher than that obtained in the present study. The stocking density was low in the former study (1.5 PL/m²) and that might be the reason for the higher growth rate.
Sundararajan *et al.* (1979) also reported high growth rate for tiger shrimp (1.59 mm/day; 0.390 g/day), and an average weight of 32.26 g in 80 days rearing. Here the stocking density was as low as 20,000/ha (= 0.2/m²) and the ponds were fertilized with urea and superphosphate. Sebastian *et al.* (1980) observed an average growth rate of 38.4 mm/month at a stocking density of 7,000/ha. The growth rate observed by Sundararajan *et al.* (1979) in the salinity range of 10.9 to 22.4 ppt was 47.7 mm/month. The average growth rates reported by Delmondo and Rabanal (1956), Kubo (1956), Poernomo (1968) and Verghese *et al.* (1975) vary between 13.8 and 17.5 mm/month. Chakraborti *et al.* (1986) observed steady growth of *P. monodon* for the first two months of rearing, as also the occurrence of two size groups at the end of this period. With formulated feed and a stocking density of 1.58 shrimps/m² (*P. monodon*), and with paddle wheel aerators and water exchange, Liu and Mancebo (1983) obtained an average final weight of 31.4 g after 106 days rearing. In the present study, the final average weights after 120 days rearing without aeration, but with three different feeds were, 30.00 g (clam meat), 30.18 g (clam meat + dough ball) and 31.60 g (pelleted feed). As observed in the present study, an average harvest weight between 30-32 g in 120 days culture with supplemental feeding, for this species is reported by several workers (Kungvankij *et al.*, 1976; Liao, 1977; Liu and Mancebo, 1983; Tiro *et al.*, 1986).
For *P. monodon*, Sebastian et al. (1980) reported very fast growth rate during the first 30 days of rearing. Chakraborti et al. (1986) noted a fall in growth rate after two months. Pillai et al. (1987) also reported on fast growth of *P. monodon* in the early period of culture. AQUACOP (1984) reported that *P. monodon* grows slowly up to 3-4 g body weight and thereafter at an accelerated rate. Gundermann and Popper (1977) also observed very slow growth in the earlier days (first 40 days) of culture for *P. monodon*; the growth rate was maximum between 70 and 120 days. Chen et al. (1989a) reported that the growth rate of *P. monodon* was the fastest from 94 mm to 161 mm and the slowest thereafter. The present results are in agreement with those of AQUACOP, Gundermann and Popper and Chen et al., mentioned above: here the growth rate was fast after about 60 days of rearing (ca. 9-10 cm length; 5-6 g weight), till 120 days.

In 1992, Haran and coworkers reported that the growth of *P. monodon* in semi-intensive systems in Andhra Pradesh, is about 25 g in 120 days rearing, with Hanaqua feed and paddle wheel aerators; the mean stocking density was 26-28 shrimps/m². In comparison, the standard growth rate of *P. monodon* fed Hanaqua feed is 29.0 g in 120 days. In the present study, the growth of *P. monodon* was 30 g, or a little more, in 120 days.

Even though some studies suggest that shrimp growth is inversely related to stocking density, there was no evidence in the present study to corroborate this, as also reported by AQUACOP (1984) and Wyban et
al. (1987a). The high growth rate obtained in the present study may be because of the combined effect of feed and fertilizer applied to the culture system. The addition of phosphorus and nitrogen to aquatic systems increases phytoplankton populations (Boyd, 1979). Benthic microbial activity increases in response to sedimentation of phytoplankton blooms, and benthic biomass is capable of doubling because of increased microbial production (Graf et al., 1982). Research done in Israel with organic fertilizers in fish culture may have application to shrimp culture. This research has shown that increased production of the microbial community which utilises manure and organic matter, greatly enhances fish growth in earthen ponds (Schroeder, 1978). An increase in the benthic biomass would likewise be expected to increase shrimp production. The application of fertilizer in shrimp grow-out ponds is to stimulate phytoplankton production. This increase in primary production, propagating through the trophic chain, leads to an increase in the food available for shrimps and, therefore, it supports a greater crustacean biomass.

Rubright et al. (1981) attributed the increase in shrimp production in ponds in which fertilizers and feed are added, to the abundant occurrence of polychaetes, copepods and nematodes. This was implicitly corroborated by Anderson et al. (1987), who showed that, when natural foods are abundant, 53 to 77% of the growth of P. vannamei are due to grazing on pond biota, whereas 23 to 47% were contributed by the feed added. Crustaceans, polychaetes and nematodes are the main
diet of *Penaeus* species (Wassenberg and Hill, 1987) and their importance as nutritious food sources for marine invertebrates, from a standpoint of energy, protein and essential nutrient requirements, was pointed out by Phillips (1984). The usefulness of fertilization in fish/shrimp culture systems is its beneficial effects on autotrophic and heterotrophic productivity and on the detrital cycle (Buck et al., 1981; Rubright et al., 1981; Wohlfarth et al., 1985).

Deshimaru and Shigueno (1972) reported a total biomass increase of 897.60 g/m² for 60 days at the rate of 14.96 g/m²/day for *P. japonicus*, at a stocking density of 17 shrimps/m² and 92% survival. Sick et al. (1972) for *P. setiferus* reported 47.4 g/m² (0.680 g/m²/day) as biomass increase at a stocking rate of 12.7 shrimps/m² and a survival of 83%. Sick and Andrews (1973) observed 77.2 g/m² as biomass increase (0.920 g/m²/day) for *P. duorarum* at 23.6 shrimps/m² stocking density and 87% survival. In the present study the mean biomass increase was 95.33 g/m² for 120 days at the rate of 0.795 g/m²/day at an average stocking density of 6.31 shrimps/m² and a survival rate of 50.21%.

Gundermann and Popper (1977) reported a biomass increase of 603.8 g/day/ha for *P. monodon* in a polyculture system with fertilizer alone (at a stocking density of 0.75 shrimps/m² and a survival of 90%). Eldani and Primavera (1981) reported a biomass increase of 2.34 kg/ha/day, in monoculture of tiger shrimp, with fertilizer alone and 2,000 shrimps/ha stocking density. With chicken manure fertilizer and
with 100% survival, a biomass increase of 1.18 kg/ha/day for this species is reported by Subosa (1992). In the present study the biomass increase was higher than that obtained in any of these studies. The high biomass increase may be due to the high stocking density (and probably because of the addition of fertilizers and supplementary feed). A significant positive correlation ($r = 0.884$, $P < 0.001$) between stocking density and biomass increase per day was observed in this study. Similar results are reported for *P. vannamei* by Lee et al. (1986), Sandifer et al. (1987) and Wyban et al. (1987a).

The survival rate of shrimps in the present study varied between 38% and 58% (mean = 50.21%). A survival rate of 50%, even though comparatively low, is consistent with figures reported in commercial shrimp culture. Shrimps grown in brackishwater ponds in Philippines have a survival rate of 10–50% (Delmondo and Rabanal, 1956) and 20% (Caces-Borja and Rasalan, 1958; Eldani and Primavera, 1981) after of 5–8 months rearing. In monoculture of tiger shrimp, Badapanda et al. (1985) obtained 32.7%, Chakraborti et al. (1985), 25.8% in nursery ponds, and Pillai et al. (1987), 34.6%. Chakraborti et al. (1986) obtained 25.2% to 33% survival at a stocking rate of 4 PL/m$^2$ and Chen et al. (1989a) observed a survival rate of 40–67.7% in highly intensive systems (124 to 143 PL/m$^2$). Trino et al. (1992) obtained 51.4% to 73.6% survival in feed and fertilized systems.

The exact reason for this low survival rate is still a matter of speculation. Wickins (1976b) reported that shrimps are stressed when
dissolved oxygen falls below 2.0 ppm. The same author reported that *P. monodon* post-larvae are however, unaffected by a pH as low as 6.45. It seems that adverse dissolved oxygen or pH were not the reasons for the low survival rate noted in the present study, in which both these parameters were well within the tolerance limits. It is not known whether shrimps were already weakened by diseases or physiological malfunction, or, if otherwise healthy, succumbed to the aggressiveness of their fellows in the crowded conditions.

It is reported that survival of *P. monodon* post-larvae is directly influenced by the organic content and dissolved oxygen in the water. The detrimental effects of organic pollution are high BOD, low dissolved oxygen, high ammonia and NO$_2$-N. At sublethal levels, a combination of these adverse environmental conditions can induce stress and result in decreased survival (Millamena, 1990). In the present study mortality was high in the larval stages. As the shrimp post-larvae were mostly transported from other States, transportation stress (combined with the other stress factors stated above) might have induced high mortality. From Andhra Pradesh and Orissa hatcheries, shrimp post-larvae are packed at a density of 3,000/5 litres (one packet). An average 36 h transportation time is required for bringing the larvae to the culture site. It should be evaluated whether this packing density is safe enough for the shrimp larvae to withstand the long transportation time.
Another reason for high mortality could be the salinity change. High mortality and poor growth rates of *P. monodon* juveniles occur at salinities lower than 10 ppt (Cawthorne *et al.*, 1983). Some workers have reported that *P. monodon* larvae survived and grew well at lower salinities (Musig and Rutthanasrigit, 1982). Moulting at extremely high or low salinities requires more time and this renders shrimps more vulnerable to predation (where predators are inadvertently introduced in the culture ponds) and cannibalism, and prolongs their inability to forage for food (Chien, 1993). Rapid changes in salinity also usually cause high mortality of *P. monodon* (Tseng, 1987). Transferring shrimp directly into grow-out ponds is always detrimental.

In the present study there was no significant correlation between salinity and survival rate of shrimps. Further, post-larvae from hatcheries were directly introduced into the grow-out ponds (either into hapas in the grow-out ponds or into a delineated nursery section in the grow-out ponds). Thus, transportation stress and stress induced by sudden transfer of post-larvae into the grow-out ponds might also have contributed to the low survival rate noted in the present study.

Though survival rate in culture system is inversely related to stocking density (Chamberlain *et al.*, 1981), in the present study, with moderate survival at all stocking densities, such a correlation was not found. Chen and Wang (1990) for *P. monodon* and Garson *et al.* (1986), Sandifer *et al.* (1987), Wyban *et al.* (1987a), Goxe *et al.* (1988), Sivakami (1988) and Hernandez-Llamas *et al.* (1992) for other penaeid
species, also did not find any significant correlation between stocking density and survival rate.

Different types of conventional feed are used in aquaculture. Ghittino (1972) had reported on the use of selected slaughter house byproducts as supplementary diet in the culture of salmonid fish. In Japan meat of short-necked clam (*Tapes philippinarum*) and mussel (*Mytilus edulis*) is used as supplementary feed for the culture of *P. japonicus* (Deshimaru and Shigueno, 1972). Jhingran and Gopalakrishnan (1973) used mustard oil cake as supplementary feed in the monoculture of mullets. Qasim (1975) described the use of oil cakes as direct manure in polyculture ponds of fish and shrimps in many southeast Asian countries. Maguire *et al.* (1981) reported that Sydney rock oyster (*Crassostrea commercialis*) improves the meat condition of cultured shrimp. According to Maguire and Leedow (1983), Pipi flesh (*Plebidona deltoides*) can sustain very high growth and survival rate even at high stocking densities of the school prawn, *Metapenaeus macleayi*.

In the shrimp farms selected for the present study three types feeds were used by farmers. The conventional feed used was fresh clam meat. A compounded feed (dough ball) along with clam meat and a farm-made pelleted feed were the other two feeds used. The mean AFCR for clam meat was 1.70, for clam meat + dough ball, 1.59 and for the pelleted feed, 1.55. The AFCR for the three feeds were not significantly different.
Fresh clam meat is conventionally used as supplemental feed in shrimp culture. Kanazawa et al. (1970) reported that for Penaeus japonicus, a diet of fresh meat of the short-necked clam, Tapes philippinarum, gave better growth than compounded feed. Forster and Beard (1973, 1974) obtained fast growth for Palaemon serratus fed fresh mussel meat. But, according to Villegas (1978), the growth and survival of Penaeus monodon larvae fed with the meat of T. philippinarum were only next to those fed compounded diets. Colvin (1976a) used a diet of fresh mussel meat and prawn meat (50:50) as control diet for P. indicus and found remarkably slow growth with this diet. Ali (1982), who used fresh meat of Sunetta scripta as control diet for evaluating the efficacy of certain protein sources in the growth of P. indicus, found not only inferior performance but also heavy mortality of the prawns fed fresh clam meat. Even though there is a difference of opinion as to the efficacy of fresh clam meat as supplementary diet for prawn/shrimp, it would appear that the available information does not weigh in favour of fresh clam meat as the ideal feed for realising better growth in prawn/shrimp. This poor performance of fresh clam meat may be because of the high rate of chitinoclastic bacterial infection of the animals fed fresh clam meat (Venkataramaiah et al., 1975b). Ali (1982) also emphasised this point, and he reported that the growth was high, and the food conversion ratio the best, in juvenile P. indicus fed dry, powdered meat of Vellorita cyprenoides.
The gross energy (502.72 kcal/100 g) as well as the protein content (52.60%) were higher for clam meat than for the other two feeds. The protein to energy ratio (P/E ratio) for this feed was 104.63 mg protein/kcal. Shrimps, like all other animals, feed primarily to satisfy their energy requirements (Cho and Kaushik, 1985). If the feed has an excess of dietary energy, it may result in decreased feed intake, and consequently, the intake of other essential nutrients may also be lowered. Both these can adversely affect the growth. On the other hand, if the dietary energy is too low, the shrimp utilises other nutrients such as protein for fulfilling its energy requirements rather than for growth. Therefore, P/E ratio of the feed is crucial and there is an optimum P/E ratio at which the growth will be the maximum. Hajra et al. (1988) found that the most efficient dietary energy for *Penaeus monodon* was 412.60 kcal/100 g feed. It should be noted that various factors such as water temperature and quality and the size and physiological state of the animal, affect its energy requirements. The energy in clam meat used by farmers in Kerala was higher than the optimum recommended by Hajra et al. (1988) and therefore, this feed might have been underutilised by the shrimp.

In the present study the AFCR for fresh clam meat was 1.70, which is lower than that reported by many earlier workers for clam meat used by them: 9.45-11.70 (Mohammad Sultan et al., 1982), 2.70 (Ahamad Ali, 1988), 1.79 (Kungvankij et al., 1990) and 3.4 (Jayagopal, 1991). This was quite appreciable as, on wet weight basis, 6.80 kg of clam meat
produced 1 kg of shrimp. Deshimaru and Shigueno (1972) reported that the profiles of conjugated amino acids of *P. japonicus* and the short-necked clam, *Tapes philippinarum*, are very similar. Whether this is true for *P. monodon* and *Vellorita cyprenoides var. cochinensis* also is not known, but this traditional feed had a low AFR and it yielded high average final weight and comparatively high production, even in spite of the presumed under utilisation of this feed because of its high energy level.

Dough ball (compounded feed) is widely used for shrimp farming in India and abroad. In India at the Kakdwip Brackishwater Research Centre, West Bengal, a supplementary feed consisting of soya bean flour, brewer’s yeast, maize powder, wheat flour, calcium phosphate, vitamins and algin was formulated for feeding the post-larvae of *P. monodon*. Another feed consisting of goat offal, yeast, algal powder, wheat flour, and terramycin was used in this Centre for feeding the post-larvae of *P. indicus*. This Centre has also conducted feeding trials on *P. monodon* in cement cisterns with three feeds: a mixture of fish meal, ground nut oil cake and rice bran; fish meal alone and flesh of trash fish alone. It was reported that the flesh of trash fish gave the highest growth and the best AFR (AICRP 1978). Mohammad Sultan et al. (1982) formulated feeds with frog flesh waste and reported AFRs between 3.01 and 4.06 for *P. indicus* and 5.87 and 8.21 for *P. monodon*. In semi-intensive culture systems of *P. japonicus* in Italy (with fertilization and pelleted feed), Lumare et al. (1985) reported that
the AFCR ranged from 1.60 to 3.90. Kungvankij et al. (1990) reported an AFCR of 1.53 (at stocking density 40 PL/m² of *P. monodon*) for a feed consisting of trash fish and rice bran. Bostock (1991) reported an AFCR of 3.3 for dough ball (27% protein) and 2.9 for pelleted feed (34% protein) for *P. monodon* cultured in Andhra Pradesh. The ingredients of the dough ball were wheat flour, soya meal, rice bran, trash fish, beef and dried fish. Wood et al. (1992) reported an AFCR of 3.3 for dough ball in *P. monodon* farming systems of West Bengal. They reported an AFCR of 4.4 for pelleted feed and 7.0 for powder-based dough ball. With the dough ball, a surprising yield of 1410 kg/ha of *P. monodon* was achieved by Wood et al. (1992). The AFCR of this dough ball was 5.6 and the crude protein content, 26%.

In the present study, the moist dough ball used had a protein content of 27.71%. In combination with clam meat, the ratio of clam meat to dough ball varying from 1 : 1 to 8 : 1 in this combined feed, the protein content ranged from 40.15% to 49.79%. This combined feed had a low AFCR (1.59). This improved AFCR could be due to the presence of more than one protein source in the feed, as also reported by Alava and Lim (1983). However, the performance of shrimp fed dough ball in combination with clam meat was not significantly different from those fed fresh clam meat alone. Three plausible explanations may be put forth for the inefficacy of this feed.
1. The dough ball had a high moisture content, about 50%. This high moisture content could have resulted in fast physical disintegration of the feed leading to rapid leaching out of the nutrients thereby making them unavailable to the shrimps.

2. The feed (nutrient) input (on dry weight basis) into the system where clam meat alone was fed was more than in the feeding regime in which dough ball was fed along with clam meat (see Table 8).

3. Except on one occasion when clam meat and dough ball were mixed in nearly 1:1 ratio (see Table 8, Sl. No. 23), on all other occasions clam meat was the dominant component in this feeding regime. It is also noticeable that in this culture (C.I.I/92) the AFCR was as high as 2.62 and the production, as low as 560 kg/ha; the FCE was only 38.16%. This suggests that, increasing the proportion of the dough ball in the feed combination tends to lower the efficacy of the combined feed. Alternatively, it may be that, in the feed combination, it is the clam meat component that is more responsible for the supply of nutrients. Detailed studies are needed to evaluate the efficacy of the dough ball used by the shrimp farmers in Kerala. Notwithstanding, it is nearly unequivocal that, in the present form and manner in which it is used, the clam meat—dough ball combination is only as efficient as clam meat alone.

The present results, even though speak of the inefficacy of supplementing a conventional feed with an unscientifically formulated and prepared dough ball in the hope of realising better production of
shrimp, suggest that, in the context of the shortage of sufficient quantity of fresh clam meat, and consequently of the increasing cost of this feed, using a combination of clam meat and dough ball can help the farmers save, though only marginally, on feed cost. In the present study the input cost of fresh clam meat was higher (36.04% of the total input cost) than that for clam meat + dough ball (34.31% of total input cost).

The lowest AFCR (1.55) as well as the highest growth (mean final weight = 31.60 g) were achieved with the pelleted feed used in this study. The gross energy calculated for this feed containing 35.2% protein, was 295.91 kcal/100 g and the protein/energy ratio was 119.24 mg protein/kcal. Ali (1982) reported AFCR values ranging between 1.46 and 4.20 for compounded feeds prepared with ground nut oil cake and shrimp waste as the major ingredients. Mohammed Sultan et al. (1982) reported an AFCR of 8.21 for pelleted feed used in *P. monodon* rearing. Raman et al. (1982) conducted feeding trials on *P. indicus* using different combinations of feed ingredients such as fish meal, prawn processing waste, ground nut oil cake, gingelly cake, black gram husk, bengal gram husk, bajra, wheat flour, wheat bran, rice bran and tapioca. Among the feed combinations tested, fish meal, rice bran and tapioca in the ratio of 1:1:1 and 2:2:1 gave satisfactory results; the AFCR obtained with the first feed combination was 1.69 and with the second, 3.21.
Venkataramaiah et al. (1972a,b; 1975a,b) while studying the effects of feeding levels and salinity on the growth and AFCR in *P. aztecus*, reported that the AFCR of a standard shrimp feed varied from 1.25 to 3.73. The AFCR for the pelleted feed used in the present study is within this range. Elam and Green (1974) conducted feeding experiments on *P. setiferus* with different formula feeds and obtained AFCRs ranging from 1.8 to 2.3, which are slightly higher than the AFCR for the pelleted feed in the present study.

Forster and Beard (1973) observed that the growth of *Palaemon serratus* was high when the diet contained more than one protein source. Zein-Eldin and Corliss (1976), who obtained similar results for the same specie,s reported that inclusion of rice bran in shrimp feed improved the growth. For *Macrobrachium rosenbergii* the results were much superior when the diet contained fish meal, soya bean and shrimp meal compared to a diet having only soya bean meal, (Balazs et al., 1973). Subsequently, Balazs et al. (1974) found that the diet containing soya bean meal and tuna meal yielded significantly greater growth than the diets containing only soya bean, tuna meal or shrimp meal. These authors concluded that by using different protein sources, the possibility of approaching optimum amino acid balance in the diet was greater.

The pelleted feed was superior to the other two in realising better average final weight and growth rate of *P. monodon* in semi-intensive systems of Kerala backwaters. This may be because of the
better amino acid balance in the pelleted feeds by virtue of the four
different protein sources incorporated in the feed (mixed sources of
protein provide better amino acid balance — Balazs et al., 1973, 1974).
Alava and Lim (1983) reported that diets containing two or more protein
sources are better utilised by shrimp than those containing a single
protein source. This could be the reason for the higher mean final
weight realised with pelleted feed in the present study.

The second feed type (F2 = clam meat + dough ball) also contained
more than one protein source. However, the growth of shrimp fed this
feed was not significantly different from that fed clam meat alone.
Moreover, the results obtained with F2 were significantly inferior to
that realised with pelleted feed. The poor performance of F2 compared
to pelleted feed is attributable to the lack of any other marine
protein source, other than clam meat, in F2. The pelleted feed
contained two sources of marine protein: shrimp head waste and squilla
powder. Further it is now proven that penaeid shrimps have a dietary
requirement of native chitin (Fox, 1993). The odour of the feed (by
virtue of chitin present in it) may be attracting the animals and
making the feed more palatable (Ahamad Ali, 1988). Shrimp head meal is
not only a good source of chitin, but also of protein, cerotenoid
pigments, fatty acids and fibre (Meyers, 1986). Deshimaru and Shigueno
(1972) reported that the amino acid composition of the rations that
give the best growth performance of shrimp, most closely approximate
the amino acid composition of the shrimp. Shrimp meal in the pelleted
feed, therefore, would have ensured a desirable amino acid balance in the formulation. Besides, shrimp meal would meet the substrate requirement of chitin and provide the requisite amount of calcium needed for rapid growth of shrimps.

According to Cuzon et al. (1994) shrimp meal can be used at fairly high levels and this generally helps to sustain good growth rate. When correctly prepared and preserved, shrimp meal provides a substantial amount of essential nutrients. It is an excellent source of protein because its amino acid composition is similar to that of the whole animal. This is especially true when the product comes from local fisheries.

Cod liver oil is rich in w-3 poly unsaturated fatty acids (PUFA), whereas terrestrial plant oils (palm oil) are rich in w-6 fatty acids (Hajra et al., 1988). The presence of both w-3 and w-6 PUFAs helps in the synthesis of essential fatty acids (EFA) that are needed for rapid growth and normal moulting of penaeids (Colvin, 1976b; Guary et al., 1976). In the pelleted feed used here, cod liver oil and palm oil were incorporated.

The protein/energy ratio was the highest for pelleted feed (119.24 mg protein/kcal. This value is in agreement with that reported by Hajra et al. (1988) (107.70-120.80) and Shaiu and Chou (1990) (96.96-118.24) for the feeds they used for P. monodon.
Several authors have reported that shrimps require relatively high content of protein in their diet. The diets used by Deshimaru and Shigueno (1972) for *P. japonicus* contained over 60% protein. Lee (1972) reported optimum growth of *P. monodon* at 40% protein level and the same level was established as optimum for *P. aztecus* by Venkataramaiah et al. (1972a). According to Andrews et al. (1972), *P. setiferus* require an optimum protein level of 28-32%. Zein-Eldin and Corliss (1976) reported that 30% protein is the optimum for *P. aztecus*. Balazs et al. (1973) obtained the best growth performance of *P. aztecus* at 25-40% protein level. The feed used by Alikunhi et al. (1975) for *P. monodon* contained 20% protein. Rajyalakshmi et al. (1979) reported that a protein level in the range of 20-40% in the diet is sufficient to ensure good growth in penaeid shrimps, especially in tropical waters. The present results corroborate the above mentioned observations. The best growth was realised with pelleted feed containing about 35% protein. According to Rajyalakshmi (1982) fast growth and remarkable size of *P. monodon* are obtained with diets containing less than 40% protein.

Even though the protein content of clam meat + dough ball (1 : 1) was about 40%, this feed was not as efficient as the pelleted feed. The reasons for the inefficacy of this combined feed have already been discussed. It is to be emphasised on the basis of the present results that the protein content of a feed is not the sole criterion to assess its efficacy.
The AFCRs for the three feed types used in the present study were low compared to earlier reports on the AFCR for feeds used in shrimp cultures. This low AFCR could have been due to the better feed management with check trays and probably because of the good primary productivity prevailing in the culture ponds. It is to be noted here that, according to Gopinathan et al. (1982), the culture ponds connected to the Cochin backwater system are highly productive. The physico-chemical features of the ponds selected in the present study were well within the limits for systems showing good productivity. The application of fertilizers and use of supplementary feed to the ponds under study had an enhancing effect on primary productivity of these ponds.

In the present study fresh clam meat as a supplementary feed was used in all the three regions (Pallithode, Chellanam and Kannamaly). But the production achieved with clam meat was higher in Kannamaly than in the other two regions. The higher production is attributable to the following two reasons.

1. The higher amount of organic fertilizer used in Kannamaly (350-500 kg/ha; mean = 431.25 kg/ha) than in Pallithode (200-300 kg/ha; mean = 275.5 kg/ha) and Chellanam (200 kg/ha in all four cultures).
2. The higher nitrate and phosphate contents of the waters of Kannamaly ponds (see Table 5).
The high nitrate and phosphate contents could have resulted in high primary as well as secondary productivity. The organic manure, since after its disintegration forms food for the detritus feeders including shrimp, might have helped in augmenting productivity of the ponds and better survival and growth of shrimps. Another point deserves mention especial in this context. Sathiadas et al. (1989) reported that the distance of the culture ponds from the 'bar-mouth', and the production are inversely related. Kannamaly is closer to the Cochin 'bar-mouth'; this proximity of Kannamaly ponds to the 'bar-mouth' obviously seems to have had a positive influence on the production for these ponds.

Probably, the slightly higher survival rate in Kannamaly region (52.8%) than in Pallithode (50.4%) and Chellanam (49.5%) also might have contributed towards this end, though survival rate and production in the present study were not significantly correlated.

As evident from the observations made during the present study, the age-old practice of feeding clam meat as the sole supplementary food source in shrimp culture is still in vogue in Kerala State; of the 36 culture operations studied, in 20 this was practised. Even though this practice is conducive and recommendable to the areas where the clam (Vellarita cyprenoides) is available in plenty, it is to be remembered that this clam is a delicacy for human beings also. Yet, the clam is farmed neither for the purpose of human consumption nor for the
requirement of shrimp culture. In fact, both these needs are at present met by the wild or natural populations of the clam. With a boom in shrimp farming along the east coast of India, aquaculture feed manufactures have also started exploiting the wild populations of the clam for incorporation of its meat in compounded feeds. It is but only a matter of time before the natural resource of *V. cyprenoides* was over exploited. In this scenario, presumably with the impending acute shortage of the clam, and the consequent hike in the cost of clam meat, the practice of using clam meat as a sole supplementary feed for shrimp would, and should, gradually phase out. However, the whole-someness of this feed cannot be given a go by.

In this study, the overall performance of shrimp weighs strongly in favour of the use of pelleted feed. In terms of economics also the same holds good because, of the total production cost, 36.04% and 34.31% were accounted respectively for the cost of clam meat and clam meat + dough ball, whereas only 30.37% of the total production cost were accountable for pelleted feed. The performance of the pelleted feed in terms of growth and economy was mainly because of its quality and nutritional value. Shrimps being slow feeders, require a water-stable pellet. Further, uniformity in the particles compacted into a pellet, the nutrient density in the feeds in terms of macronutrients and micronutrients, all add to the qualities of the feed. The pelleted feed used in this study had all these qualities.
Further, this feed was made in the farm itself adopting an appropriate feed technology with maximum utilisation of locally available conventional and non-conventional ingredients. It was all these factors, which New (1992) also emphasized, that added up to advocate on-farm feed making for the small-scale, semi-intensive, monoculture systems *P. monodon*, particularly in holdings of less than one hectare, on the backwaters of Kerala State.