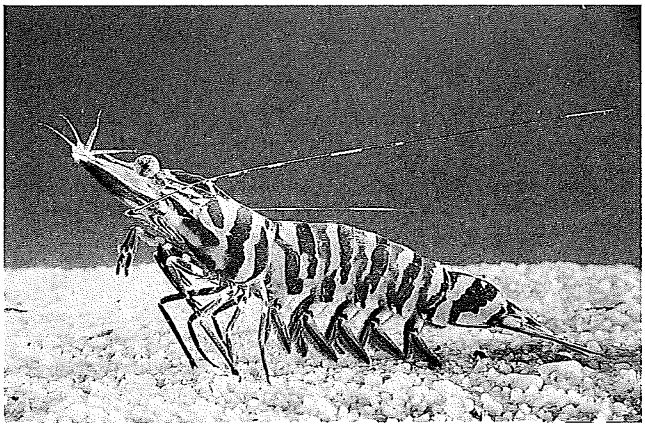

Development of the aquaculture capability of the brown tiger prawn, *Penaeus esculentus*

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96/302 Development of the aquaculture capability of the brown tiger prawn, *Penaeus esculentus*.

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Objectives

To assess and develop the aquaculture potential of *P. esculentus* by:

1. Closing the life-cycle to provide for future selective breeding;
2. Quantifying the growth performance under commercial farm culture conditions;
3. Developing a cost-effective diet for optimal on-farm growth; and
4. Evaluating the cost-benefit of trial commercial production.

Non-technical summary

Outcomes achieved

- During the project, closed cycle production for three generations, growing the prawns from eggs to reproductive adults, was achieved wholly in tank systems at CSIRO. On-farm, two generations were grown in commercial ponds, and third generation progeny were produced. Having established the feasibility of farm-scale closed cycle production for *P. esculentus*, there is now the potential for selection of the faster growing prawns at harvest, to produce a potentially faster-growing next generation. Importantly, it is possible to produce reproductively capable pond-grown broodstock within the 12-month commercial production cycle.
- An initial small-scale pilot trial in1995/96 demonstrated that *P. esculentus* could be grown successfully to a market size in a period well within the conventional growout season for Australian prawn farms, when fed a high-protein *P. japonicus* diet. This result confirmed the growth potential of *P. esculentus* and removed a major industry concern that this species has inherently slow growth in ponds.
- *Penaeus esculentus* was grown commercially during the 1996/97 and 1998/99 growout seasons, (5 farms and 2 farms, respectively). Growth rates were slightly lower by comparison to *P. monodon*, but market prices were higher.
- Crops sold on the export market to Japan received more favourable prices than those sold on the local market. This marketing exercise demonstrated the market demand for *P. esculentus,* and confirmed the opportunity to achieve a favourable price on the export market for this Australian product.
- The superior growth performance of a diet formulation specifically tailored for *P. esculentus* has been demonstrated at a laboratory scale. When produced at a pilot commercial scale, this diet formulation resulted in slightly lower growth than *P. monodon/P. japonicus* diet combinations. Further development of the laboratory-tested formulation to achieve similar performance on-farm will provide the scope for further cost-effective improvements in growth.
- The cost-benefit of production of *P. esculentus* relative to *P. monodon* has been quantified. From the farm trials, *P. monodon* production results in a higher profit per ha by a margin of 2.5%, but this would vary according to variation in a number of

parameters, and would be expected to increase with increasing farm production experience. The cost-benefit analysis supports the potential of *P. esculentus* to be grown with similar profitability to *P. monodon*. A scenario analysis was used to identify the critical values of several parameters that would make *P. esculentus* as profitable as *P. monodon*. A 5% increase in growth for *P. esculentus* would generate equal profitability. This growth improvement could be achieved through selective breeding or further development of the specific *P. esculentus* diet.

Project background

In order to provide for future growth of the Australian prawn aquaculture industry, there is a need to take a longer-term strategic view and develop production technology for alternative species that can support an export market but do not have the intense overseas competition of the current major species, *P. monodon*. This research project addresses the need for feasibility studies on farm production of an additional species that could be profitable in new or existing markets.

The strategic objective is to build on our current information to develop and test techniques for growing *P. esculentus* in a farm environment, and to quantify the commercial suitability of this species. The project is structured to demonstrate the growout and market potential of the species in pilot trials, to further develop and test an appropriate growout diet, to develop closed life cycle reproduction for future selective breeding and to evaluate the cost benefit of production of *P. esculentus*. The project commences the development of technology and assesses the potential for *P. esculentus* to become an additional species for Australian farm production.

Research Outputs

- Techniques for closed life cycle production of *P. esculentus* were developed, and the capacity for the production of multiple generations of domesticated stock demonstrated both in the laboratory and on-farm.
- Farm production trials for *P. esculentus* were carried out during 3 growout seasons, to quantify the growth performance under commercial conditions. Each trial involved between two and five farms.
- A diet formulation specifically suited to *P. esculentus* was developed and tested under both laboratory and commercial farm conditions.
- A bioeconomic model was developed to quantify the cost-benefit of commercial production of *P. esculentus*.

Conclusions

This project has demonstrated the cost-benefit of farm production of *P. esculentus* to be comparable to that of *P. monodon*, has demonstrated the capacity for closed cycle breeding, and has demonstrated the superior growth performance of a formulated *P. esculentus* diet, at a laboratory scale. The brown tiger prawn, *P. esculentus*, has been grown successfully and the product sold on the export market. Importantly, the inherently slower growth rate of *P. esculentus* compared to *P. monodon* is compensated for by its better market performance.

The outcomes of this project confirm the potential for *P. esculentus* to be grown as an additional species by Australian prawn farmers. The opportunity to capitalise on these findings now rests with the Australian prawn farming community.

Keywords: Brown tiger prawn, Farm production, Domestication, Cost benefit

2. Background

The Australian prawn farming industry is unlikely to achieve the required critical operating mass if based only on domestic demand or on production of niche exports like *P. japonicus.* (Macarthur 1995). Macarthur (1995) further stresses that "the current major farmed species, *P. monodon*, or a suitable replacement, must be competitively 'exportable' for the industry to achieve a sustainable, commercial critical mass". This research project addresses the stated need for feasibility studies on farm production of additional species that will be profitable in new or existing markets.

Prawn farming in Australia is presently limited to two species. Current annual production levels are approximately 1,100 t ($15.8 million) of *P. monodon* and approximately 257 t ($14.6 million) of *P. japonicus* (Rosenberry 1998). While *P. japonicus* production is directed exclusively at a specialist live export niche market, almost all production of *P. monodon* is for the domestic market. Throughout Asia, as well as in Australia, *P. monodon* is the dominant farm species. Farm production of *P. monodon* now constitutes about 60% of the estimated 700,000 t of total world production of farmed prawns. As a consequence, the export market for *P. monodon* is limited by price competition from overseas producers and spawner supply. Sales of *P. monodon* have been made to niche markets in Taiwan and Japan, but further sales are constrained by the relatively high production costs by Australian farmers (Macarthur 1995). The Asian countries (Thailand, China, India, Indonesia and others) will likely control or even depress future prices for Australian-produced *P. monodon* and thus limit any export market growth.

To provide for future growth of the Australian prawn aquaculture industry, there is a need to take a longer-term strategic view and develop production technology for alternative species that do not have this intense overseas competition. *Penaeus esculentus*, is an Australian native species which already has strong export market acceptance and high prices ($A22 to $A28 per kg ex-vessel and $A40+ wholesale in Japan (ABARE, 1994)) from the established Australian wild fisheries sector. Wild tiger prawn stocks are fully exploited with a current annual production of around 3,000 to 4,000 t. Wild stock production has stabilised, so future growth of this well-established and attractive market can only come from farmed prawns.

In Japan, there is a niche market for Australian tiger prawns (*P. esculentus* and *P. semisulcatus*) created by a demand for a more strikingly coloured, and hence higher priced, prawn than the mass market "black tiger" prawn (*P. monodon*). This niche is created by consumers unwilling to pay the extremely high prices for *P. japonicus* (pers com, M. Kitada, Australian Trade Commission). The capture fishery inputs to this market are based on seasonal harvests; additional production from the farm sector would assist in meeting the consistent market demand. Previous wild stock production has peaked at 10,000 t without directly affecting the market price. Prices do fluctuate, but are not dictated by Australian production. In contrast, costs of production of *P. monodon* in Australia constrain export sales due to competition from countries with lower production costs. Current prices of *P. monodon* into the local market range from $A12 to $A18 per kg, but tend towards the lower end of this range when overseas product is attracted to the domestic market (pers com, N. Ruello, Ruello & associates). With development of the technology to grow *P. esculentus* at similar costs to *P. monodon,* expected returns would be increased by around $A7 to $A9 per kg.

Early in Australia's aquaculture development the potential for *P. esculentus* was recognised, and this stimulated pilot scale trials by a number of Australian prawn farming companies. These trials showed that *P. esculentus* could be produced but techniques needed to be improved. At the time, inappropriate *P. monodon* culture techniques and feeds were used for *P. esculentus* so the true potential was not realised. Penaeid aquaculture in Australia was founded on *P. monodon* because of the availability of overseas technology. However, as the industry has developed some issues have emerged relating to the impact of high levels of overseas production on the profitable access to export markets for *P. monodon*. As well, the limited supply of *P. monodon* broodstock remains a constraint for production efficiency in this industry. Together with several prawn-farming companies, we are convinced that a strategic approach to species diversification in the industry is essential for its long-term viability. The positive attributes of *P. esculentus* as a culture species and the associated benefits to wild fisheries resources through stock enhancement make it an ideal candidate for farm production.

Because of its abundance and importance in the wild fisheries CSIRO has gained an understanding of several aspects of *P. esculentus* biology relevant to aquaculture. These include spawner availability and spawner induction, larval production, nutrient profiles of natural diets, growth performance in controlled conditions and physiological tolerance to environmental factors that determine the potential geographic range for culture. This background knowledge supports the potential for *P. esculentus* as an additional species with fairly low risk. *Penaeus esculentus* provides the opportunity to take advantage of the attributes of a native species that is pre-adapted to local conditions.

The strategic objective of this project is to build on our current information to develop and test techniques for growing *P. esculentus* in a farm environment, and to quantify the commercial suitability of this species. The project is structured to demonstrate the growout and market potential of the species in pilot trials, then to further develop and test an appropriate growout diet, and to develop closed life cycle reproduction for future selective breeding. The project commences the development of technology and assesses the potential for *P. esculentus* to become an additional species for Australian farm production.

3. Need

The need for development of the technology to farm *P. esculentus* is shared between the culture industry as a need for an additional farmed species, and the capture fishery as the need for stock enhancement initiatives to sustain fishery resources.

Aquaculture Industry:
To ensure future growth of the prawn aquaculture industry there is a need to diversify and reduce reliance on *P. monodon*, a species for which there are emerging problems for export marketing.

The Australian industry has the opportunity to capitalise on the positive market and biological attributes of a native species by developing farming methods for *P. esculentus.* This is a high value species with a developed export market from wild fisheries stocks

The companies supporting this initiative with in-kind contributions recognise the need for an alternative species and the value of this research in providing a unique position for Australian prawn farmers, independent from competition from the huge and growing southeast Asian industry.

Current industry reluctance to risk commercial scale growout of this species is based on early experiences using inappropriate technology. To encourage industry acceptance of *P. esculentus* there is a need to demonstrate its potential with appropriate culture technology.

This species requires a diet with a protein content intermediate between *P. monodon* and *P. japonicus,* so cost-effective means of developing the appropriate diet need to be investigated.

Demonstration of acceptable reproductive performance from pond-reared broodstock would effectively close the life cycle and provide the basis for genetic selection for faster growing and disease free stock.

Stock Enhancement of Wild Fisheries:
Penaeus esculentus is the species under consideration by CSIRO for development of a stock enhancement program for wild fisheries. Experience in China has shown that successful, cost-effective restocking must be a by-product of aquaculture. Stock enhancement in Australia would be dependent on the provision of seedstock from the farming industry, and hence the prior development of culture techniques for this species. Cost benefit analyses have indicated that the prawns need to be grown to a size of 1 to 2 g in a culture system before release to the wild. Release at smaller sizes would result in excessive losses due to predation. Restocking initiatives would provide benefits to resource sustainability in wild fisheries, and the additional market for seedstock would also benefit the farming industry.

4. Objectives

To assess and develop the aquaculture potential of *P. esculentus* by:

- Closing the life-cycle to provide for future selective breeding;
- Quantifying the growth performance under commercial farm culture conditions;
- Developing a cost-effective diet for optimal on-farm growth; and
- Evaluating the cost-benefit of trial commercial production.

5. Domestication: closing the life cycle

5.1 Closed cycle production

5.1.1 Objectives

- To assess the potential for closed life-cycle production; and
- To evaluate the comparative reproductive performance of wild and domesticated broodstock.

5.1.2 Methods

Closed cycle production in ponds and tanks:
Approximately 75 wild broodstock (50 females and 25 males) were trawled by a commercial supplier in the Cairns region in north Queensland in October 1995. Following spawning and larval rearing at both the Rocky Point Prawn Farm hatchery and at CSIRO, Cleveland, prawns were stocked for growout in a pond at Rocky Point, and in indoor tanks at CSIRO. This stock constituted the first generation.

At Rocky Point, postlarvae were stocked in a 1 ha commercial pond at a stocking density of 30 per m^2 in November 1995, and grown to harvest in May 1996. The prawns were fed a *P. japonicus* feed and growth was monitored on a fortnightly basis (see section 6). At harvest, approximately 120 broodstock (80 females and 40 males) were collected from this pond and transferred to 10 t tanks (Crocos and Coman, 1997) in the CSIRO broodstock facility for on-growing to adult size and maturation-conditioning for spawning. These broodstock were not selected for faster growth, and so represented the full size distribution from the pond.

At CSIRO, 500 postlarvae were stocked in each of 4 x 2.5 t tanks (2 m diameter x 1 m deep) set up with a sand bottom filtration system, supplied with flow-through seawater at 100% exchange per day, with light reduced to 20% of ambient. The prawns were fed to satiety each day on a commercial formulated *P. japonicus* diet, and growth was monitored on a fortnightly basis. The prawns were grown from November 1995 to September 1995 in these tanks, then transferred to 10 t maturation tanks (Crocos and Coman, 1997) for the final maturation phase.

The same strategy was used to produce the second-generation (G2) prawns. In November 1996, broodstock from both the first generation (G1) pond-reared and tank-reared groups were spawned. The pond-reared G1 broodstock were spawned at the Rocky Point hatchery, and the resultant second-generation (G2) postlarvae were stocked into a pond at the farm (see section 6). At harvest in May 1997, 120 of these G2 broodstock were collected from this pond and transferred to the 10 t tanks in the CSIRO broodstock facility for on-growing to adult size and maturation-conditioning for spawning. The tank-reared G1 broodstock were spawned at CSIRO, and the resultant second-generation (G2) postlarvae were stocked in 2.5 t tanks for growout to adult size over the following 11 months to October 1997. These G2 broodstock were transferred to maturation tanks in October 1997 for maturation conditioning in preparation for spawning in January-February 1998.

Similarly, third-generation (G3) stocks were produced from spawnings of the G2 pond and tank broodstock. The G3 progeny from the tank-reared G2 broodstock were grown in tanks at CSIRO, but the G3 progeny from the pond-reared G2 broodstock were not stocked back to the farm as the farm did not plan to grow *P. esculentus* in that production year.

For each of the lines produced, pond-reared and tank-reared, G1, G2 and G3, the growth performance was monitored during the growout on-farm or in the CSIRO tanks.

Comparative reproductive performance of wild and domesticated broodstock:
All spawnings occurring during the course of the production of the pond-reared and tank-reared lines over the three generations were monitored, with data recorded for eggs per spawning, hatch rate and survival. The prime objective with these spawnings was to establish the pond and tank lines. Hence it was considered that this broad-scale spawning information did not cover the necessary range of parameters, or to have been obtained under the strictly controlled conditions required for a robust comparison of the reproductive performance of the various lines. Therefore, specific reproductive performance trials were carried out to make standard comparisons between the broodstock classes.

Reproductive performance trials were of 8 weeks duration, and provided for standard measures of reproductive performance parameters measured at each stage of the maturation and spawning process (Crocos and Coman, 1997). In each trial there were two replicates of each treatment with 25 females and 15 males in each 10 t maturation tank. Differences in reproductive performance among the treatment groups were compared by analysis of variance using the SAS (SAS Institute) software. After examining the data for homogeneity of variance using the F-test, differences among the lines were tested using least significant differences (LSD) pairwise comparisons.

Since the age and size of penaeid broodstock is known to affect many reproductive parameters (Crocos and Coman, 1997), adjustments based on age and size of the broodstock were made to enable standardised comparisons. Hence the reproductive performance data was compared across three categories: unadjusted data, adjusted for age and adjusted for size. The age adjustment was calculated using values obtained in a study examining the reproductive performance of *P. semisulcatus* broodstock at different ages (Crocos and Coman, 1997). Each reproductive performance measure was standardised to a value for a 12 month-old spawner, using estimates derived through interpolation of the *P. semisulcatus* data (Crocos and Coman, 1997). The formula used to calculate the age adjustment was as follows:

$$\text{PE 12mo} = \text{PE age}\chi \times \frac{\text{PS 12mo}}{\text{PS age}\chi}$$

Where: PE 12mo is the age adjusted performance of *P. esculentus* at 12 months
PE ageχ is the observed performance of the *P. esculentus* at χ months
PS 12mo is the observed value of *P. semisulcatus* at 12 months
PS ageχ is the observed value of *P. semisulcatus* at χ months

The weight adjustment standardised the reproductive performance values of all broodstock to that of a 60 g animal. This weight was the average for the wild *P. esculentus* broodstock at 12 months of age. This adjustment is regarded as being less robust than the age adjustment, but it is presented for comparative purposes only. The formula for the weight adjustment follows:

$$\text{PE 60g} = \text{PE wt}\chi \times \frac{60}{\text{Wt}\,\chi}$$

Where: PE 60g is the weight-adjusted performance of *P. esculentus* at 60g
PE wtχ is the observed performance of *P. esculentus* at weight χ
Wt χ is the observed weight of the spawner

Comparisons were made between wild broodstock, pond-reared broodstock and tank-reared broodstock. The first trial in November 1997 compared wild broodstock trawled from the Cairns region in north Queensland in late October 1997, and pond-reared broodstock from the 1996/97 growout at Rocky Point prawn farm. These pond broodstock were collected at harvest in May 1997, then on-grown in the CSIRO broodstock facility until November 1997, then the reproductive performance trial was carried from November 1997 to January 1998. The second trial in January 1999 assessed the performance of tank-reared broodstock that had been grown from egg to adult in the CSIRO facility during 1998.

5.1.3 Results

Summary: Closed cycle production in ponds and tanks:
During the course of the project, 3 generations (G1, G2 and G3) of *P. esculentus* were produced (Figs. 5.1, 5.2). At Rocky Point Prawn Farm (RPPF), 2 generations (G1 and G2) were grown in commercial ponds, and third generation (G3) progeny were produced from these G2 broodstock, but not stocked on-farm. At CSIRO, three generations were grown from egg to adult entirely in tank systems (Fig. 5.2). The capacity for closed cycle production of *P. esculentus* at pond and tank scales has been demonstrated.

Closed cycle production in ponds:
The first generation (G1) was the progeny of wild broodstock spawned in October 1995 at the RPPF hatchery. The G1 postlarvae were stocked at RPPF and the crop harvested in May 1996 (Fig. 5.2 and section 6). These prawns grew to a mean weight of 31.98 g ±3.96 g in 28 weeks of pond growout (Fig. 5.1, component (a)). At harvest, approximately 120 broodstock (80 females and 40 males) were collected from this pond and transferred to 10 t tanks in the CSIRO broodstock facility for on-growing to adult size and maturation-conditioning for spawning. These G1 broodstock grew to a mean weight of 51.49 g ± 8.9 g by October 1996, and were by then 52 weeks old (Fig. 5.1, component (b) and Fig.5.2).

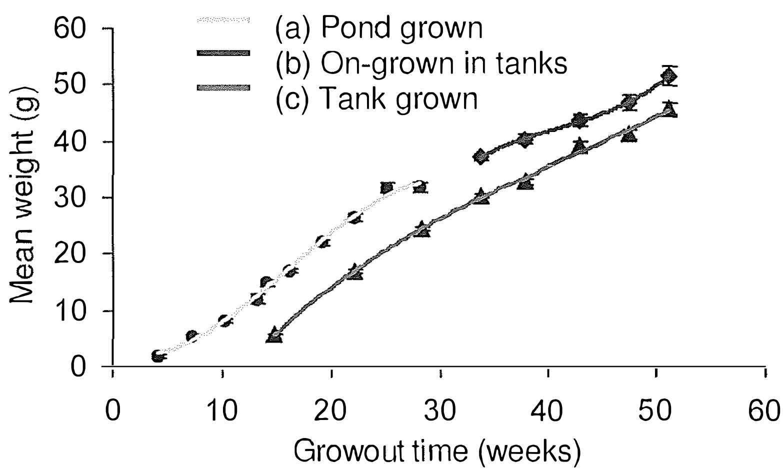


Figure 5.1. *Penaeus esculentus*: Growth performance of pond-reared and tank-reared broodstock, mean weight (g) ±SE in the 1996 growout season.
(a) Prawns grown in ponds to commercial harvest.
(b) Prawns from (a) transferred at harvest to tanks at CSIRO for on-growing to broodstock size.
(c) Prawns grown from egg to broodstock size in tanks at CSIRO.

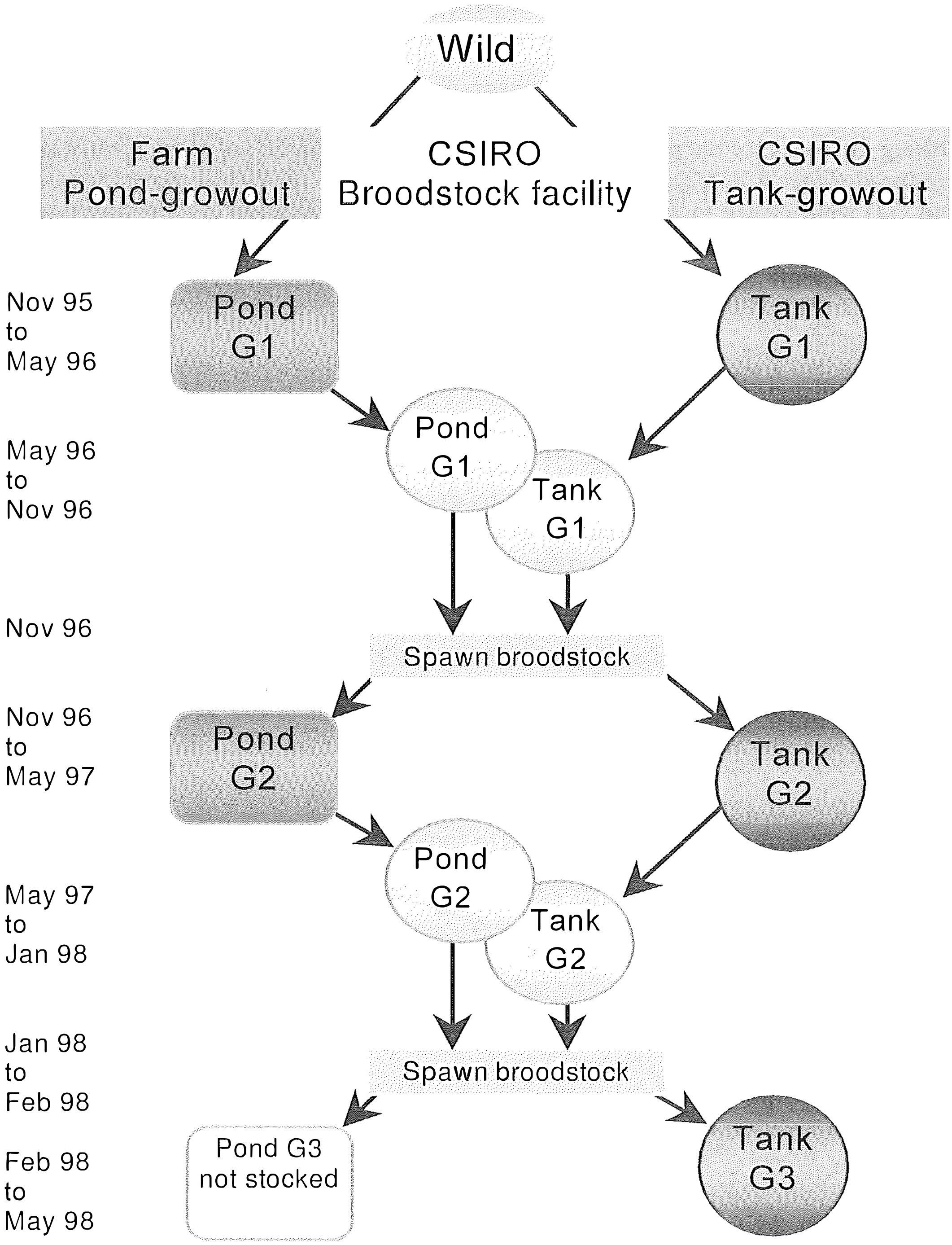


Figure 5.2. *Penaeus esculentus*: Summary of lines produced. First and second generation stocks (G1 and G2) were grown on-farm, and first, second and third generation stocks (G1, G2, G3) were grown in tanks. G1 and G2 broodstock were on-grown to adult size and matured to spawning stage in the CSIRO broodstock facility to produce the G2 and G3 stocks, respectively.

In November 1996, the G1 pond-grown broodstock (Figs. 5.1 (b), 5.2) were spawned at CSIRO to produce G2 progeny (Fig. 5.2) that were stocked to a pond at Rocky Point prawn farm (Fig. 5.2). This crop was harvested in May 1997 with a mean weight of 19.8 g (Fig. 5.2). At harvest, approximately 90 of these G2 broodstock were transferred from the growout pond to the CSIRO broodstock tanks, on-grown to broodstock size and spawned in January 1998 at an age of 13 months (Fig. 5.2). Third-generation (G3) progeny were reared to the postlarval stage at CSIRO, but were not stocked in ponds, as the farm was not able to provide pond space for the 1998 growout season (Fig. 5.2).

Closed cycle production in tanks:
The progeny of the wild broodstock spawned in October 1995 were stocked to tanks at CSIRO and grown through to adult size. These first generation (G1) tank-grown stocks grew to a mean weight of 45.7 g ±8.6 g by October 1996 after 51 weeks (Fig. 5.1, component (c) and section 6). In November 1996, these G1 broodstock were spawned at CSIRO to produce G2 progeny that were again stocked to tanks at CSIRO and grown to a mean weight of 48.6 g ±7.61 g by December 1997 at 13 months old (Fig. 5.2). The G2 broodstock were spawned in January 1998 to produce G3 progeny. These G3 postlarvae were stocked to tanks at CSIRO and grown to a mean weight of 10 g by April 1998 when the growout was discontinued due to lack of tank resources (Fig. 5.2).

Comparative reproductive performance of wild and domesticated broodstock:
The reproductive performance of wild and domesticated broodstock was compared in the course of three standard reproductive performance trials. The first two trials, in November 1997 to January 1998, compared wild broodstock (estimated to be 12 months old) with pond-reared broodstock that had been grown to commercial harvest size in ponds at Rocky Point prawn farm, then transferred to CSIRO tanks for on-growing to broodstock size (Fig. 5.3). The pond-reared broodstock were younger at the time of the trial (10 months) than the wild and tank-reared groups (Fig. 5.4a). The mean weight of the wild broodstock was higher than the pond and tank broodstock at 59g, 42g and 49g, respectively (Fig. 5.4a). Progeny from the wild broodstock used in this trial were grown from egg to adult in tanks at CSIRO and their reproductive performance evaluated in January 1999 at 13 months old (Figs. 5.3, 5.4a).

Survival of broodstock during the 2-month trial was high at around 80%, but not significantly different among the wild, pond and tank broodstock groups, despite a trend towards better survival in the tank-reared group (Fig. 5.4b).

Pond-reared broodstock produced the highest mean spawning rate (1.42 spawns per female per month) for the unadjusted data (Fig. 4c), and a further increased nominal rate when the data was adjusted for the younger age and smaller size of these broodstock (1.84 and 1.90, respectively) (Fig. 5.4c). By comparison, the wild broodstock produced 1.31 spawns per female per month (1.31 and 1.38 adjusted for age and size, respectively), and the tank-reared broodstock produced a significantly lower spawning rate at 0.62 spawns per female per month (0.71 and 0.65, adjusted) (Fig. 5.4c).

The wild spawners produced the highest mean number of eggs per spawning on an unadjusted basis (46,780, 33,320, 17,450, for wild, pond and tank, respectively)

Fig. 5.4d). When adjusted for the effects of age and size, the nominal egg production for wild broodstock and pond-reared broodstock was not significantly different, but the tank-reared broodstock produced significantly fewer eggs per spawning (Fig. 5.4d).

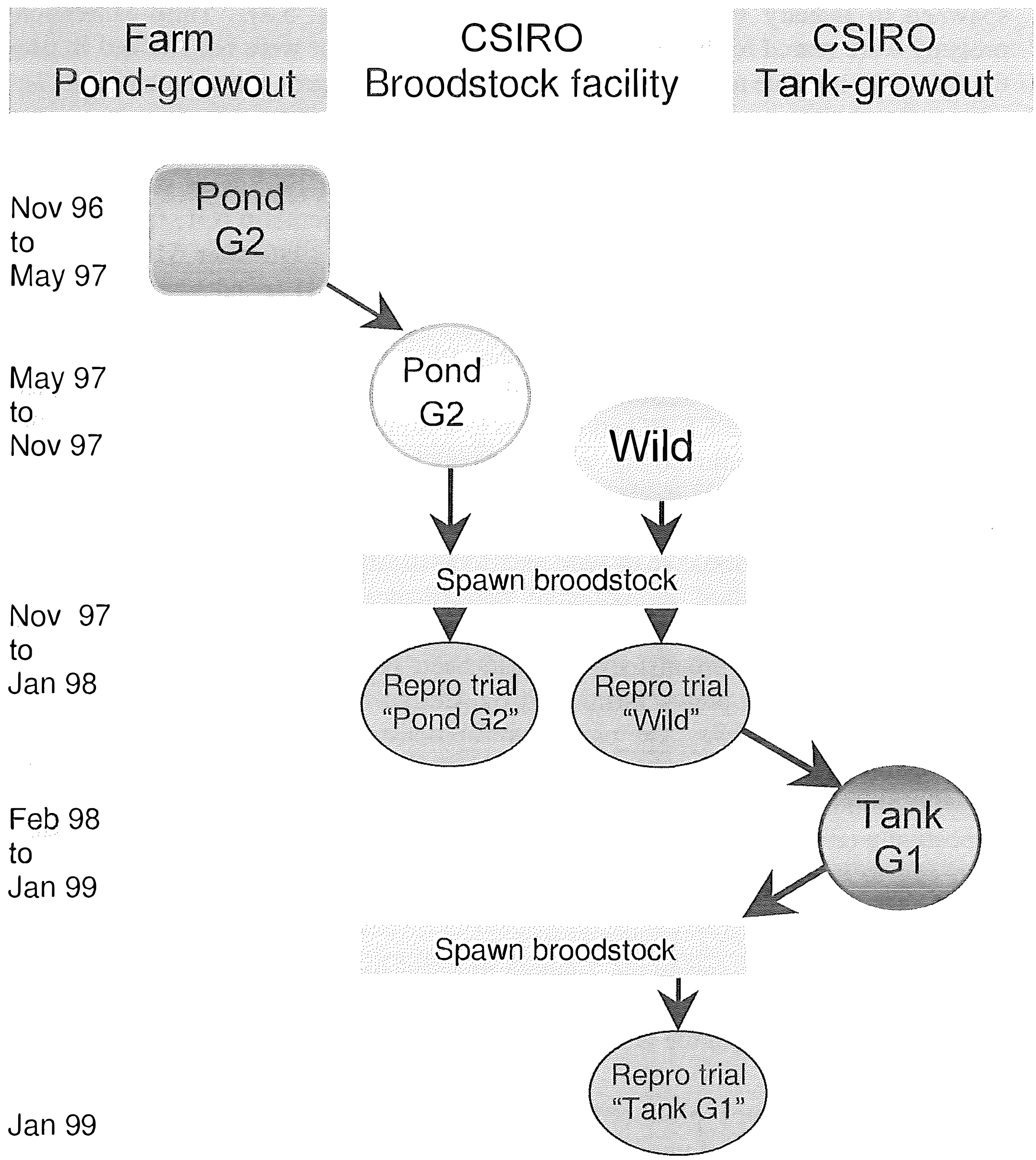


Figure 5.3. *Penaeus esculentus*: Summary of stocks used for the comparative evaluation of the reproductive performance of wild broodstock, pond-reared broodstock and tank-reared broodstock. In each of the three cases, reproductive performance was evaluated from a standardised 8 week trial (Crocos and Coman 1997).

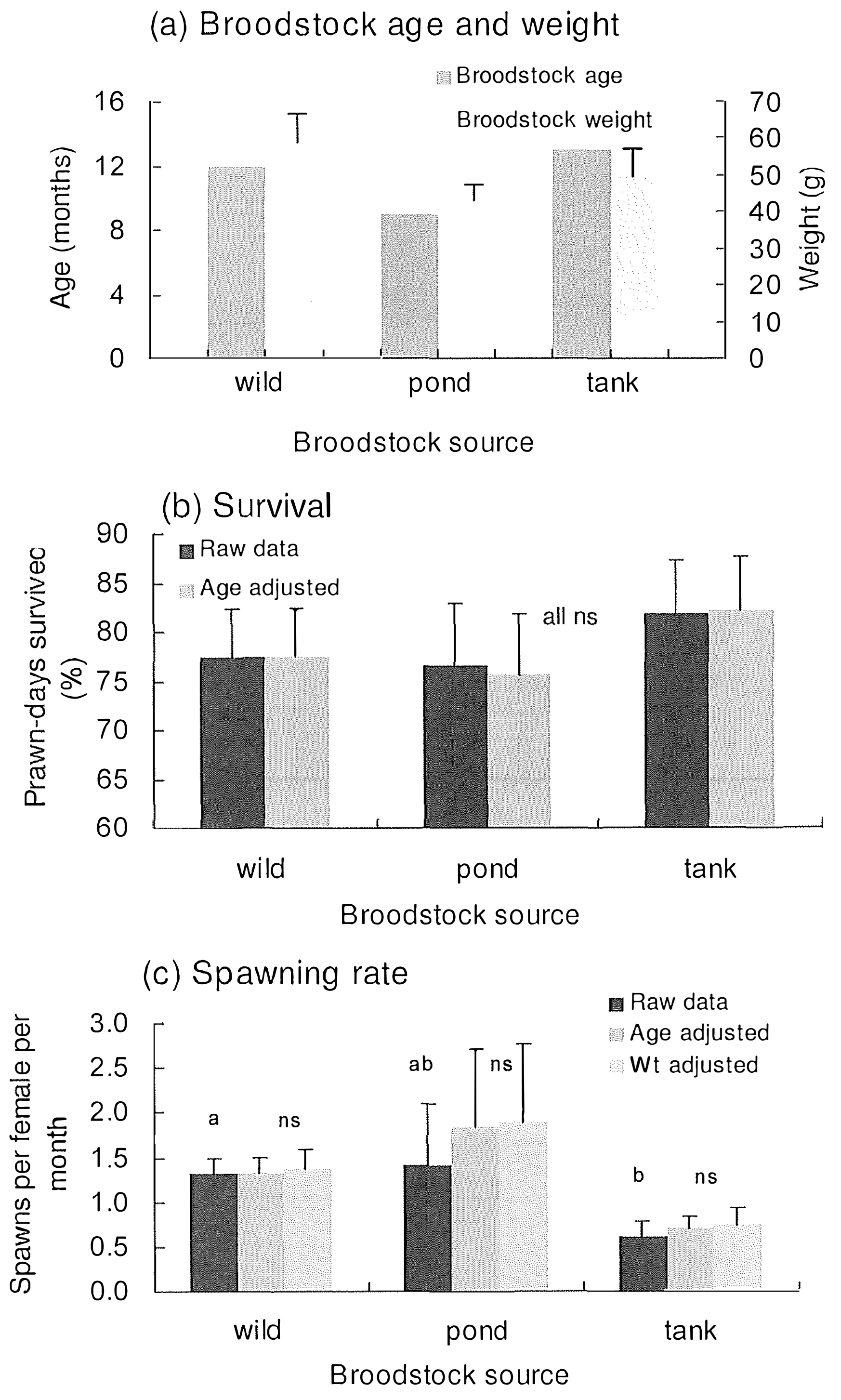


Figure 5.4. *Penaeus esculentus*: Comparative reproductive performance of wild, pond-reared and tank-reared broodstock in standardised reproductive performance trials. (a) Survival of broodstock, (b) Maturation rate (mean number of maturations to ready-to-spawn stage per female per month), (c) Spawning rate (mean number of spawns per female per month).

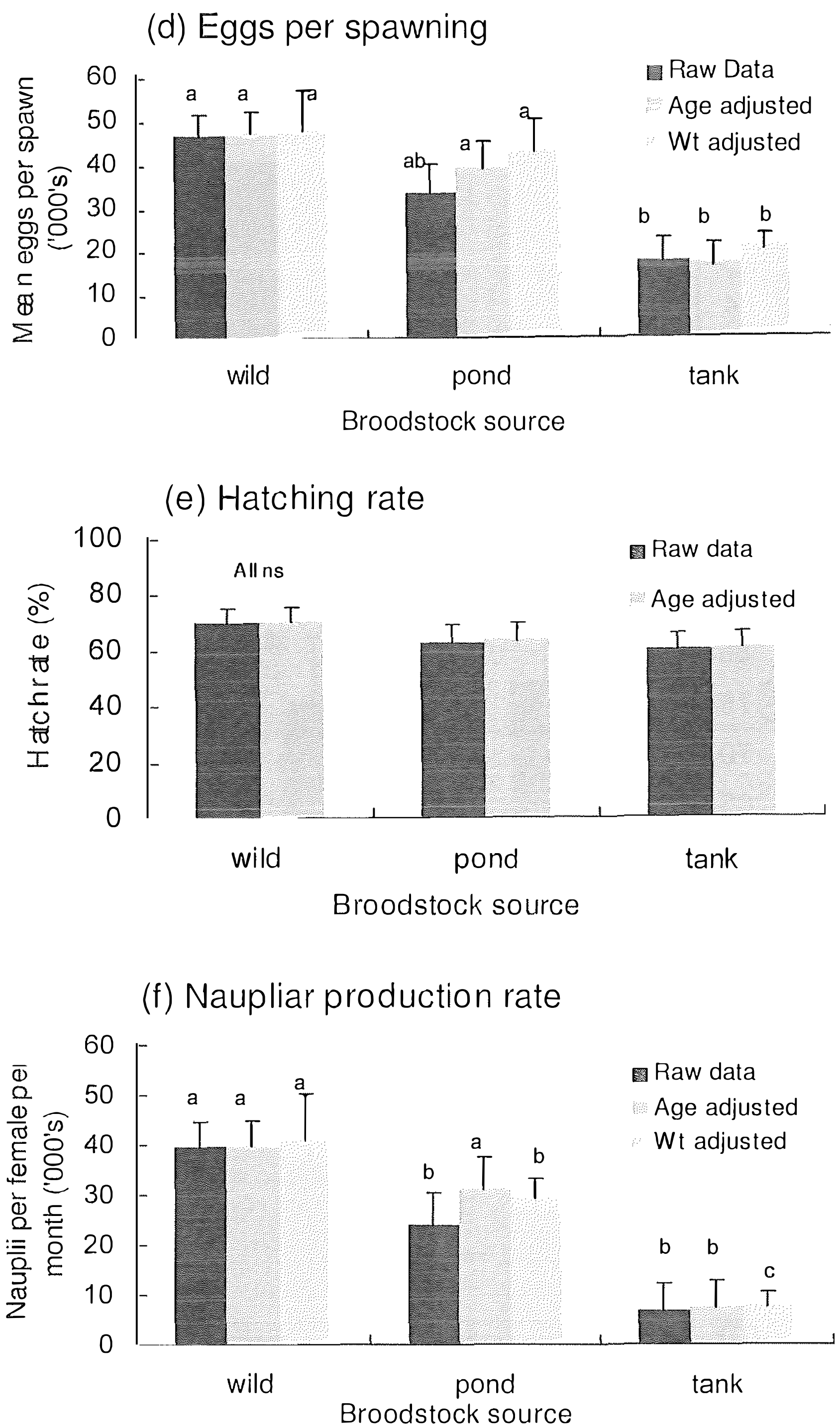


Figure 5.4 (cont). *Penaeus esculentus*: Comparative reproductive performance of wild, pond-reared and tank-reared broodstock in standardised reproductive performance trials. (d) Mean number of eggs per spawning, (e) Mean hatching rate (%), (f) Mean naupliar production rate (nauplii per female per month). Within each plot, means with the same superscript were not significantly different (P>0.05).

The hatching rate of eggs spawned was not significantly different among the three broodstock groups, ranging from a mean of 71% for wild broodstock, 63% for pond broodstock to 62% for tank-reared broodstock (Fig. 5.4e).

The overall naupliar production rate is a function of the spawning rate, the number of eggs per spawning and the hatching success of the eggs produced. Hence the wild broodstock produced the highest mean number of nauplii per female per month as a result of the combination of a slightly higher spawning rate, a slightly higher number of eggs per spawning and a slightly higher hatching rate. For the unadjusted data, the wild broodstock produced a mean of 39,540 nauplii per female per month, pond broodstock 25,094, and tank broodstock 6,780 (Fig. 5.4f). When adjusted for age and size effects, the pond broodstock were not significantly different from the wild broodstock, but the tank broodstock still produced significantly less nauplii per female per month (Fig. 4f).

5.1.4 Discussion

The capacity for production of multiple generations of *P. esculentus* in both farm ponds and experimental tanks has been demonstrated. During the project, three generations (G1, G2 and G3) of *P. esculentus* were produced. At Rocky Point Prawn Farm (RPPF), two generations (G1 and G2) were grown in commercial ponds, and third generation (G3) progeny were produced from these G2 broodstock. Closed cycle production for three generations, growing the prawns from eggs to reproductive adults, was achieved wholly in tank systems at CSIRO (Fig. 5.2).

Closed cycle production in tanks:
The overall growth rate of *P. esculentus* grown entirely in the tank system were similar to that of the parallel stocks grown in ponds (Fig. 5.1). However, there was a lag-time of around 6 weeks involved, with the mean weight for the tank-grown stocks being lower at a similar time after stocking (Fig. 5.1). Following harvest of the pond-grown stocks and transfer to the CSIRO tanks for on-growing to broodstock size, the growth rate of these stocks were again similar to that of the wholly tank-grown stocks (Fig. 5.1). We considered it likely that the natural biota in the pond system constituted an additional food source for the early stage postlarvae and juveniles, thus promoting their faster growth in these early stages. By comparison, the tank-grown stocks were completely reliant on the formulated feed supplied. Growth of the tank-reared stocks in these early stages was likely slowed by the lack of a supplementary natural-biota food source. To test this hypothesis, we carried out several experiments to evaluate the effects of a supplementary natural-biota food source for the early stages of tank growout. The provision of natural feed supplementation was shown to improve the growth of early juvenile stages (see section 7).

To advance the development of genetic improvement of *P. esculentus,* there is a need for the capacity to produce multiple generations of stocks grown in a controlled-environment tank system. This capacity enables the quantification of genetic parameters (for example, measures of heritability and response to selection) in a controlled system where the genetic and environmental effects can be separated (Hetzel *et al.* 2000). In addition, it is possible to produce and manage selection lines independently of a farm-based growout system, thus providing greater security against disease and farm-production constraints for the selection lines. The demonstrated production of three generations of *P. esculentus* wholly in tanks provides a foundation for future research and development for the genetic improvement of this species.

Closed cycle production in ponds:
Broodstock were collected at harvest from a commercial crop of first-generation (G1) prawns at Rocky Point prawn farm, then on-grown to broodstock size in maturation tanks at CSIRO. These broodstock were spawned at 12 months of age to produce a second-generation (G2) crop at Rocky Point prawn farm, thus demonstrating the capacity to produce closed-cycle stocks on-farm. Again, at harvest, prawns from this G2 stock were on-grown in tanks to broodstock size, and spawned to produce G3 progeny (Fig. 5.2).

Having established the feasibility of farm-scale closed cycle production for *P. esculentus*, there is now the potential for selection of the faster growing prawns at harvest, on-growing these to broodstock size and spawning them to produce a potentially faster-growing next generation. Importantly, it is possible to produce reproductively capable pond-grown broodstock within the 12-month commercial production cycle. Using this mass selection approach, significant gains in on-farm growth performance have been achieved with another species, *P. japonicus*, in Australia (Preston and Crocos, 1999). Gains of around 13% in growth and a resultant 21% increase in value have been achieved from second-generation selected stocks on a commercial farm. These gains in production efficiency are cumulative and permanent once a selective breeding program is in place. Similar benefits from selective breeding could potentially be achieved with *P. esculentus*; thus improving the cost-benefit of production for this species (see section 8).

Comparative reproductive performance of wild and domesticated broodstock:
The domestication and genetic improvement of farmed prawns has been relatively slow compared to that of some other aquaculture species and most terrestrial livestock. The principal barriers have been the ready availability of wild prawn broodstock and postlarvae, a lack of understanding of prawn reproductive biology and perceptions of low genetic variation among prawns. At the forefront of concerns about the potential for prawns to be successfully grown from domesticated broodstock at a commercial scale was the perception that pond-reared spawners could not provide an equivalent reproductive output to that of wild-sourced spawners.

In this project, the protocols developed for the on-growing of pond-grown broodstock, and the subsequent maturation and spawning protocols for *P. esculentus* have resulted in reproductive performance from captive broodstock at a level comparable to broodstock captured from the wild fishery. In standardised experimental evaluation of reproductive performance, the spawning rates for pond-grown broodstock were higher than for wild spawners and hatch rates were the same (Fig. 5.4). Due to the larger size, and therefore fecundity (Crocos, 1987), of the wild spawners, the slightly higher number of eggs per spawning, combined with identical hatching rates, resulted in a slightly higher overall, but non-significant, production of nauplii for the wild spawners (Fig. 5.4). Even so, the pond-reared spawners demonstrated a level of reproductive output sufficient for hatchery production at a commercial scale (see section 6).

The spawners grown entirely in tanks from egg to adult-broodstock size had significantly lower spawning rates and numbers of eggs per spawning, and consequently a lower naupliar production rate compared to the wild and pond-grown broodstock (Fig. 5.4). The lower reproductive performance of this group did not prevent closed-cycle production at a tank scale (see section 6), but these spawners would likely not be suitable for commercial-scale hatchery production. Further improvements to the tank growout protocols, particularly with early-stage nutrition, may improve the ultimate reproductive performance of broodstock reared in this manner.

Summary:

The current reliance of the prawn farm industry on wild broodstock is risky, inefficient and precludes the opportunity to enhance production through selective breeding and controlling the spread of disease. Farming of *P. monodon* in Australia is constrained by the limitations of using wild broodstock: unpredictable supply of broodstock and consequent delays in stocking combined with the lack of opportunity for selective breeding and disease management. In many countries with substantial prawn farming industries, particularly those in Asia, belated efforts to domesticate broodstock are now hampered by a very high incidence of viral diseases in farm stocks.

In Australia, research advances by CSIRO in prawn domestication and selective breeding, have placed Australia in a favourable position to make rapid advances in genetic improvement of farmed prawns. The techniques for domestication of *P. esculentus* developed and demonstrated in the course of this project clearly support the reality of closed-cycle production at a commercial scale for this species.

5.2 Larval rearing for *P. esculentus*

5.2 Larval rearing for *P. esculentus*

5.2.1 Background

Efficient production of larvae in a commercial aquaculture hatchery requires the larvae to be reared at an optimal temperature. An optimal rearing temperature is critical for good larval survival, growth rate and uniformity of development. In Australia, the optimal rearing temperature for the established prawn aquaculture species, *P. japonicus* and *P. monodon,* is 28 to 30°C. *Penaeus esculentus* is a relatively new species to aquaculture and little research has been done on commercial larval production. This study was designed to determine an optimal rearing temperature for the larval culture of *P. esculentus.*

5.2.2 Objective

- Evaluate the effect of different rearing temperatures on larval survival and development from nauplii to mysis stage 1.

5.2.3 Methods

Larval rearing experiments were carried out to compare the survival and development time of larvae from nauplii to mysis at rearing temperatures between 24°C and 28°C. Two trials were carried out. A pilot trial used larvae from a single spawning reared at three temperatures (24°C, 26°C and 28°C). The outcome of this trial determined the treatment temperatures (26°C and 28°C) used for the second trial.

Spawnings for these experiments were from wild-caught broodstock collected from Moreton Bay, Queensland, and held at the CSIRO, Cleveland laboratories. Management of the spawners and spawning were carried out according to the protocols described by Crocos and Coman (1997). Each trial was conducted with larvae from a single spawning.

Treatments in all experiments had at least 7 fed replicates and 2 starved replicates, each comprising of 1.2 l plastic bottles stocked with 100 larvae from a single spawning. The treatment temperatures were maintained within ±1°C by incubating the bottles in a water bath. Nauplii were counted into the larval bottles with an electronic particle counter. A stocking error was calculated from test counts and the stocking number adjusted accordingly.

All fed-treatments were provided with *Chaetoceros muelleri* at a nominal rate of 1 x 10^5cells/ml. The seawater in each container was exchanged every 2 d. The larvae were staged regularly throughout the experiment. The experiment was ended 12 h after the first mysis was sighted. At this point, the larvae for that treatment were collected and fixed in 70% ethanol, then counted and staged. Development time from hatching to mysis 1 was calculated from a recorded hatching time and the time the treatment was collected and fixed.

Starved treatments were continued until no live larvae remained. The time of "total death" was recorded and used as a subjective indicator of the quality of the spawning. Survival was calculated as a percentage of the number originally stocked. A growth index was calculated from the number of remaining larvae at each substage and used to summarise the stage of development in each bottle. The growth index (modified from Villegas & Kanazawa, 1980) was calculated using the formulae:

$$Growth\ Index = (\Sigma A)/n$$

where n is total number of surviving larvae, and A is the larval substage (protozoea I, A = 1; protozoea II, A = 2; protozoea III, A = 3; mysis I, A = 4 etc).

For example, if a sample contained 5 protozoea III and 10 mysis I, the growth index would be [(5x3)+(10x4)]/15 = 3.67

A biomass index was used to summarise the interaction between developmental stage and survival at a particular point in the development cycle. The Biomass Index is the sum total of all the stages present (ΣA).

$$Biomass\ Index = \Sigma A$$

where A is the larval substage (protozoea I, A = 1; protozoea II, A = 2; protozoea III, A = 3; mysis I, A = 4 etc).

The uniformity of development was measured by comparing the coefficient of variation of the growth and biomass indexes. The quality of the larvae within a spawning was assessed by comparison with the survival time of two starved replicates per treatment per experiment. Differences in the survival, growth index and biomass index at the different temperature treatments were compared by analysis of variance using the SAS (SAS Institute) software. Where appropriate, differences between temperature treatments were tested using Tukey's pairwise comparison.

5.2.4 Results and Discussion

Pilot trial:

The performance of the starved replicates indicated that the particular spawning used in the pilot trial was poor (Fig. 5.5a). Consequently, larval survival was low in all treatments (mean 32%, 34% and 14% for 24°C, 26°C and 28°C, respectively). In addition, survival was also highly variable and consequently, no significant difference was found between survival or growth at any of the treatment temperatures ($P<0.05$). Despite this there was a marked trend for a difference in growth between treatments.

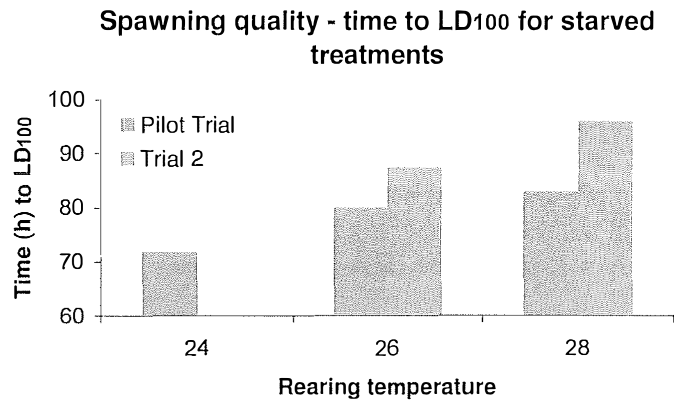


Fig 5.5a Spawning quality assessed by the length of time it took for all starved individuals to die.

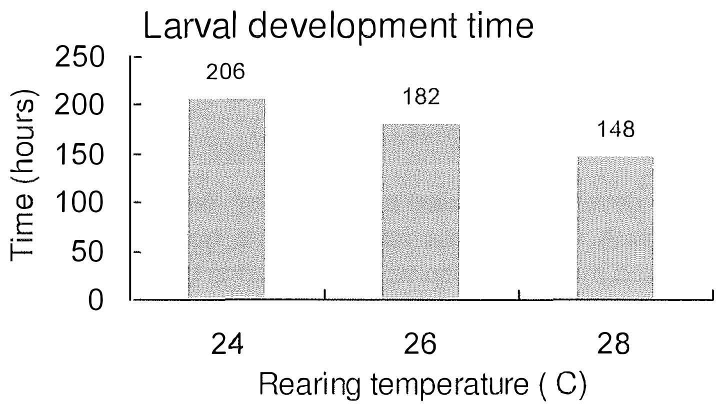


Figure 5.5b. Pilot trial: Development time from hatching to mysis stage1 at 3 larval rearing temperatures 24°C, 26°C and 28°C.

Development time (or growth rate) from hatching to mysis 1 was affected by temperature. The larvae in the 28°C treatments turned to mysis 1 approximately 5.7 d after hatching, at 26°C the larvae turned approximately one day later (at approximately 6.7 days), and at 24°C turned another day and a half later again (at approximately 8 days) (Fig. 5.5b).

Although survival was highest at 24°C the large coefficient of variance of the growth index indicated there was a large variation in the development stage achieved (Fig. 5.6a). Survival was lowest at 28°C with less surviving individuals reaching mysis, as indicated by the growth and biomass indices (Fig. 5.6 a, b). The replicates at 26°C had high growth and biomass indexes and correspondingly low coefficients of variance, indicating better survival and consistent development to mysis at 26°C (Figs. 5.5b, 5.6).

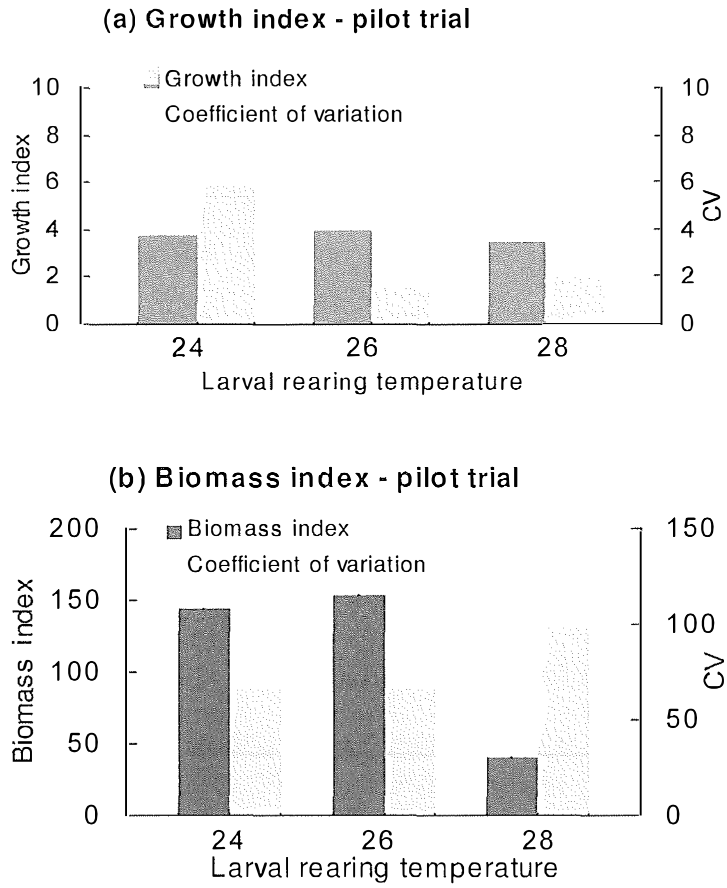


Figure 5.6. Pilot trial: Comparative growth indices and corresponding coefficients of variance for *P. esculentus* larvae reared at 24°C, 26°C and 28°C, (a) growth index, (b) biomass index.

There was no statistically significant difference between the survival and development of the larvae at any of the temperatures. However, development rate was slower and more variable at 24°C than at the higher temperatures (Fig. 5.5b). Time is a critical factor in a commercial hatchery situation, consequently it was considered commercially impractical to rear larvae at 24°C, hence the second experiment compared rearing at 26°C with the industry standard of 28°C.

Trial 2: Comparison of 26 °C and 28 °C rearing temperatures:
Since there was no significant difference ($P<0.05$) between results from the pilot trial and the second experiment for temperatures of 26°C and 28°C, the two experiments were grouped for the following analysis (Table 5.1).

Effects	d.f.	Survival		Growth Index		Biomass Index	
		MS[a]	Pr > F	MS[a]	Pr > F	MS[a]	Pr > F
Experiment	1	0.38	0.0747	0.00	0.9717	49367	0.0710
Temp	1	0.62	0.0253	1.19	0.0392	85186	0.0203
Expt x Temp	1	0.00	0.8849	.001	0.8094	285	0.8872
Error	26	0.11		0.25		13928	
R^2		0.26		0.18		0.27	

[a]Type III Mean Squares

Table 5.1. ANOVA results for the combined trials

Survival of the larvae was 47±8% at 26°C and 21±7% at 28°C. The mean growth index was also significantly higher at 26°C than 28°C (3.93^a and 3.51^b, respectively) (Fig. 5.7a). On average 48% of the initially stocked nauplii grew to mysis stage 1 in the 26°C treatment compared to 18.6% at 28°C. Furthermore, development was more consistent at 26°C than at 28°C, as indicated by the difference in the coefficients of variation (1.78% and 18.6%, respectively) (Fig. 5.7a). The biomass index was 193.1 ± 22.38 at 26°C, which was significantly greater than 86.67 ± 30.01 at 28°C ($P<0.05$), indicating more individuals survived and reached mysis stage 1 at 26°C (Fig. 5.7b). However, larvae at 28°C developed to mysis stage 1 a day earlier than those at 26°C.

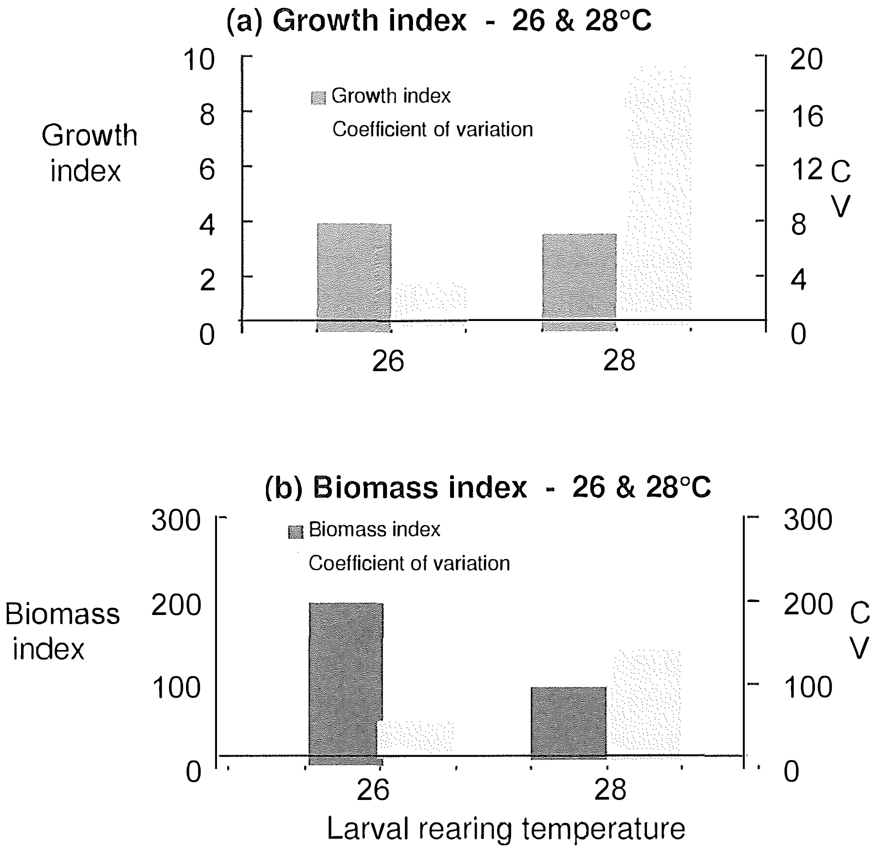


Figure 5.7. Trial 2: Comparative growth and biomass indices and corresponding coefficients of variation for *P. esculentus* larvae reared at 26°C and 28°C. (a) growth index, (b) biomass index.

This study indicates that 26°C is a more suitable larval rearing temperature for early stage *P. esculentus* larvae than 28°C. Not only did the larvae show a 20% improvement in survival at 26°C but they also had a higher proportion turn to mysis within a 12 h development window. Healthy, robust larvae growing in suitable conditions will develop uniformly through the larval stages. Hatchery protocols are designed to rely on uniform development. Improved survival and more uniform development at 26°C suggests this temperature is more suitable for rearing *P. esculentus* larvae and that the uniformity of development would compensate for the slightly longer development time compared to 28°C.

6. Growth performance in farm culture conditions

6.1 Objective

- To quantify the growth performance of *P. esculentus* under commercial farm culture conditions.

6.2 Methods

Over the duration of the project, growout trials for *P. esculentus* were carried out in growout seasons 1995/96, 1996/97 and 1998/99. The 1995/96 trial was a small-scale comparison of the growth performance of *P. esculentus* and *P. japonicus* co-stocked in a 1 ha pond at Rocky Point prawn farm, using *P. japonicus* feed exclusively. In 1996/97, *P. esculentus* was grown at four farms in southeast Queensland, and one farm in north Queensland, using *P. monodon* feed but supplemented on one farm with *P. japonicus* feed. In 1998/99, two farms grew *P. esculentus* using the specific diet formulated by CSIRO.

Comparative trial, P. esculentus and P. japonicus, 1995/96:
During the 1996 growout season, a single pond at Rocky Point prawn farm was co-stocked with *P. japonicus* and *P. esculentus* postlarvae produced at the Rocky Point hatchery. The 1 ha pond was stocked at 30 prawns per m^2, comprising 50% *P. japonicus* and 50% *P. esculentus*. The pond was fed with *P. japonicus* formulated diet (Higashimaru), and managed according to normal *P. japonicus* growout practice. Each fortnight during the growout season, a sample of 60 prawns (~30 females and 30 males) per pond was taken using a cast-net and the individual weights of both species were recorded.

Commercial trial, P. esculentus, - five farms, 1996/97:
In late November 1996, a commercial pond was stocked with *P. esculentus* at each of four farms in the Logan River region, southeast Queensland. Postlarvae (PL) were produced at the Rocky Point prawn farm hatchery and the Gold Coast Marine hatchery. At Rocky Point prawn farm 300,000 PLs were stocked to a 1 ha pond at 30 per m^2; at Gold Coast Marine 330,000 PLs were stocked to a 1 ha pond at 33 per m^2; at Rossman Brothers 220,000 PLs (ex Rocky Point hatchery) were stocked to a 1 ha pond at 22 per m^2; and at Truloff Prawn Farms 150,000 PLs (ex Rocky Point hatchery) were stocked to a 0.4 ha pond at 35 per m^2. Postlarvae raised from CSIRO tank-conditioned broodstock were successfully spawned at Rocky Point hatchery, and these seedstock were grown at Rocky Point Prawn Farm. In north Queensland, 350,000 PLs were stocked to a 1 ha pond at Seafarm in October 1996. At each farm the prawns were fed according to each farms' normal commercial practice using a diet formulated for *P. monodon*. At Gold Coast Marine, this diet was supplemented with a higher protein *P. japonicus* diet from March until harvest in early June. Pond management practices on each farm were the same as for normal commercial operations for the production of *P. monodon*.

For the four farms in southeast Queensland, a fortnightly sampling program was established to monitor growth performance during the production season. A sample of 200 prawns (100 females and 100 males) from each of the trial ponds was taken using a cast-net, and weights of individuals recorded. Sampling began in early February 1997 as prawns reached an appropriate size, and continued until harvest in early June 1997. Harvest data was available from the northern farm.

Commercial trial, P. esculentus, 1998/99:
In November 1998, a full-scale commercial growout trial was commenced at each of two farms: Gold Coast Marine Aquaculture and Rocky Point Prawn Farm, both on the Logan River, SE Queensland. At Gold Coast Marine a 0.8 ha pond was stocked with 275,000 PLs (~34 per m^2), and at Rocky Point a 0.4 ha pond was stocked with 110,000 PLs (~28 per m^2). The PLs were produced at the respective farms' hatcheries. The prawns were fed the CSIRO/FRDC formulated feed developed as part of this project specifically for *P. esculentus* (see section 8).

Fortnightly monitoring of the growth performance of the stocks in each pond commenced in January 1999, when the prawns had reached a size sufficient to enable quantitative sampling in the pond, and continued until harvest. A sample of 200 prawns (100 females and 100 males) was collected by cast-net and individual weights recorded. Pond management practices during the growout period were as for normal commercial production.

Assessment of growth performance
Growth performance for each trial was evaluated using a Gompertz growth function. The first step was to estimate growth curves, Both Gompertz and Logistic growth functions were tested but it was found that *P. esculentus* growth is better described by the Gompertz function.

The Gompertz equation is:

$$w_t = \alpha_E \cdot \exp(-\beta_E \cdot \exp(-\gamma_E \cdot t))$$

where t represents growout time in weeks, w_t represents prawn weight (g) at any time t, and the parameters α_M, β_M and γ_M are estimated statistically based on the data. When t=0 weight is described by $w_0=\alpha_M/(1+\beta_M)$ and as $t \to \infty$ w_t approaches α_M, thus this parameter represents the maximum weight achievable during a growing season. The parameter γ_M is the intrinsic growth rate. When t=0 weight is described by $w_0=\alpha_E \cdot \exp(-\beta_E)$ and as $t \to \infty$ w_t approaches α_E, thus this parameter represents the maximum weight achievable during a growing season. The parameter γ_E is directly related to growth potential of the species.

Assessment of mortality:
In order to estimate prawn yields and feed efficiency it was necessary to obtain a mortality estimate. This was based on the yields reported for GCMH in 1996/97 where: 330,000 PLs were stocked in a 1-ha pond in late November 1996 and 4.6 t were harvested in early June 1997. The mean prawn weight was 20g, therefore there were approximately 230,000 prawns in the pond at harvest time. The growout season lasted approximately 26 weeks, therefore the weekly mortality rate was estimated to be 0.0139. This was estimated by solving the growth function $N_t = N_0 \cdot \exp(-m \cdot t)$,

where N is the number of prawns and m is the mortality rate. Therefore, substituting our values we have $230000 = 330000 \cdot \exp(-m \cdot 26)$, which solves to:

$$m = -\ln(23/33)/26 = 0.0139.$$

Additional data were available in the form of stocking and harvest records from RPPF 1998/99. It was possible to estimate survival by assuming that any prawns stocked that were not reported as harvested died during the growing season. Another source of data was provided by harvest and sale information from GCMH for both 1996/97 and 1998/99. The resulting estimates will be subject to a high degree of uncertainty and are therefore an important target for sensitivity analysis in the cost-benefit section.

Feed conversion efficiency:
Feeding rates (kg per pond) were reported on a weekly basis while prawn weights (g per prawn) were measured at approximately fortnightly intervals. To gain an approximate estimate feed efficiency it was necessary to transform feeding rates to a per-prawn basis, this calculation was based on the mortality rate estimated above and the actual number of PLs stocked in each pond.

6.3 Results

6.3.1 Growth performance of *P. esculentus*

Comparative trial, P. esculentus and P. japonicus, 1995/96
Fortnightly growth monitoring began in late-November 1995 approximately 4 weeks after stocking; at this time the mean weight for *P. esculentus* was 1.8 g and *P. japonicus* was 1.7 g (Fig. 6.1). By the middle of the growout season (early February, 14 weeks),

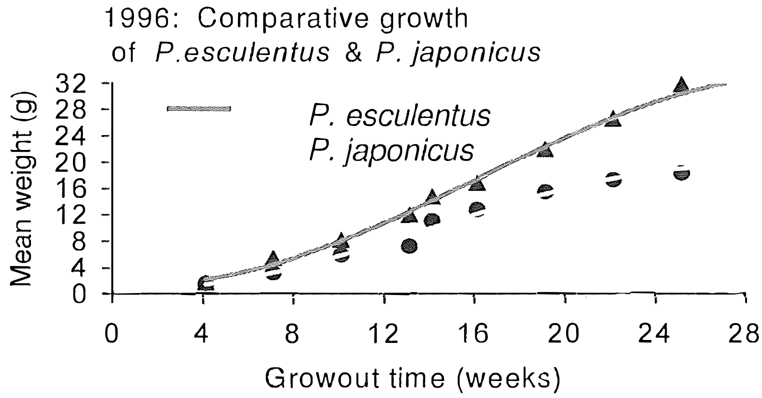


Figure 6.1. Comparative growth performance of *P. esculentus* and *P. japonicus* grown in the same pond at Rocky Point prawn farm.

P. esculentus had grown to a mean weight of 15.0 g and *P. japonicus* to 11.2 g. At harvest in May, after 28 weeks growout, *P. esculentus* had grown to a mean weight of

31.9 g and *P. japonicus* to 19.9 g (Fig. 6.1). This pilot trial demonstrated the capacity for *P. esculentus* to be successfully grown in ponds at a commercially acceptable growth rate when fed a high protein *P. japonicus* diet.

Commercial trial, P. esculentus, - four farms, 1996/97
Fortnightly sampling at all 4 farms was established by early February, approximately 12 weeks into the growing season. At this stage each farmer reported favourable growth and survival of *P. esculentus*. Variation in the size of prawns at each farm was due to differences in age, stocking density, feed type and pond conditions. The mean weight of prawns after 12 weeks of growout at Gold Coast Marine was 7.4 g; at Rocky Point 5.6 g; at Truloff's 7.2 g ; and at Rossman's the mean weight was 6.8 g (Fig. 6.2). In the Gold Coast Marine stocks, evidence of a growth plateau was observed at about 12 g (weeks 15 to 17) where the prawns had seemingly stopped growing. As a result of this concern, the feeding strategy was changed at this time, with the *P. monodon* feed used to date being supplemented with 30% *P. japonicus* feed for the remainder of the growout period.

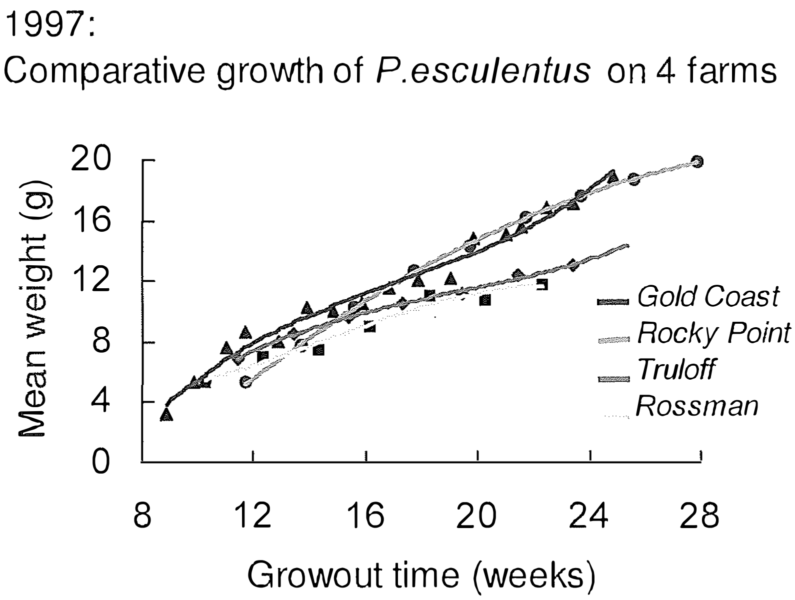


Figure 6.2. Comparative growth performance of *P. esculentus* at the 4 Logan River farms in 1997.

By harvest in late May to early June, the prawns at Gold Coast Marine had grown to a mean weight of 19.7 g (26 weeks growout), at Rocky Point 19.8 g (28 weeks), at Truloff's 13.6 g (25 weeks) and at Rossman's to a mean weight of 11.9 g (22 weeks) (Fig. 6.2). The pond at Truloff's farm was maintained at a high stocking density for the whole season due to the unavailability of a planned larger pond to complete the *P. esculentus* growout. If this larger pond had become available, the stock would have been thinned out and grown at a lower density in a pond with more appropriate water quality management. At Rossman's farm, the crop was harvested early as the growth rate was lower than expected. This was largely a consequence of the very high effective stocking density due to a large co-existing pond population of *M. bennettae,* which had apparently developed from spawners taken in from the river with the incoming water. Hence the relatively slower growth at the Truloff's and Rossman's farms was likely associated with the continuing problems of high density and lack of a suitable production pond. The very high effective stocking density at Rossman's due to the large population of competing *M. bennettae* in the pond had a similar effect. At Seafarm in north Queensland, growth was not monitored through the growout season, but the prawns grew to a mean size of 20 g by harvest in March 1997.

Commercial trial, P. esculentus, 1998/99, and comparison with 1996/97 trial
Growth rates for *P. esculentus* at both Gold Coast Marine and Rocky Point farms in 1998/99 were lower than for the 1996/97 trial (Figs. 6.3, 6.4). In 1999, prawns at Gold Coast Marine were harvested at a mean weight of 16.3 g after 28 weeks growout, compared to a mean harvest weight of 19.7 g after 26 weeks in 1997 (Figs. 6.2, 6.1).

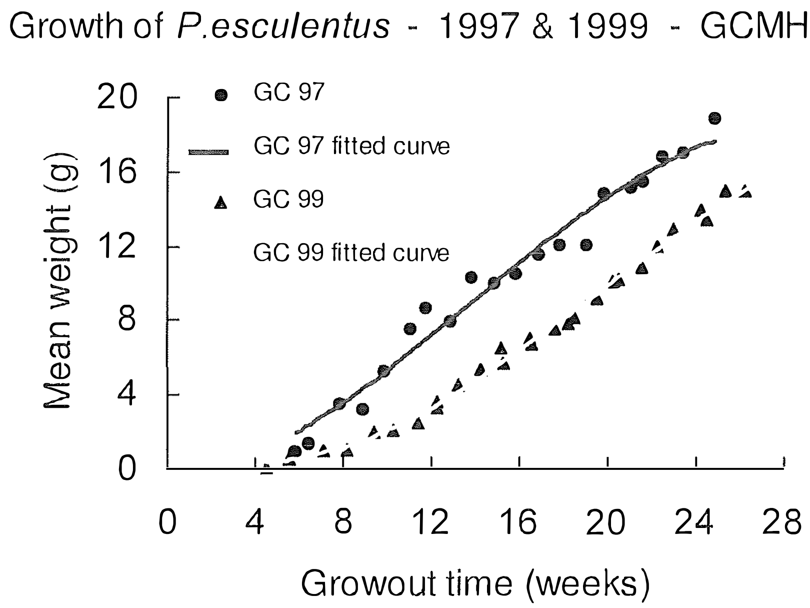


Figure 6.3. Comparative growth performance of *P. esculentus* at Gold Coast Marine in 1997 and 1999.

At Rocky Point prawn farm in 1999, the growth rate of prawns, and hence the harvest size were lower than for 1997. The 1999 crop was harvested at a mean weight of 12.9 g after 24 weeks growout, whereas in 1997 the prawns grew to 19.8 g in 25 weeks (Fig. 6.4).

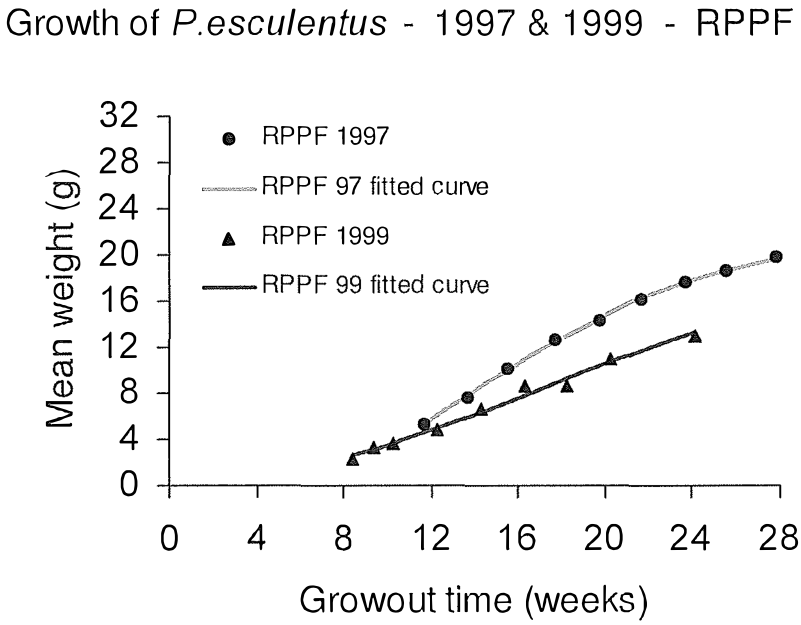


Figure 6.4. Comparative growth performance of *P. esculentus* at Rocky Point Prawn Farm in 1997 and 1999.

The parameters estimated for *P. esculentus* from the Gompertz growth function indicate that the maximum mean weight achievable in a growing season of 26 weeks is 22.7g (Table 6.1). This mean is based on estimates for W_{max} of 22.2 g and 23.3 g for Gold Coast Marine, 1997 and 1999 respectively, and 22.4 g and 23.1 g for Rocky Point, 1997 and 1999 respectively.

Table 6.1. Parameter estimates for *P. esculentus* growth, Gompertz equation. W_0 and W_{max} represent estimated initial weight and maximum weight based on parameter values.

	Growout trial				
Parameter	**GCMH-97**	**GCMH-99**	**RPPF-97**	**RPPF-99**	**Mean**
α_E	22.1698	23.3426	22.4179	23.0490	22.7448
β_E	5.4109	5.5614	17.4946[a]	5.8845	5.6189
γ_E	0.1205	0.1038	0.1497	0.0878	0.1155
W_0	0.099	0.090	0.000	0.064	0.083
W_{max}	22.17	23.34	22.42	23.05	22.74

[a] This estimate may not be accurate because sampling started in week 16.

Pond temperatures during growout seasons 96/97 and 98/99:

The seasonal pond temperature regimes for GCMH for the 96/97 and 98/99 trials for *P. esculentus* were similar for the 2 years. Twice-daily pond temperatures were recorded for the *P. esculentus* growout ponds at GCMH (Fig. 6.5;). The fitted regression lines indicated similar overall trends through the season for both years (Fig, 6.5a). The moving 30-day mean pond temperature trend indicated a warmer start to the 96/97 season (from 4 to 8 weeks), but this was offset by a prolonged cooler period from 8 to 14 weeks by comparison to the 98/99 season (Fig. 6.5b).

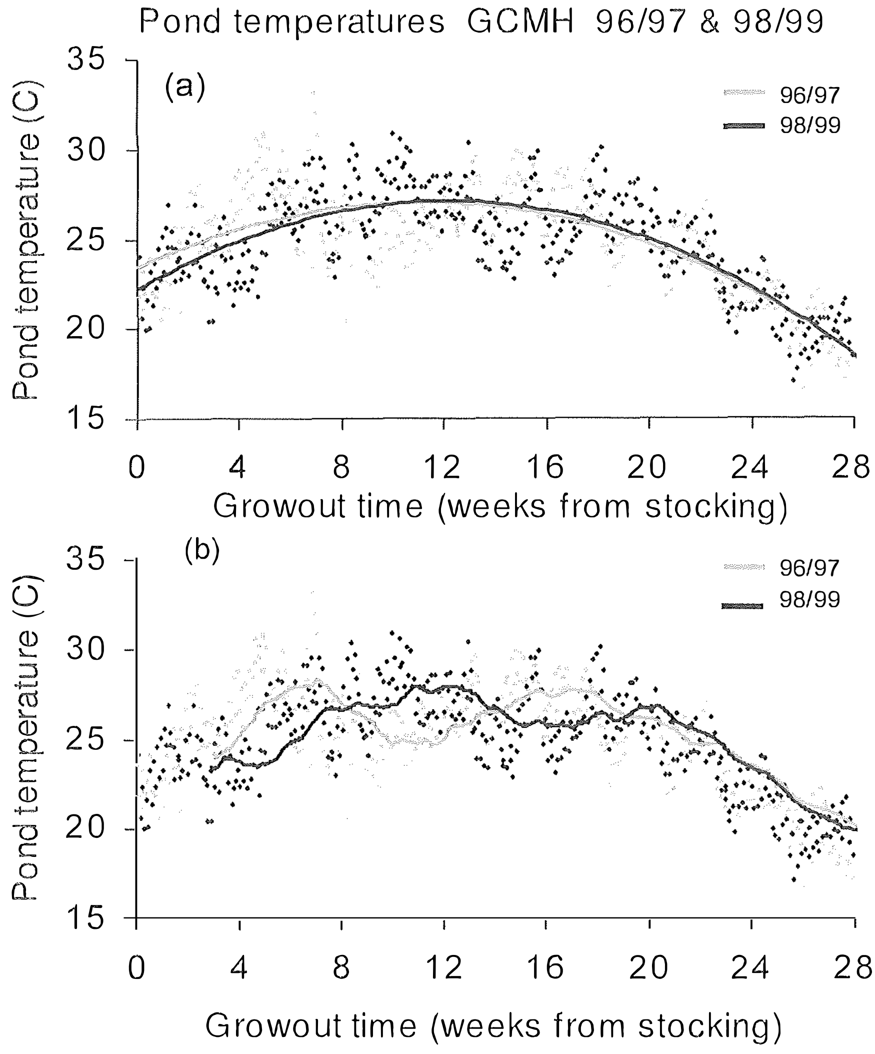


Figure 6.5. Pond temperatures (°C) for the *P. esculentus* growout ponds at GCMH for growout seasons 1996/97 and 98/99. (a) Fitted regression. (b) Moving 30-day mean. Data courtesy Malcolm Austin, CSIRO Marine Research, and CRC for Aquaculture.

Comparative growth of P. esculentus and P. monodon

In the 1998/99 growing season, three ponds of *P. monodon* at GCMH were monitored throughout the season to enable a comparison of growth performance with the *P. esculentus* trial. The three ponds of *P. monodon* showed consistent growth rates, with the stock reaching a mean size of 25 to 27 g at harvest, after a growout period of 20 to 22 weeks (Fig. 6.6). Even though comparison between years can only be approximate, *Penaeus monodon* grew faster than *P. esculentus*, with the best growth for *P. esculentus* being a mean size of 20 g in 26 to 28 weeks in the 1997 trial (Fig. 6.6). Despite this faster in growth rate, the *P. monodon* crops had a higher cost of production (higher total tonnage of feed used (Fig. 6.8)), and the crop received a lower price per kg at harvest (Table 8.1). Hence the resultant difference in profitability was not as marked as the difference in growth rates (see section 9).

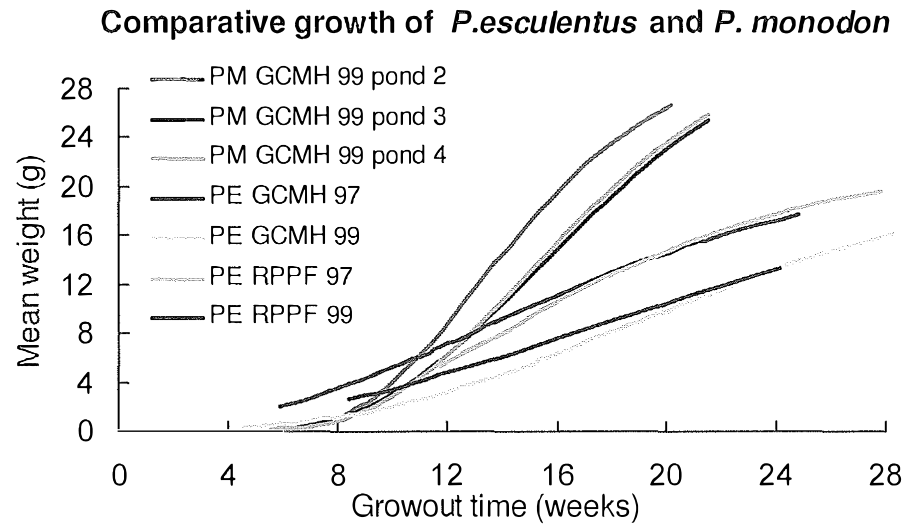
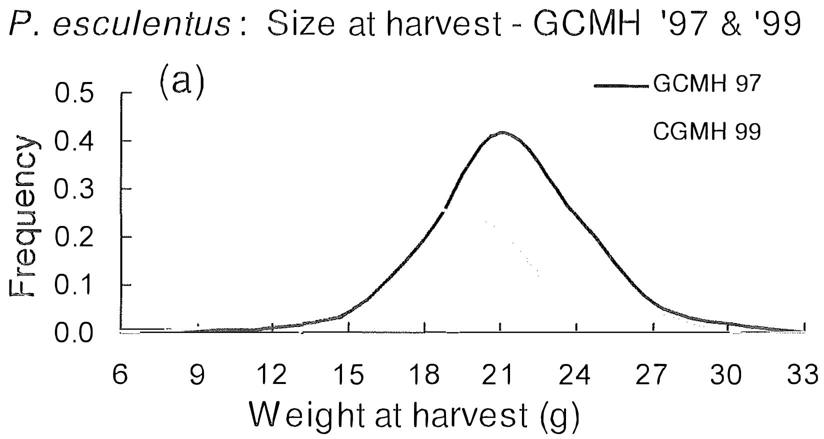


Figure 6.6. Comparative growth of *P. esculentus* (PE), 1997 and 1999, and *P. monodon* (PM), 1999, on two farms, Gold Coast Marine (GCMH) and Rocky Point (RPPF). The *P. esculentus* data is the same as that expressed in Figs 6.2, 6.3, and 6.4.

6.3.2 Size distribution at harvest

Commercial trial, P. esculentus, 1999, and comparison with 1997 trial



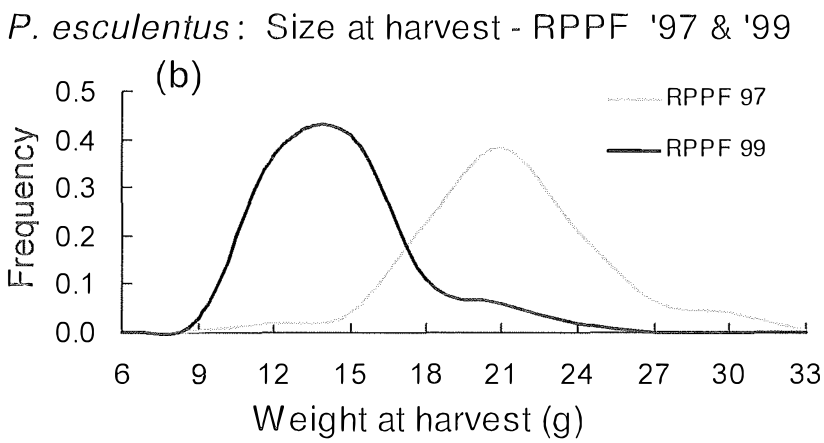


Figure 6.7. *Penaeus esculentus*: Size distribution at harvest, (a) Gold Coast Marine and (b) Rocky Point prawn farms, 1997 and 1999 commercial trials.

Size distribution at harvest is an important production parameter since the price received per kg depends on the size of individual prawns. At both Gold Coast Marine and Rocky Point prawn farms, the mean size at harvest and the overall size distribution was smaller in 1999 compared to 1997. At Gold Coast Marine, the mean size at harvest was 19.7 g (± 3.45 g) in 1997 and 16.3 g (± 3.49 g) in 1999, with a range of 5 to 30 g in 1997 and 9 to 26 g in 1999 (Fig. 6.7a and Table 6.1). At Rocky Point, the mean size at harvest was 19.8 g (± 3.71 g) in 1997 and 12.9 g (± 2.87 g) in 1999, with a range of 9 to 31 g in 1997 and 7 to 22 g in 1999 (Fig. 6.7b and Table 6.2). Coefficients of variation (CV) ranged from 0.18 to 0.22 (Table 6.2).

Hence overall growth conditions were more favourable in 1997 then in 1999. Furthermore, there were virtually no differences between farms in 1997, whereas the prawns at GCMH performed better than in RPPF during 1999.

Table 6.2. Size distribution of *P. esculentus* at harvest, summary statistics.

	RPPF-97	GCMH-97	RPPF-99	CGMH-99
N	214	318	100	100
Mean	19.84	19.67	12.98	16.31
SD	3.71	3.45	2.87	3.49
CV	0.19	0.18	0.22	0.21
Min	8.50	4.90	7.30	8.70
Max	30.60	29.26	21.70	25.80

The measurements in Figure 6.7 suggest that harvest weights conform to a normal distribution. This assumption was used to simulate growth of both *P. esculentus* and also for *P. monodon* for comparative purposes in the cost-benefit analysis (section 9). In the absence of direct information for *P. monodon* it was assumed that the CV for this species was 0.2, which is within the range estimated for *P. esculentus*. Therefore, for the purposes of comparison in the cost-benefit analysis, the predicted harvest weight and coefficients of variation for each species were used to estimate standard deviation, this information was then used to distribute the harvest into size intervals based on a normal distribution.

6.3.3 Mortality

In order to estimate prawn yields and feed efficiency for the cost-benefit analysis, and to compare *P. esculentus* and *P. monodon* it was necessary to obtain a mortality estimate for both species. Mortality estimates for *P. esculentus* were obtained using several sets of data: farm-stocking data, size at harvest and yield for GCMH and RPPF in 1997 and 1999. Mortality was estimated for *P. monodon* from the stocking and yield data for 1999. For *P. esculentus* the yields obtained for GCMH-97 were as follows: 330,000 PLs were stocked in a 1 ha pond in late November and 4.6 t were harvested in early June. The mean prawn weight was 20 g, therefore there were approximately 230,000 prawns in the pond at harvest time. The season lasted approximately 26 weeks, hence the weekly mortality rate was estimated to be 0.0139. This estimate was obtained by solving the growth function $N_t = N_0 \cdot \exp(-m \cdot t)$, where N is the number of prawns and m is the mortality rate. Hence:

$230{,}000 = 330{,}000 \cdot \exp(-m \cdot 26)$, which solves to $m = -\ln(23/33)/26 = 0.0139$.

Additional data from the stocking and harvest records from RPPF 99 for both species were also used. The ponds in this experiment were subject to partial harvests during the growing season, however it was possible to estimate survival by assuming that any prawns stocked that were not reported as harvested died during the growing season. Another source of data was provided by harvest and sale information from GCMH for both years. The resulting estimates (Table 6.3) are subject to a high degree of uncertainty and are therefore an important target for sensitivity analysis in the cost-benefit exercise.

Table 6.3. Estimated survival (at harvest) and weekly mortality rates.

	Survival (%)		Mortality rate
	Mean	Range	
P. esculentus, 1997	66.0	63.2 - 68.9	0.0139
P. esculentus, 1999	64.9	59.6 - 70.3	0.0145
P. monodon, 1999	60.9	42.7 - 76.9	0.0207

6.3.4 Feed conversion efficiency - FCR

Feed conversion ratio estimates were also required for the cost benefit analysis. Feeding rate data (kg per pond) were collected on a weekly basis (Fig 6.8), and prawn weight data (g per prawn) was measured on a fortnightly basis.

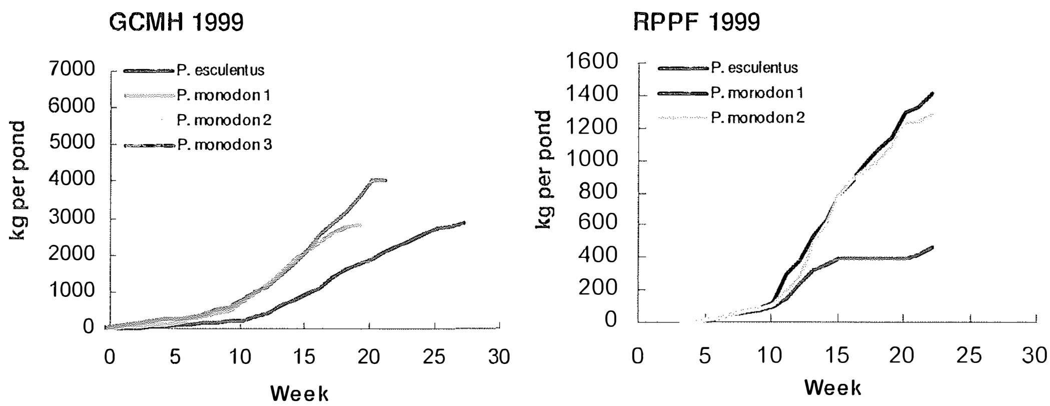


Figure 6.8. Feeding rates for GCMH and RPPF in the 1999 growout season, for *P. esculentus* and comparative data for *P. monodon*. Feeding rates are expressed as cumulative feed per pond (kg per pond). The farms supplied the feeding rate data.

To estimate feed conversion ratio, the feeding rate data was transformed to a per-prawn basis, with this calculation being based on the mortality rate estimated above and the actual number of postlarvae stocked in each pond. Feeding rates were much lower in RPPF because of partial harvesting was undertaken during the growing season.

The growth curves estimated previously were used to calculate prawn weight at 5-week intervals. Feed conversion ratio estimates, were obtained by dividing weight gain by feed consumed over each interval. In all cases feed ratio increases between week 5 and 10 and then decreases steadily. Presumably this is a result of the interaction between natural feed accumulated in the pond during the first few weeks of feeding and the transition period as juveniles start eating the artificial feed.

The average feed conversion ratio for the whole growing season ranges between 1.94 and 1.96 (Table 6.4). However these estimates are sensitive to the assumed mortality rate; by changing mortality rates within the ranges reported in Table 4 feed conversion ratio estimates ranged from 1.63 to 2.21. Obviously, this is another important variable for sensitivity analysis (section 9).

Table 6.4. Feed conversion ratio estimates for *P. esculentus* in 1997 and 1999, and *P. monodon* in 1999.

	P. esculentus		***P. monodon***
Week	**1997**	**1999**	**1999**
5	3.27	3.26	2.40
10	4.57	4.54	4.26
15	1.44	1.42	2.25
20	0.88	0.87	0.62
25	0.84	0.82	0.18
30	0.78	0.76	
Mean	1.96	1.95	1.94

6.4 Discussion

Growth performance

The initial small-scale pilot trial at Rocky Point Prawn Farm during the 1995/96 growout season, in which *P. esculentus* was co-stocked with a normal *P. japonicus* crop, demonstrated that *P. esculentus* had the potential to be successfully grown in ponds at an acceptable growth rate when fed a high-protein *P. japonicus* diet (Fig. 6.1). The trial demonstrated that *P. esculentus* could be grown to a marketable size in a period well within the conventional growout season for Australian prawn farms. This result confirmed the growth potential of *P. esculentus* and removed a major industry concern that this species has inherently slow growth in ponds. This positive outcome enabled us to move to the next phase and quantify the growth performance under commercial conditions, and begin to develop an appropriate cost-effective diet (see section 8).

The findings of the pilot trial stimulated the interest of several farmers in trialling *P. esculentus* under commercial conditions in the 1996/97 grow-out season. As a consequence we modified the research strategy slightly in order to accommodate this early interest by farmers. Initially, it was planned to undertake full-scale commercial trials in the third year of the project, once dietary requirements had been carefully established and an appropriate definitive feed could be formulated. However the interest shown by several farmers following the successful outcome of the pilot trial brought the commercial trials forward to the 1996/97 growout season, using existing feeds.

In the 1996/97 growout season, four farms in southeast Queensland, and one farm in north Queensland, stocked *P. esculentus,* and used predominantly *P. monodon* feed.

The growth performance achieved at Gold Coast Marine (GCMH) and Rocky Point (RPPF) farms resulted in a mean size of around 20g after 26 to 28 weeks of growout (Fig. 6.2). Results were similar at Seafarm in north Queensland, but growth data through the season was not available for this farm. Production at the other two Logan River farms, Truloff's and Rossman's, was lower with the crops being harvested at a mean size of around 12 to 14 g after 22 to 14 weeks growout (Fig. 6.2). The lesser growth performance at the latter two farms could be explained by the particular production constraints at each farm. Namely, the lack of a suitable pond at Truloff's and the very high effective stocking rate at Rossman's due to the presence of a very large incidental population of *M. bennettae* in the pond. Hence the growth performance at GCMH and RPPF was considered to be most representative. The crop at GCMH performed slightly better (20 g in 26 weeks) than at RPPF (20 g in 28 weeks), most likely due the supplementary feeding of the GCMH crop with *P. japonicus* feed in the latter stages of growout.

The crop grown at GCMH (4.6 t) was sold on the export market to Japan at more favourable prices than those received for the other farms' crops sold on the local market. The pricing issues and the cost benefit of production is discussed fully in section 9. However the exercise demonstrated the export market demand for *P. esculentus,* and confirmed the opportunity to achieve a favourable price on the export market for this Australian product.

In the 1998/99 growout season, both GCMH and RPPF stocked *P. esculentus* as part of the evaluation of the specific *P. esculentus* formulated feed developed in the course of this project (see section 7). At both farms, growth rates were lower in 1999 than in 1997 (Figs. 6.3 & 6.4). In 1999, the crop at GCMH grew to a mean size of 16.3 g after 27 weeks (c/f 20 g in 26 weeks in 1997), and at RPPF grew to a mean size of 12.9 g, after 25 weeks (c/f 20 g in 28 weeks). Daily pond temperature data was collected throughout both the 1997 and 1999 growout seasons at each farm. Overall the two seasons were very similar in their temperature regimes (Fig. 6.5). The moving 30-day mean pond temperature trend indicated a warmer start to the 96/97 season (from 4 to 8 weeks), but this was offset by a prolonged cooler period from 8 to 14 weeks by comparison to the 98/99 season. Hence it is considered that the differences in growth performance between the 2 years was not due to temperature difference impacting on the growth rates of the prawns in each year. Even though differences between ponds can be significant, the same trend in growth performance between the 2 years was evident at each farm. While the laboratory trials of the specific *P. esculentus* diet developed in the project (see section 8) were most favourable, the formulation used in the 1999 commercial trial did not perform as expected on the farms. Therefore, there needs to be more development to produce the experimental diet on a commercial scale to be able to demonstrate the favourable laboratory results in a commercial environment. These issues are further discussed in section 8.

Size distribution at harvest and potential for genetic improvement

The size distribution at harvest will largely determine the value of the crop, since the price received depends on the size of the prawns. While both the mean sizes and the size distributions were lower at both farms in 1999 compared to 1997, there was also a more skewed distribution for the 1999 crop at both farms (Fig. 6.7). While the 1997 crops both showed a normal distribution of sizes, the size distribution was clearly skewed to the right (larger sized prawns) for both the 1999 crops. This suggests a relatively higher proportion of prawns at the larger end of the distribution in 1999 compared to 1997, indicating that a higher proportion of the population was able to grow relatively faster than average under the prevailing growout conditions in 1999.

In a genetic selection program, the faster growing prawns from the larger end of the distribution (probably the top 5 to 10%) would be selected as broodstock for the next generation (Hetzel *et al.*, 2000). The capacity for faster growth of the prawns from the larger end of the distribution is potentially due to a combination of traits for inherently faster growth, and traits that better suit them to this particular growout environment. In the case of the 1999 crop, prawns selected from the faster-growing group could form the basis of selected lines of prawns able to exhibit fast growth with this particular diet or environmental regime. In any case, the wide distribution of sizes at harvest in each of the 1997 and 1999 crops suggest that there is adequate genetic variability in these populations to enable successful genetic selection for faster growth.

Feed conversion efficiency

Comparative estimates of feed conversion ratios for both the trial *P. esculentus* crops and comparable *P. monodon* crops were required as inputs to the cost benefit analysis (section 9). Despite the much larger cumulative weight of feed provided to the *P. monodon* crop, the overall average feed conversion ratios were very similar for *P. esculentus* and *P. monodon*, ranging between 1.94 and 1.96 using mean values for mortality (Fig. 6.8 & Table 6.3). This is likely a consequence of the lower mean size and therefore lower biomass of prawns in the *P. esculentus* ponds. If the full range of mortality estimates is used, then the feed conversion ratio can be as high as 2.3. Since the feed costs are a significant component in the cost of production, it was considered essential to include a sensitivity analysis covering the range of estimated mortalities and feed conversion efficiencies in the cost-benefit analysis.

7. Natural-feed supplementation for juveniles

7.1 Background

During the 1997 on-farm grow-out trials it was noticed that the ponds with more edge macrophytes , and obvious natural biota, supported juvenile *P. esculentus* better than the clearer ponds. Growth data from pond and tank populations of *P. esculentus* in 1996 (Figure 5.1, section 5) indicate growth rates are similar throughout the majority of the period of the life cycle monitored, except for the early phase. In this early phase, growth rates of the juveniles in the tank population were noticeably lower than those juveniles grown in a pond environment at the same time.

In natural populations, the nursery areas of *P. esculentus*, are almost exclusively, seagrass beds (Staples *et al.,* 1985), and large juvenile *P. esculentus* have a preference for structures (Hill and Wassenberg, 1993; Kenyon *et al.*, 1995). Furthermore, wild populations of juvenile *P. esculentus* have been described as omnivorous with food preferences including small protozoa, diatoms, algae and seagrass (O'Brien, 1992). These findings suggest that juvenile *P. esculentus* may benefit from the addition of artificial structures, and the associated natural food supply, during the early stages of the commercial grow-out phase.

7.2 Objective

- To assess the effect of additional structures and natural feed supplementation on growth and survival of juvenile *P. esculentus.*

7.3 Methods

A pilot trial and two subsequent trials examined the effect of simple structures, either conditioned with natural biota, or not, on the growth and survival of juvenile *P. esculentus.* During 1998, a pilot trial compared the survival and growth of a mixed batch of early stage juveniles (1.5 to 2 months old) reared for 3 weeks in tanks with and without structures, uncolonised and colonised, and with and or without supplementary formulated feed.

The second trial was carried out with 4 month-old prawns, and consisted of two components: An initial 6 week trial compared the effects of physical structures only, and a 2 week trial compared the effects of natural biota-colonised and non-colonised structures.

A third trial was conducted in 1999 and compared the effects of structures and natural feed supplementation on growth and survival of 2-month-old juvenile *P. esculentus* over a 6 week growout period.

Each of the 3 trials had 4 treatments and 6 replicates:

1. No structures, formulated pellet feed added
2. Clean structures, formulated pellet feed added
3. Colonised Structures, formulated pellet feed added
4. Colonised Structures, no formulated pellet feed added

Design of structures

The structures were rectangular pieces of 90% shadecloth suspended vertically from a fishing line strung across the tank. The bottom edge of each structure was weighted down with a piece of PVC rod. In the clean-structure treatment debris and biofilm were removed from the structures every 2 d. In the colonised-structure treatment, the structures were placed in an unfiltered seawater environment (Moreton Bay seawater) and colonised naturally with a local population of diatoms, protozoa, algae and detritus for 3 weeks prior to stocking. Structures were conditioned in a commercial prawn pond effluent canal for the first two trials and in an outdoor conditioning tank at CSIRO for the third trial. As the experimental animals grazed the colonised structures, the structures were exchanged with freshly conditioned replacements, approximately every 2 d. Qualitative observations regarding the condition of the colonising biota (quantity and species composition of organisms) were recorded for each trial. In each of the fed treatments, prawns were fed commercial pelleted diets (CP and Higashimaru pellets) to satiation. Every second day the uneaten food and faeces were siphoned from the tanks.

All tanks were supplied with 28°C water at 0.75 L per min, giving a total exchange every 2 h. One aerator and a directed water outlet maintained water circulation. The light cycle was set at 14 h light:10 h dark regime.

Survival was calculated on a per tank basis as the percentage of the number of surviving prawns from the number originally stocked. Differences in the growth and survival among treatments were compared by analysis of variance using the SAS (SAS Institute) software. Differences between the treatments were tested using Tukey's pairwise comparison.

Trial 1. Pilot - 1.5 to 2 month-old juveniles

Three *P. esculentus* families were spawned from wild caught broodstock and reared at CSIRO. A mixture of PL30 to PL50 (1.5 to 2.0 months old) prawns were stocked into each of the 6 replicate rectangular plastic 35 L tanks (20 cm x 55 cm x 35 cm) at a stocking density of 70 prawns per m^2. Growth rates were calculated from the difference between initial and final mean weights in each tank.

Trial 2. Four month old juveniles

A family of *P. esculentus* was spawned from wild caught broodstock and reared for 4 months (PL115) at the CSIRO laboratories. This trial was designed to compare the effects of additional physical structure with and without the colonising biota, and with or without formulated feeds. Due to conditioning problems two of the treatments (colonised structures with and without feed) were only maintained for the first 2 weeks of the 6 week trial.

The treatments and duration time were as follows:

1. No structures, formulated pellet feed added (6 weeks duration)
2. Clean structures, formulated pellet feed added (6 weeks duration)
3. Colonised structure, formulated pellet feed added (2 week duration)
4. Colonised structures, no formulated pellet feed added (2 week duration)

Each treatment consisted of six replicate round plastic 100 L tanks (38cm high x 54cm diameter). Each tank was stocked with 6 prawns, 3 of each sex. Stocking density was low at 21 prawns per m^2 of the bottom surface area. At stocking the prawns were sexed, weighed and tagged individually. Prawn weights were measured every 2 weeks. Growth rates were calculated from the individual weight gained over the experimental period.

Trial 3. 2 month old juveniles
This third trial compared the effects of structures and natural supplementary feeds on younger prawns (2 months old, PL50), over a 6 week period.

This experiment was blocked according to prawn weight. The first block was stocked with 9 of the smallest animals per tank (stocking density 32 prawns per m^2) and the remaining blocks were stocked with 8 animals per tank (stocking density 28 prawns per m^2). There were 4 replicate round plastic 100L tanks per treatment. Prawn weights were measured every 2 weeks. Individual growth information was not possible as the PL 55 prawns were too small to sex or tag. Therefore, growth rates were calculated as the increase in mean weights of the animals in the tanks over the experimental period. The tank biomass was calculated from the total weight gained per tank.

7.4 Results and Discussion

Trial 1. (Pilot)
In the pilot trial, the conditioned structures were colonised with a diverse mixture of filamentous algae, diatoms (*Pleurosigma sp.*, *Navicula sp.*, *Nitzschia sp.*), copepods, nematodes and many protozoa, before they were placed in the experimental tanks. The best growth was observed in the treatment with colonised structures and formulated feed (weight gain of 0.751g), followed by smaller gains in the unfed colonised-structure treatment (weight gain 0.314g) (Fig. 7.1). The fed clean-structure treatment gave a lower weight gain (0.219g), and the no-structure treatments gave the lowest weight gain (0.178g). Survival was also highest in the colonised-structure treatments (88% unfed, 87% fed) and lowest in the clean-structure and no-structure treatments (42% and 33%, respectively).

The pilot trial suggested that structures and supplementary natural feeds could be beneficial to early juvenile growth. The trends observed in this pilot trial were used as the basis for the design of the following trials.

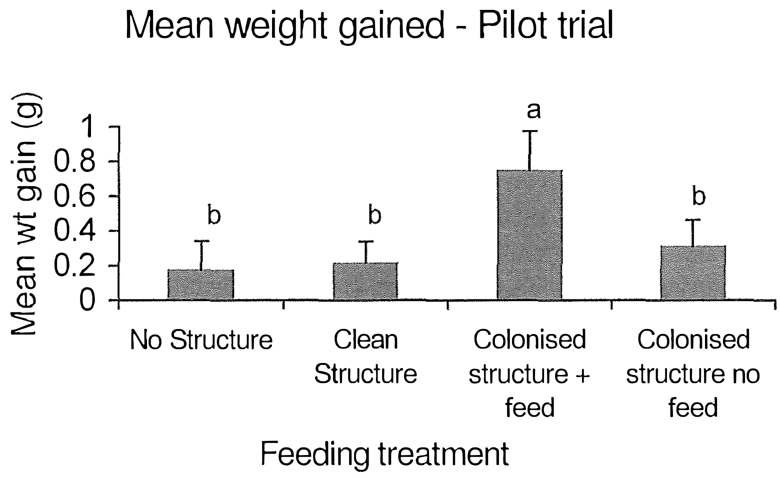


Figure 7.1. *Penaeus esculentus*: Mean weight gain (g) (±SD) during 3 weeks growth with various structure and feeding treatments, in the pilot trial. Means with similar subscripts are not significantly different ($P>0.05$).

Trial 2.

(a) Two week, structure and diet trial

The first 2 weeks of trial two compared the combined effects of structures and supplementary natural feed. Unfortunately, colonisation of the structures in this trial was hampered by unusual weather conditions, hence the conditioned-structure treatment was terminated after 2 weeks. Observations of the early colonising biota indicated that both the number and diversity of the colonising organisms was lower than those seen in the pilot trial. Although, the mix of diatoms, protozoa, nematodes and algae were similar, there were also additional amounts of clay particles.

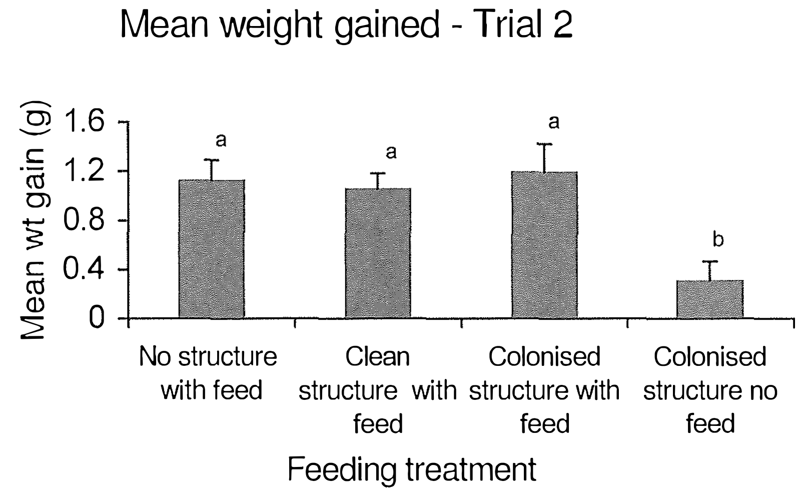


Figure 7.2. *Penaeus esculentus*: Mean weight gain (g) (±SD) during 2 weeks growth with various structure and feeding treatments for Trial 2. Means with similar subscripts are not significantly different ($P>0.05$)

In this short trial, there was no effect on survival, and only an insignificant effect on growth, by the addition of structures and supplementary natural feed (Table 7.1). Survival was good in all treatments; 100% survived in the clean and fed colonised-structure treatments and 97% and 94% in the no-structure and unfed colonised-structure treatments, respectively.Growth was similar in the treatments supplied with formulated feed regardless of the presence of structures or the addition of natural biota (1.13±.16 g for no-structure, 1.06±.12 g for clean-structure and 1.2±0.23 g for the fed colonised-structure). There was however, a significantly lower growth rate in the unfed treatment with colonised-structures (0.32±0.15 g) (Fig. 7.2). It appeared that the colonising biota on the conditioned structures in this experiment were not sufficient to support strong growth in juvenile *P. esculentus* without the addition of formulated pellets.

Effects		Survival		Growth	
a. Structure and diet (2weeks)	d.f.	MS[a]	Pr > F	MS[a]	Pr > F
Treatment	3	0.0524	0.2691	0.9887	<.0001
Error	20	0.0371		0.0284	
b. Structure only (6 weeks)					
Treatment	1	0.0286	0.5490	0.1249	0.2899
Error	10	0.0743		0.1000	

[a]Type III Mean Squares

Table 7.1. Anova results for Trial 2.

(b) Six week, structures vs no-structures trial

Over the 6 week period there was no significant difference between growth and survival of prawns with or without structure (Table 7.1). Both treatments had a 97% survival and final size was also very similar (2.86±0.38 g without structure, and 2.66±0.22 g with structure). This trial has indicated that in a controlled environment with very low densities, the presence of simple vertical structures has no effect on the growth or survival of 4 month-old *P. esculentus* juveniles.

Trial 3.

Structure and supplementary diet

Results from this trial almost mirrored those of the 2-week component of Trial 2. Survival was consistently high in all of the fed treatments (86% no-structure, 89% clean-structure, 84% colonised-structure, with artificial feed. (Fig. 7.3).

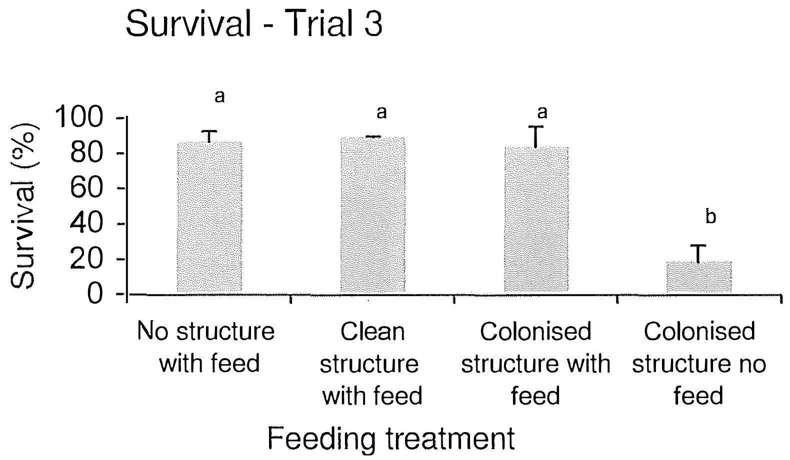


Figure 7.3. *Penaeus esculentus*: Survival (%) during 6 weeks growth with various structure and feeding treatments. Trial 3. Means with similar subscripts are not significantly different (P>0.05).

However, only 19% of the animals in the unfed treatment survived the 6 week trial and very few actually grew; on average only 0.175 g was gained over 6 weeks (Fig. 7.3, 7.4). Due to the low growth and very low survival, around 1.5 g of biomass was lost on average from the unfed replicates during the experimental time. This indicated that the colonising biota was not sufficient to sustain normal growth and survival in this trial.

Effects		Survival		Growth		Biomass	
	d.f.	MS[a]	Pr > F	MS[a]	Pr > F	MS[a]	Pr > F
Treatment	3	0.7553	<.0001	2.0162	<.0001	18.2009	<.0001
Block	3	0.0209	0.2150	0.1632	<.0001	0.0889	0.8494
Error	9	0.0115		0.0058		0.3363	

[a]Type III Mean Squares

Table 7.2. Anova results for Trial 3.

Growth and survival of juvenile *P. esculentus* was not affected by the addition of a simple clean structure. There was no difference (P<0.05) between the growth in the no-structure treatment (3.18±.0.7 g) and the clean structure treatment (3.16±1.06 g) . Prawns did however, grow best when fed a formulated diet with the addition of colonised structures (3.69±0.76 g) (Fig. 7.4.).

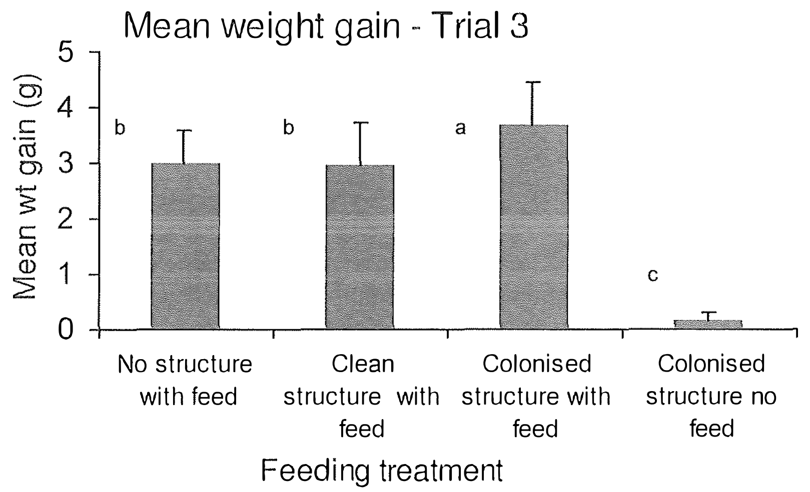


Figure 7.4. *Penaeus esculentus*: Mean weight gain (g) during 6 weeks growth with various structure and feeding treatments. Trial 3. Means with similar subscripts are not significantly different (P>0.05)

7.5 Conclusion

The similar growth and survival found in the current trials suggest that at low densities, and in very controlled conditions, juvenile *P. esculentus* do not benefit from the addition of simple unconditioned vertical structure. There was an indication from the pilot trial that at higher densities physical structures had a positive effect on growth and survival. It may be useful to develop and test at more complex forms of structures in varying densities. The colonising biota was fairly standard in species composition throughout the trials, even though the conditioning environments varied.

This study found that good growth and survival of juvenile *P. esculentus* in tanks could not be sustained with the colonising biota alone. However, growth in juvenile *P. esculentus* prawns can be promoted by the addition of colonised structures to prawns fed a formulated diet. The pilot trial suggested that this could have a larger effect at higher densities and with better colonising of the structures.

The study supports the hypothesis that natural supplementary feeds found abundantly in ponds will help promote juvenile growth rates of *P. esculentus*. If *P. esculentus* are to be reared within a tank environment it may be advisable to supplement the diet with natural biota during the juvenile stages. Lower growth in the tank systems may be attributable to the lack of this component in nutrition. Whether the lack of these nutrients during the juvenile phase has any effect on adult processes such as reproduction has yet to be determined. It may be that growth is not the only process affected by access to a varied diet during the juvenile phase.

8.0 Development of a cost-effective *P. esculentus* diet

8.1 Introduction

At the start of this project there was no commercial diet available specifically formulated for *Penaeus esculentus*. Little was known about the nutrient requirements of this species, though its natural diet in nursery and commercial fishery habitats had been studied in detail (Moriarty and Barclay, 1981; Wassenberg and Hill, 1987; Dall *et al.*, 1992a, b, O'Brien, 1994). Several studies have been carried out investigating the growth response of juvenile *P. esculentus* to dietary protein content (Hewitt and Irving, 1990; AQUACOP and Cuzon, 1992; Hewitt, 1992). However, these studies did not result in a precise determination of the optimum protein content, though Hewitt and Irving (1990) reported that 40% dietary crude protein (CP) resulted in a higher growth rate than 30% or 50% CP.

In contrast, preliminary trials on commercial prawn farms in the summer of 1995/96 showed that *P. esculentus* grew very well when fed a diet formulated for *P. japonicus* that contained 59% CP (on a dry matter basis, (DMB)). They also grew at a significantly faster rate on this diet than when fed a diet formulated for *P. monodon* that contained 41% CP (FRDC Progress Report Project 96/302, 1997).

During the course of this project, there was strong interest from sections of the prawn farming industry who wanted to try commercial production of *P. esculentus*. Ridley Agriproducts P/L was consulted and agreed to manufacture a feed for on-farm trials based a closely as possible on the diet formulation developed during this project. In response to the urgent need for a cost-effective diet to feed prawns already stocked on farms, the focus of this study changed from the planned systematic approach of defining nutrient requirements and using this information to formulate an effective diet. Instead a prototype diet was formulated, tested and refined. Through this iterative process, we have formulated a number of diets for *P. esculentus* and have tested them in aquarium tank growth assays. The final diet formulation was manufactured on a commercial scale and evaluated on prawn farms.

8.2 General Methods

8.2.1 Growth assay design principles

During the development of the diet for *P. esculentus*, the performance of the formulations was assessed in comparative growth assays with two reference diets, a commercial diet formulated for *P. monodon* (Charoen Pokphand #4004) and one for *P. japoncus* (Higashimaru - Ebi 12, or Lucky Star). The growth assays were of 6 to 10 weeks duration with between six and ten replicates (tanks) for each treatment. Within an experiment, each tank was stocked an equal number of prawns, usually five; the number being dependant on the initial weight of the prawns. To maximise the statistical power, prawns with the narrowest possible size range were used to stock the tanks. Where the size range at the start of the experiment was >0.5 g, the prawns were grouped into weight classes of <0.5 g variation and stocked as blocks according to weight. Experiments constituted either a randomised balanced block design or an incomplete balanced block design.

8.2.2 Growth assay protocol

The prawns were either obtained from Rocky Point Prawn Farm, as approximately 2 g animals or were reared onsite from cultured postlarvae. The post-larvae were on-grown in 3 x 2.5 t outdoor tanks supplied with flowing seawater and aeration. They were fed a variety of diets specific for their stage of development, but always included some Higashimaru *P. japonicus* diet of the appropriate size and/or formulation.

For the growth assays, prawns were held in rectangular 90 L tanks (0.6 x 0.5 x 0.3 m deep), supplied with flowing seawater at 300 L per min and maintained at 28 ± 1°C. The aquarium room was set-up with a 12h light:12h dark regimen with the lights coming on at 0600 h. The prawns were weighed and stocked into tanks 5 to 7 d before the start of an experiment to allow them to adapt to the tank conditions. During this period they were fed a diet formulated for *P. japonicus* (either Higashimaru or Lucky Star, whichever was to be used as a reference diet in that experiment). They were then re-weighed at the start of the experiment and again at either 2-week or 4-week intervals.

Prawns were fed to just above satiation with the daily feed allocation adjusted according to the amount of food left uneaten in each tank on the previous day. The daily allocation was divided into five portions that were issued using automatic feeders. The smallest portion was given at about mid-day with the remaining portions being given at about 1800 h, 2200 h, 0200 h and 0600 h. Tanks were inspected and cleaned daily. Water temperatures were monitored daily and exuvia and mortalities noted.

8.2.3 Laboratory preparation of diets

The test diets were prepared in the laboratory by mixing the ingredients, adding enough water to form a stiff dough and extruding through a Hobart mincer. The spaghetti-like strands of extruded diet were steamed for 5 min, air dried overnight and broken up into 5 to 8 mm long pellets. These were stored at -10°C until used.

The water stability of the pellets was determined from weighed samples of feed pellets. These were placed on a 1.0 mm mesh nylon screen in jars containing 100 mL of distilled water. The jars were agitated in a shaking water bath (60 rpm) at 28°C for 4 h. After that period the material retained by the screen was dried at 105°C for 4 h, cooled in a desiccator and weighed. The pellet stability was calculated as the percentage of dry matter retained on the screen.

8.2.4 Chemical and statistical analyses

Proximate composition of the major ingredients and diets was analysed using Association of Official Analytical Chemists procedures (AOAC, 1990). Dry matter was determined by weighing before and after drying at 105°C for 16 h and cooling in a vacuum desiccator; ash by heating a weighed and dried sample at 550°C for 16 h before cooling in a desiccator and re-weighing. Crude protein was determined following Kjeldahl digestion, distillation of the liberated ammonia into 3% boric acid, and titration of the boric acid with hydrochloric acid to an end point at pH 5.0. Total lipid was determined gravimetrically following a chloroform-methanol (2:1) extraction using the method of Folch *et al.* (1957). Gross energy was determined by isothermal bomb calorimetry using a Leco AC200 Bomb Calorimeter. For ease of comparison between diets, all nutrient composition data have been expressed on a dry matter basis (DMB).

Differences in growth, apparent food intake and FCR were tested using ANOVA in accordance with the design of the experiment.

8.3 Development and evaluation of prototype diet

8.3.1 Materials and methods

A prototype diet was formulated based on the small amount of information available in the literature, on our knowledge of the nutrient requirements of *P. monodon* and *P. japonicus* and on our experience in formulating diets for *P. monodon.* Our recent studies have indicated that growth response in *P. monodon* is not greatly affected by dietary lipid levels, provided that the fatty acid profile of the lipid is balanced and the total lipid content is between 8 and 10%. With this information, we decided that to formulate the *P. esculentus* diets to contain conservative amounts of lipid, varying between 8.5% and 9.8%. However, the fatty acid profile was kept very similar across the diets and similar to that typically observed in marine organisms.

The diet was formulated for steam pelleting on the understanding that the diets would be prepared on the small-scale steam pellet press at Ridley Agriproducts, Narangba. However, this equipment became unavailable, so the diet was reformulated to make it more suitable for extrusion. Two formulations were made into pellets using the twin-screw extruder at CSIRO Division of Food Science and Technology, North Ryde, NSW. These diets were formulated on a DMB to contain 54.4% CP (45% digestible CP) and 10% lipid. The diet designated PE 1.1 (Table 8.1) was selected for further testing in a 6-week growth assay on the basis of its better water stability and sinking rate. In the growth assay, the diet was compared against a commercial diet formulated for *P. japoncus* (Higashimaru - Ebi 12) containing 57% CP and 12% lipid and two commercial diets formulated for *P. monodon*, (Higashimaru and Charoen Pokphand #4004) both of which contained 46% CP and 11% lipid.

Table 8.1. Ingredient and nutrient composition of diet PE 1.1 formulated for *P. esculentus*. Nutrient composition expressed on a dry matter basis (DMB).

Ingredients (% w/w)	PE 1.1	Nutrients	Composition (DMB)
Fishmeal (68% CP)	42.0	Ash (%)	12.3
Meat meal (52% CP)	5.0	Gross Energy (MJ/kg)	18.6
Soybean (45% CP)	5.0	Digest. Energy (MJ/kg)	15.5
Crustacean meal	16.0	Crude Protein (%)	54.5
Squid meal	5.0	Digestible Crude Protein (%)	45.8
Wheat	19.1	Total lipid	9.8
Cholesterol	0.1		
Lecithin	1.5		
Vitamin C	0.1		
Vitamin Premix	0.2		
Gluten (wheat)	3.0		
Binder	3.0		

8.3.2 Results and discussion

The initial preference testing of the CSIRO laboratory-prepared diet PE 1.1, indicated that it was well accepted by the prawns. The dry diet intake was about 8% of the prawns' live body weight, which is the expected feed intake for prawns of that size.

In the growth assay, the performance of the PE 1.1 diet fell midway between the high growth rate obtained with the extruded Higashimaru *P. japonicus* diet and the lower growth rates obtained with the commercial *P. monodon* diets (Table 8.2).

The survival of the prawns over the 6 weeks (Table 8.2) was high with three of the diets but significantly lower ($P < 0.05$) with the Higashimaru *P. monodon* diet. However, the prawns fed the Charoen Pokphand *P. monodon* diet did not appear to be as healthy in the final 2 weeks of the experiment, while the prawns fed the PE 1.1 diet started to look listless in the last week. Prawns fed the *P. monodon* and the PE 1.1 diets were also much lighter in clour than those fed the *P. japonicus* diet.

As a result of these findings, it was decided that future *P. esculentus* formulations would contain supplementary carotenoids, particularly astaxanthin, by including 0.05% of Carophyll Pink (Roche). In addition, the next series of diets would contain the same amount of crude protein as was in the high performing Higashimaru *P. japonicus* diet.

Table 8.2. Weight data (Mean ± S.E.) and survival (%) of prawns after 6 weeks in a growth assay comparing the prototype diet for *P. esculentus* with commercial diets. PM (Hig) *P. monodon* diet made by Higashimaru PM (CP), *P. monodon* diet made by Charoen Pokphand; PE 1.1, prototype diet for *P. esculentus*; PJ (Hig), *P. japonicus* diet made by Higashimaru.

Treatment	Initial Weight (g)	6-week Weight (g)	Weight gain (g/wk)	Survival (%)
PM (CP)	7.52 ± 0.19	10.87 ± 0.26	0.56 ± 0.03	95 ± 3
PM (Hig.)	7.36 ± 0.14	9.15 ± 0.22	0.30 ± 0.02	85 ± 6
PE 1.1	7.60 ± 0.17	13.81 ± 0.21	0.72 ± 0.03	100
PJ (Hig.)	7.51 ± 0.17	11.92 ± 0.30	1.05 ± 0.03	98 ± 3

8.4 Refinement of prototype diet

8.4.1 Materials and methods

The diet formulation PE 1.1 was modified with the objective of improving the growth performance and food conversion ratio and also improving the colouration of the prawns. Three alternative *P. esculentus* diets, designated the PE 2 series, were formulated using least cost formulation with closely matching nutrient specifications but differing in some of the ingredients use to make-up the diet (Table 8.3). The CP content of the diets was 60%, the digestible CP was close to 52% and lipid content 9%. The diets were prepared on-site using laboratory scale equipment (Section 8.1.2). %. The cost of individual ingredients was obtained from feed industry sources. Using that data, the estimated commercial cost of the three diets ranged from $1750 to $2000 per t. The performance of the diets was compared against that of two reference commercial diets, the *P. monodon* diet (Charoen Pokphand, #4004) and the *P. japonicus* diet (Higashimaru – Ebi 12) used in the earlier study. These diets were analysed to determine their proximate composition.

8.4.2 Results and discussion

Growth rates with the PE 2 series of diets were similar to that obtained with the *P. monodon* diet made by Charoen Pokphand and significantly less ($P < 0.05$) than that obtained with the *P. japonicus* diet made by Higashimaru (Table 8.5). In addition, the survival with the *P. monodon*, PE 2.1 and PE 2.2 diets were lower than with PE 2.3

and the Higashimaru diets (Table 8.5). There was a marked increase in the prawn mortalities during the 9th week of the experiment. This high mortality led to the experiment being terminated at 10 weeks rather than 12 weeks as originally planned.

Table 8.3. Ingredient and nutrient composition of PE 2 series of grow-out diets for *Penaeus esculentus.*

Ingredients (% w/w)	**PE 2.1**	**PE 2.2**	**PE 2.3**
Fishmeal (68% CP)	40.0	50.3	54.1
Meat meal (52% CP)	15.0	-	-
Soybean (45% CP)	15.0	15.0	-
Crustacean meal	10.0	10.0	10.0
Squid meal	5.0	5.0	10.0
Wheat	5.6	10.3	16.6
Cholesterol	0.05	0.05	-
Lecithin	-	-	-
Vitamin C	0.1	0.1	0.1
Vitamin Premix	0.2	0.2	0.2
Binder	3.0	3.0	3.0
Gluten (wheat)	6.0	6.0	6.0
Others	0.05	0.05	0.05
Nutrients (DMB)	**2.1**	**2.2**	**2.3**
Ash (%)	14.8	10.9	11.2
Gross energy (MJ/kg)	16.4	19.2	19.5
Digest. Energy (MJ/kg)	15.4	15.9	16.3
Crude Protein (%)	60.2	60.0	60.5
Digest. Crude Protein (%)	51.5	52.3	52.3
Total Lipid (%)	9.3	8.5	9.2

Table 8.4. Weight data (Mean ± S.E.) and survival (%) of prawns at 10 weeks in growth assay comparing the PE 2 series of diets for *P. esculentus* with commercial diets. PM (CP), *P. monodon* diet (Charoen Pokphand); PJ (Hig), *P. japonicus* diet (Higashimaru).

Treatment	Initial Weight (g)	10-week Weight (g)	Weight gain (g/wk)	Survival (%)
PM (CP)	3.4 ± 0.23	9.0 ± 0.43	0.56 ± 0.08	85 ± 5.0
PE 2.1	3.4 ± 0.20	8.4 ± 0.32	0.50 ± 0.017	68 ± 11.3
PE 2.2	3.6 ± 0.27	9.4 ± 0.30	0.59 ± 0.026	80 ± 5.4
PE 2.3	3.5 ± 0.18	9.3 ± 0.24	0.58 ± 0.016	93 ± 5.3
PJ (Hig)	3.4 ± 0.24	12.5 ± 0.41	0.91 ± 0.036	93 ± 3.7

8.5 Testing of final diet formulation

8.5.1 Materials and methods

As a result of the observed performance of the PE 2 series of diets, the formulations were re-formulated with specifications more closely matching those of the PE 1.1 diet and tested in an aquarium tank experiment. The test diets, designated as the PE 3 series, sought to test the efficacy of 10% and 20% inclusions of a freeze dried crustacean meal made at CSIRO Marine Research and a similar commercial preparation (Table 8.5). These diets were compared against: (a) Lucky Star (Taiwan) formulated for *P. japonicus* (64% CP and 12 % lipid DMB); (b) Charoen Pokphand #4004 grow-out diet for *P. monodon* and (c) PE 1.1 (Table 8.1, but including 0.05% of Carophyll pink). The PE 1.1 diet and the PE 3 series of diets were prepared on-site using laboratory scale pelleting equipment.

Table 8.5. Ingredient and nutrient composition of PE 3 series of grow-out diets for *Penaeus esculentus.* Nutrient composition expressed on a dry matter basis (DMB).

Ingredients (% w/w)	PE 3.1	PE 3.2	PE 3.3	PE 3.4
Fishmeal (68% CP)	45.8	37.8	51.1	48.3
Squid meal	5.0	5.0	5.0	5.0
Crustacean meal (Lab)	10.0	20.0	-	-
Crustacean meal (Com)	-	-	10.0	20.0
Wheat	28.7	26.7	23.4	16.2
Cholesterol	0.1	0.1	0.1	0.1
Lecithin	1.0	1.0	1.0	1.0
Vitamin C	0.1	0.1	0.1	0.1
Vitamin Premix	0.2	0.2	0.2	0.2
Binder	3.0	3.0	3.0	3.0
Gluten (wheat)	6.0	6.0	6.0	6.0
Nutrients (DMB)				
Ash (%)	10.1	10.7	12.3	14.9
Gross energy (MJ/kg)	18.8	18.5	18.7	18.2
Digest. Energy (MJ/kg)	16.5	16.2	16.3	15.6
Crude Protein (%)	53.4	53.9	53.9	54.9
Digest. Crude Protein (%)	47.4	47.4	47.1	46.9
Total Lipid	8.3	8.1	8.8	9.1

8.5.2 Results and discussion

The prawns fed the reference commercial diets showed the same growth response as had been observed in previous experiments, with prawns fed the *P. japonicus* diet having the highest growth rate and those fed the *P. monodon* diet having a relatively low growth rate. There was also a high survival rate across all treatments (Table 8.6).

The lowest growth rate was with diet PE 1.1 and this was not significantly different ($P > 0.05$) from that obtained with the *P. monodon* diet. However, the growth rate of prawns fed the PE 3 series diets was significantly greater ($P < 0.05$) than that obtained with the *P. monodon* diet. There was also an increase in growth rate with each incremental increase in the proportion of crustacean meal in the PE 3 diets (Table 8.6, Figure 8.1). Prawns fed the PE 3.4 diet grew at a rate that was slightly less than, but not significantly different from, that of prawns fed the *P. japonicus* diet ($P > 0.05$).

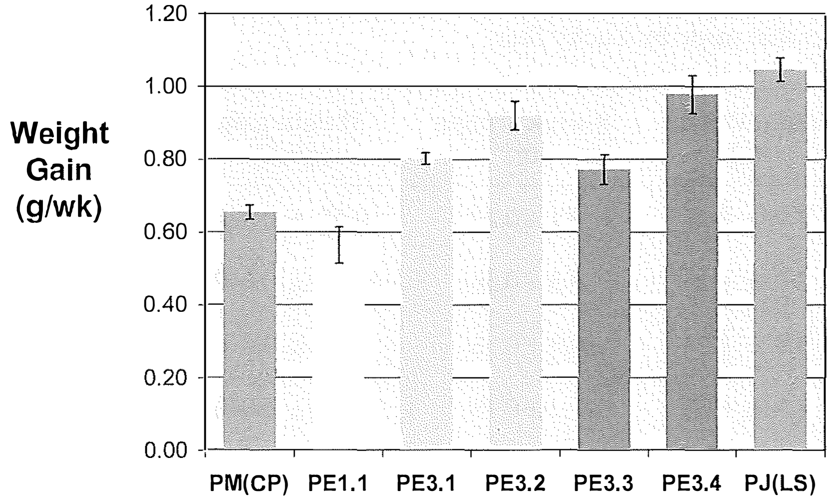


Figure 8.1. Weight gain of *P. esculentus* at 8 weeks in growth assay comparing the PE 3 series of diets and the PE 1.1 diet for *P. esculentus* with commercial diets. PM (CP), *P. monodon* diet made by Charoen Pokphand; PJ (LS), *P. japonicus* diet made by Lucky Star.

The PE 1.1 diet contained 54.5% CP (estimated digestible CP of 45.8%), which was greater than in the commercial *P. monodon* diets and slightly less that in the Higahimaru *P.japonicus* diet. The PE 2 series of diets contained 60% protein. This change resulted in a general reduction in performance but it also demonstrated that the quality or type of protein sources used in the diets had a large bearing on the performance of the diet. The PE 3 series of diets had a similar CP content to the PE 1.1 diet but contained more of high quality marine invertebrate protein in the form of crustacean meal. Again, the performance of the PE 3 series compared to that of PE 1.1 gave further evidence of the importance of the quality of the protein sources used in the diet.

The commercial cost of PE 3.4 was estimated to be $2150 per t. At this price, and based on the previous performance of prawns fed the diet, it was considered that this formulation would be a cost-effective feed for commercial production of *P. esculentus*. As a result, Ridley Agriproducts were advised of the diet formulation and the quantities of feed that would be required for the on-farm testing.

Table 8.6. Weight data (Mean ± S.E.) and survival (%) of prawns at 8 weeks in growth assay comparing the PE 3 series of diets and the PE 1.1 diet for *P. esculentus* with commercial diets. PM (CP), *P. monodon* diet made by Charoen Pokphand; PJ (LS), *P. japonicus* diet made by Lucky Star.

Treatment	Initial Weight (g)	8-week Weight (g)	Weight gain (g/wk)	Survival (%)
PM (CP)	3.9 ± 0.29	9.1 ± 0.24	0.65 ± 0.020	92 ± 4.5
PE 1.1	3.9 ± 0.25	8.3 ± 0.56	0.56 ± 0.049	100
PE 3.1	3.9 ± 0.23	10.3 ± 0.33	0.80 ± 0.016	100
PE 3.2	3.9 ± 0.23	11.2 ± 0.13	0.92 ± 0.040	100
PE 3.3	3.9 ± 0.30	10.1 ± 0.11	0.77 ± 0.041	92 ± 4.5
PE 3.4	3.9 ± 0.31	11.7 ± 0.67	0.98 ± 0.052	88 ± 4.7
PJ (LS)	3.9 ± 0.26	12.2 ± 0.27	1.05 ± 0.032	92 ± 4.5

8.6 Commercial production of *P. esculentus* diet

8.6.1 Materials and methods

Due to major modifications taking place at their Narangba aquaculture feed manufacturing plant, Ridley Agriproducts were unable to manufacture the PE 3.4 diet for on-farm testing. However, they were able to provide the required ingredients. As a contingency, arrangements were made to manufacture the feed on a pilot-scale steam pellet press at CSIRO Division of Animal Production (CAP), Prospect, NSW. A small batch of ingredients was shipped from Narangba to Prospect to test the capacity of the plant to produce feed pellets of the required quality. The performance of the first batch of feed was compared to a batch of the laboratory-made PE 3.4 in a 2-week quality control growth assay.

8.6.2 Results and discussion

The growth response and survival of prawns fed PE 3.4 diet prepared in the laboratory was not significantly different ($P > 0.05$) from that of prawns fed the diet prepared on a commercial steam pellet press (Table 8.7). These results suggested that the diet prepared on the steam pellet press could be validly tested in a pond trial.

Table 8.7. Weight data (Mean ± S.E.M) and survival (%) of *P. esculentus* after 2 weeks in growth assay comparing the PE 3.4 diets made in the laboratory (PE 3.4 Lab) and on a commercial steam pellet press (PE 3.4 Com).

Treatment	Initial Weight (g)	2-week Weight (g)	Weight gain (g/wk)	Survival (%)
PE 3.4 Lab	12.5 ± 0.05	13.7 ± 0.07	0.58 ± 0.035	94 ± 5.8
PE 3.4 Com	12.4 ± 0.05	13.4 ± 0.07	0.50 ± 0.035	97 ± 4.4

8.7 Farm evaluation of *P. esculentus* diet

8.7.1 Materials and methods

Following the satisfactory results from the quality control assay, commercial quantities of PE 3.4 were produced at CAP to meet the requirements of the farmers carrying out the grow-out trials. As before, the ingredients were purchased from Ridley Agriproducts. However, because production difficulties resulting from the engineering work that was underway at the Narangba plant, the ingredients could not be ground in the plant used for aquaculture feed production but were consigned to Ridley's stockfeed plant at Tamworth, NSW, for grinding and mixing. As a result, the grind size of the ingredients was not as fine as is specified for prawn feeds. The ingredients were supplied in three batches to meet the increasing requirements of the on-farm trials. Four pellet size grades of the diet were prepared to suit prawns of different sizes: #3 (2.3 x 2 mm); #4 (2.3 x 4 mm), #5 (2.3 x 5 mm) and #6 (2.3 x 7 mm). The stability of the diets was determined for each production run, particularly as the grind size of the ingredients appeared to vary from batch to batch which made production of a high quality pellet very difficult.

The CAP-manufactured diet was tested on two prawn farms in southeast Queensland: Gold Coast Marine Hatchery (GCMH) and Rocky Point Prawn Farm (RPPF). At GCMH, one 0.8 ha pond was stocked with *P. esculentus* postlarvae at a density of 34 prawns per m^2 and fed the PE 3.4 diet until harvested at 26 weeks. The prawns were fed 4 to 5 times per d according to standard farm practice with the bulk of the feed being given at night. At RPPF, one 0.4 ha pond was stocked *P. escultentus* post-larvae at a rate of 28 prawns per m^2. Prawns were initially fed a *P. japonicus* diet for about 8 weeks and thereafter fed the PE 3.4 diet until harvest at 26 weeks.

8.7.2 Results and discussion

At GCMH, the growth rate of prawns fed the CAP-manufactured PE 3.4 diet was initially relatively low (Fig. 8.2a yellow) Once the prawns had reached about 2 g, their growth rate increased rapidly and averaged about 0.8 g per wk overall. This was less than observed in the laboratory tank study but comparable to that seen in 1997 on GCMH when a mixture of *P. monodon* and *P. japonicus* diets were used (Figure 8.2a). At RPPF in 1999, the growth rate of prawns when fed the PE 3.4 diet was less than 0.65 g per wk, which is not considered a satisfactory rate (Figure 8.2b).

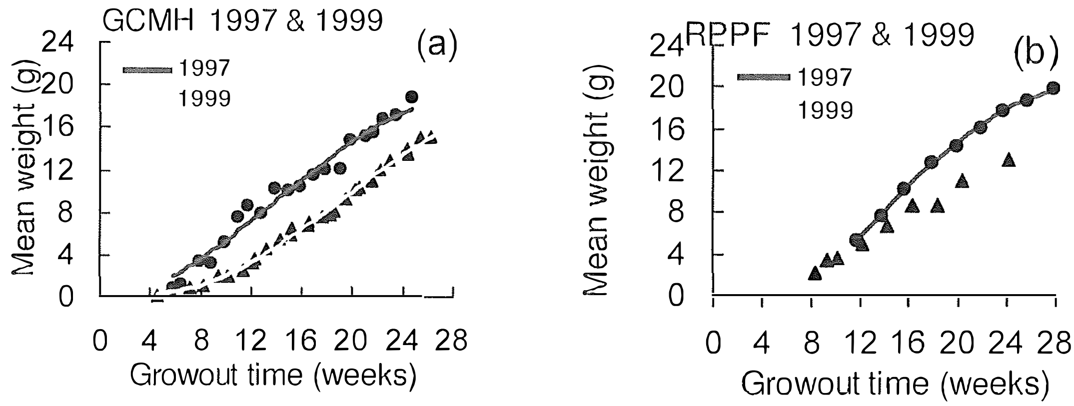


Figure 8.2 Growth response of *P. esculentus* fed mixed *P. monodon* and *P. japonicus* diets in 1997 and the PE 3.4 diet in 1999. (a) Gold Coast Marine Hatchery (GCMH), (b) Rocky Point Prawn Farm (RPPF). See also Figs. 6.3 and 6.4.

The stability of feed pellets in the first batches produced at CAP using the finely ground ingredients from Ridley's Narangba plant initially was high (Table 8.9). Later batches, made from coarsely ground ingredients from Ridley's Tamworth plant, were much less stable. Generally, pellet stability of >90% would be considered acceptable in a commercial feed. It is likely that the grind size of the feed ingredients had a significant bearing on the stability of the feeds. The grind size also influences the digestibility of the diets, with higher digestibility being observed in diets where the ingredients are more finely ground. The consequence of the feed not being manufactured in an aquaculture feed manufacturing plant, with its fine grinding facility, is that the formulation could not be properly assessed on its merits. However at the time, the two ponds were already stocked and the diets were urgently required, so the diets had to be used as they were. Feed was supplied to the prawn farms at slightly different times, with the bulk of the feed from the later that had lower stability, going to RPPF. This could be part of the reason for the different response seen on the two farms.

Table 8.9. Pellet stability data of batches of CAP-manufactured feed indicating the plant where the ingredients were mixed and ground.

	Plant	Stability (%)
Batch 1	Narangba	93
Batch 2	Narangba	93
Batch 3	Narangba/Tamworth	96
Batch 4	Tamworth	91
Batch 5	Tamworth	83
Batch 6	Tamworth	85

8.7 General discussion

The performance of the commercial diets used as reference diets in the laboratory evaluation of the PE 1.1 diet and the PE 2 diets was consistent with their performance in commercial prawn ponds. High growth rates and survival were obtained with the Higashimaru *P. japonicus* diet and lower growth rates and survival were obtained with the two *P. monodon* diets (Higashimaru and Charoen Pokphand) (Table 8.4). The poor growth seen with the *P. monodon* diets is not necessarily a reflection of the quality of the diets, but more on the suitability of the diets to meet the specific nutritional requirements for rapid growth of *P. esculentus.* However, in a subsequent experiment, with the PE 3 series diets, the Charoen Pokphand diet out-performed the PE 1.1 diet that had been made on-site (Table 8.6). The reason for this reversal in performance is not clear, though the first version PE 1.1 was manufactured by extrusion and the later version was made in the laboratory. This would have had an effect on the pellet stability and digestiblity.

The developmental process used in this project has led to the formulation of a diet that performed, under laboratory conditions, almost as well as the far more expensive *P. japonicus* diet (Table 8. 6). The results were sufficiently convincing that we sought commercial production of the diet to meet the requirements of prawn farmers who had stocked ponds in anticipation of this diet becoming available. However, the 13 tonnes of feed prepared for the on-farm testing could not be manufactured in a commercial aquaculture-feed mill and, possibly as a result of this, did not perform as well as expected from the laboratory experiments. The feed did not meet the specifications normally applied to commercial prawn diets for grind size of the ingredients or pellet stability. As such, the feed tested in the ponds may not truly reflect the potential of the diet formulation. The potential of the diet that was developed warrants further evaluation using feed prepared as a commercial prawn feed would be prepared and tested under more controlled conditions with adequate replication.

9. Cost-benefit analysis of trial *P. esculentus* production

9.1 Background

A robust analysis of the comparative cost-benefit of farmers producing *P. esculentus* versus any other prawn species must take account of not just the relative growth rates and market prices of the species, but a broad range of production and market parameters that will affect profitability. The evaluation of the performance of *P. esculentus* as a potential commercially viable species for production must balance its inherently slower growth rate compared to *P. monodon*, against the higher market price and access to broader markets for *P. esculentus*.

To establish the relative cost benefit of production of *P. esculentus*, a bioeconomic model has been developed to take account of the full range of biological and cost and price variables that determine profitability (Cacho, 1999). The model uses actual farm production data from the *P. esculentus* growout trials in this project, and comparative farm production data for *P. monodon*. The model has been used to test the sensitivity of profitability to a range of production parameters, and has also provided a framework to evaluate a range of scenarios and to predict profitability with changes in the production variables.

9.2 Objective

- To quantify the cost benefit of production of *P. esculentus* under commercial farm culture conditions.

9.3 Methods

A cost-benefit analysis for the production of *P. esculentus* on commercial farms was carried out using the production and financial data from the experimental trials with *P. esculentus*. The farms made production and financial data for *P. monodon* available for comparative purposes.

Growth performance data, mortality estimates and feed conversion efficiency estimates for *P. esculentus* were available for two seasons of experimental trials, 1996/97 and 1998/99, at two farms: Gold Coast Marine Hatchery (GCMH) and Rocky Point Prawn Farm (RPPF) (for details see section 6). These trials were denoted as: GCMH-97, RPPF-97, GCMH-99 and RPPF-99. For comparison, data for six ponds of *P. monodon* were available, three for GCMH-99 and three for RPPF-99. Production-cost data and marketing data were available for all trials.

A cost-benefit model was developed, and simulation runs of a base-case scenario and sensitivity analyses of critical parameters were evaluated. Sensitivity analysis was performed on survival, feed efficiency and prawn prices by setting each variable in turn at likely low and high values and comparing the profit obtained in the best *P. esculentus* crop (1997) with the *P. monodon* crop.

A variation on the sensitivity analysis approach was also performed. By determining the value of key variables that would make *P. esculentus* as attractive as *P. monodon* in terms of profit obtained. This is termed *scenario analysis* and consists of finding the value of each variable (i.e. growth parameters, prices, costs) that would make the profit obtained by *P. esculentus* equal to that obtained by *P. monodon*.

9.4 Results

Disclaimer - farm economic data
Economic data used in the cost benefit analysis were provided in good faith by the collaborating industry partners in this project, or calculated from the data collected by CSIRO in the course of the project. To provide a degree of commercial confidentiality with this information, the data presented has been standardised for variable costs of production between the farms. The overall objective of providing a robust comparison of *P. esculentus* and *P. monodon* production has been strictly adhered to. While the specific figures presented may not be an exact representation of the situation for each farm, nonetheless the species comparison remains robust.

9.4.1 Price and cost inputs to model

Prawn prices
Based on actual sales, prawn prices were assumed to range from $16.50 to $19.00 per kg for *P. esculentus* and from $13.00 to $16.30 for *P. monodon*. Small prawns (above 40 per lb) were given a price of $10.00 (Table 9.1).

Penaeus esculentus have export potential (mostly to Japan), while *P. monodon* are sold domestically, therefore exchange rate fluctuations between the Yen and the Australian dollar can be important. Also, prices received for smaller sizes of *P. esculentus* (31/40 to 21/25) in 1999 were higher ($17.00 to $18.25 per kg). Thus this is an important variable for sensitivity analysis.

Table 9.1. Prawn price schedules used in the cost benefit model.

P esculentus			***P. monodon***	
Size	**Price ($/kg)**		**Size**	**Price**
(no./lb)	1997	1999	(no./lb)	($/kg)
13/15	19.00	19.00	<10	16.30
16/20	19.00	19.00	10/15	15.50
21/25	18.00	18.25	16/20	14.50
26/30	18.00	18.25	21/25	14.50
31/40	16.50	17.00	26/30	14.50
Small	10.00	10.00	31/40	13.00

Feed costs
The price of *P. esculentus* feed for the 1999 trial was $2.15 per kg. Feed costs for *P. esculentus* in 1997 averaged $2.30 per kg, as the *P. monodon* feed was supplemented with *P. japonicus* in the final stages of growout. The price of *P. monodon* feed was $1.69 per kg on average (range $1.58 to $1.74).

Seedstock: Postlarvae (PL) costs:
The costs per female were $40 to $60 for *P. esculentus* and $60 to $150 for *P. monodon*. Other hatchery costs are assumed to be the same for both species. The *P. esculentus* broodstock produce less eggs, so it takes 1.5 to 2 times as many *P. esculentus* spawners to stock a pond (e.g. 4 to 5 *P. monodon* spawners to 8 to 10 *P. esculentus* spawners per pond). The cost of *P. monodon* PLs is $0.017 per unit (Brennan, 1999). The range of female costs reported above implies that *P. esculentus* prices are about half as much as for *P. monodon*, while twice as many spawners are required. Thus it is reasonable to assume that PL costs are the same for both species. Therefore, a price of $17.00 per 1000 postlarvae for *P. esculentus* was assumed (Brennan, 1999).

9.4.2 Cost-benefit analysis: Base case

The base case figures are based on a 1 ha pond, commercial stocking rates, with the production figures for GCMH in 1997 and 1999 being used in the model. The interest rate was set at 6% and the product prices were as reported (Table 9.1). The base-case assumptions for the two *P. esculentus* crops (1997 and 1999) and one *P. monodon* crop (1999) (Table 9.2). The growout season length for *P. esculentus* (28 to 30 weeks) is longer than for *P. monodon* (24 to 26 weeks), because of the slower growth rate of *P. esculentus*. The cost of a longer growing season is taken into account through interest payment on operating costs.

Table 9.2. Base case assumptions – summary.

	P. monodon	*P. esculentus*	
	1999	**1997**	**1999**
Growth parameters:			
α_i	27.357	22.294	23.196
β_i	151.668	5.411	5.723
γ_i	0.410	0.135	0.096
Management:			
Stocking rate ('000 PL per ha)	350	350	350
Feed efficiency	1.94	1.96	1.95
Season length (weeks)	26	30	30
Survival (%)	60.9	66.0	64.9
CV (%)	20.00	18.10	21.80
Prices & Costs:			
Price scalar[a]	1.00	1.00	1.00
Postlarvae ($ per 1000 PL)	17.00	17.00	17.00
Feed $ per kg	1.69	2.30	2.15

[a] The price scalar is used to represents shifts in the price schedule and changes in exchange rates.

Table 9.3. Outcomes of base case scenario.

	P. monodon	*P. esculentus*	
	1999	**1997**	**1999**
Feed (kg/ha)	5756	4457	4237
Body weight (g)	27.2	20.3	16.79
Harvest yield (kg/ha)	5809	4688	3814
Average Price ($/kg)	14.89	18.06	17.56
Costs ($/ha)	16,148	16,070	15,580
Revenue ($/ha)	86,495	84,674	66,981
Profit ($/ha)	70,348	68,604	51,401

Penaeus monodon consumes more feed, but the feed is cheaper and the prawns grow larger, resulting in a higher profit per ha ($70,348) than for *P. esculentus* ($68,604), despite the lower market price of *P. monodon* (Table 9.3, Fig.9.1). There is a marked difference in the profit obtained by *P. esculentus* between years, with the 1999 crop, (profit $51,401) being less profitable than the 1997 crop (profit $68,604) by about $17,200 per ha.

The average price received for the 1997 crop was $0.50 per kg higher than the price received in 1999 (Table 9.3, Fig. 9.1), despite the fact that in 1999 overall prices were higher (Table 9.1). This is because the average price obtained from the crop depends on the final body weight and on the size distribution, which is affected by the coefficient of variation.

This base case analysis suggests that *P. monodon* is a more profitable crop than the best *P. esculentus* crop by a margin of $1,744 per ha or about 2.5%. However, given the uncertainty attached to the values of certain variables it is important to perform sensitivity analyses to account for this variability, before drawing final conclusions.

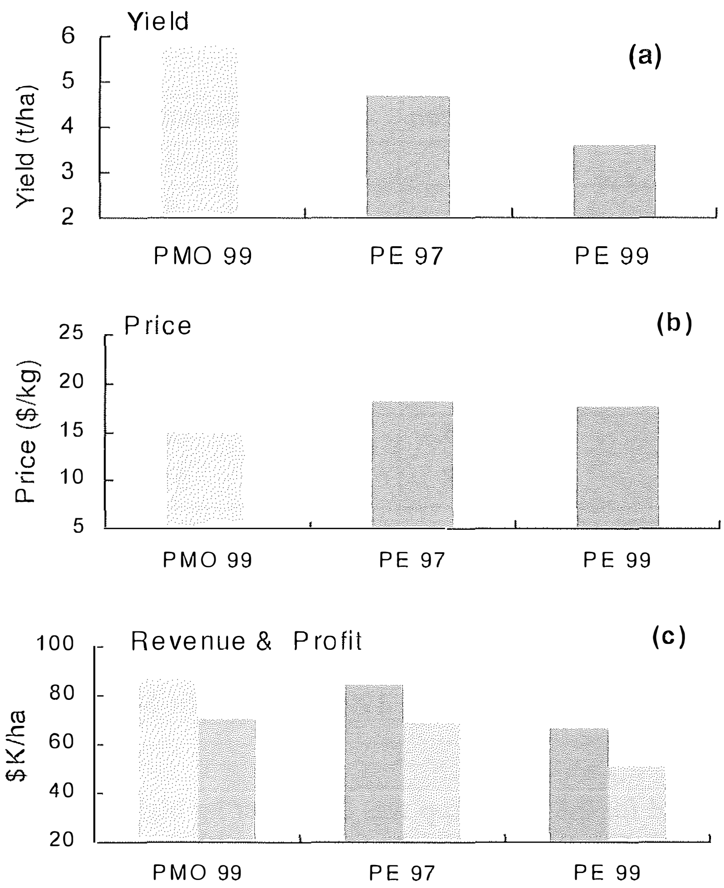


Figure 9.1. *Penaeus esculentus* and *P. monodon*: Outcomes for base-case scenario for cost-benefit analysis. (a) Comparative yield (t per ha) of 1997 and 1999 *P. esculentus* (PE) crops, and 1999 *P. monodon* (PM) crop. (b) Price received for each crop. (c) Comparative revenue (left-hand bar) and profit (right-hand bar) ($K) for each crop.

9.4.3 Sensitivity Analysis

The effects of 27 combinations of survival, feed efficiency and exchange rates on the profitability of the 1997 *P. esculentus* crop were examined (Table 9.4). Profits range from $51,418 per ha for the low-survival, low feed efficiency, low exchange rate combination (representing a weak Yen relative to the Australian dollar) to $83,934 for the high survival, high feed efficiency, high exchange rate (strong Yen) combination.

The sensitivity of profits can be determined by estimating elasticities. The elasticity of A with respect to B represents the percentage change that variable A will exhibit in response to a one percent change in the value of variable B. The relationship is said to be elastic when the value is greater than 1.0 and inelastic when the value is less than 1.0. Elasticities of profit with respect to survival, feed efficiency and exchange rate (price) were examined (Table 9.5). *Penaeus esculentus* profits are elastic with respect to both survival and price (mean 1.16 and 1.24 respectively) and inelastic with respect to feed efficiency (mean 0.157). This means that, on average, a 1% increase in the price of prawns will cause a 1.24% increase in profit. This occurs because revenues increase by 1% while costs remain as before, thus the increase in profit is more than proportional. Note that the elasticity of profit with respect to one variable is affected by the values of other variables. Thus the elasticity with respect to survival is 1.19 at low price and feed efficiency, and it decreases to 1.13 at high price and high feed efficiency.

Table 9.4. Sensitivity analysis outcomes. Profit ($ per ha) as affected by survival, feed conversion efficiency and currency exchange rate.

	Feed efficiency		
Survival	1.63	1.96	2.21
	Exchange rate × 0.9		
59.6	51,418	53,311	54,369
66.0	58,130	60,137	61,258
70.3	62,651	64,733	65,896
	Exchange rate × 1.0		
59.6	59,065	60,958	62,015
66.0	66,597	68,604	69,726
70.3	71,670	73,752	74,915
	Exchange rate × 1.1		
59.6	66,711	68,604	69,662
66.0	75,064	77,071	78,193
70.3	80,689	82,771	83,934

Given that prices and exchange rates are out of the control of the farmer, the appropriate strategy would be to concentrate on improving either survival or feed conversion efficiency. Feed conversion efficiency would have to be increased by almost 10% to obtain the same increase in profits as what would be obtained by increasing survival by 1% (i.e. 0.157 x 10 is close to 1.155). Hence the farmer must assess which class of improvement would be easier (or cheaper) to achieve, or whether it may be appropriate to attempt simultaneous improvement in both survival and feed conversion efficiency.

Table 9.5. Sensitivity analysis results. Elasticities of profit with respect to survival, feed efficiency and currency exchange rate (price).

Elasticity with respect to survival

	Feed conversion efficiency			
Price	Low	Med	High	Mean
Low	1.192	1.172	1.161	1.175
Medium	1.168	1.150	1.141	1.153
High	1.149	1.134	1.126	1.136
Mean	1.169	1.152	1.143	1.155

Elasticity with respect to feed conversion efficiency

	Survival			
Price	Low	Med	High	Mean
Low	0.187	0.176	0.169	0.177
Medium	0.164	0.154	0.149	0.155
High	0.145	0.137	0.132	0.138
Mean	0.165	0.156	0.150	0.157

Elasticity with respect to price

	Feed conversion efficiency			
Survival	Low	Med	High	Mean
Low	1.295	1.271	1.258	1.275
Medium	1.254	1.234	1.223	1.237
High	1.233	1.214	1.204	1.217
Mean	1.261	1.240	1.228	1.243

9.4.4 Scenario Analysis

Further insight can be obtained by studying alternative scenarios (Table 9.6). As indicated previously, scenario analysis was accomplished by estimating the change in parameter or variable values that would be required to make *P. esculentus* as profitable as *P. monodon*.

We can, for example, focus on increasing the maximum weight achievable in a growing season (α_E) to 22.7 g (by 1.97%) or on increasing the growth parameter (γ_E) to 0.142 (by 4.85%). These changes could be achieved through selective breeding for improved growth performance, better management of existing strains, or both. There are a number of options available to make *P. esculentus* as profitable as *P. monodon*; these options, and the critical values for each parameter include (Table 9.6):

- increasing the maximum weight achievable in a growing season (α_E) to 22.7 g (by 1.97%), potentially by selective breeding.
- increasing the growth parameter (γ_E) to 0.142 (by 4.85%), potentially by selective breeding
- increasing stocking rate to 358,897 PL/ha while keeping everything else constant (including survival, feed efficiency and size distribution), which may be difficult or impossible).
- increasing FCR 2.38 (at constant feed cost);
- increasing survival to 67.5%;
- decreasing feed cost to $1.77 per kg; or
- decreasing PL costs to $12.80 per 1000 PL.

Table 9.6. Results of scenario analysis. Critical values are those that make *P. esculentus* profit equal to *P. monodon* profit ($70,348/ha).

Parameter or Variable	Critical Value	Change from base (%)	Results at harvest: Feed (kg/ha)	Body weight (g)	Harvest (kg/ha)	Average Price ($/kg)	Cost ($/ha)	Revenue ($/ha)
α_E	22.734	1.97	4545	20.70	4781	18.12	16,266	86,614
β_E	4.632	-14.40	4275	20.57	4752	18.10	15,664	86,012
γ_E	0.1417	4.85	4419	20.64	4768	18.11	15,986	86,334
Stocking rate	358897	2.54	4570	20.30	4808	18.06	16,478	86,826
Feed	2.38	21.35	3673	20.30	4688	18.06	14,326	84,674
Survival	67.5	2.21	4513	20.30	4792	18.06	16,196	86,544
Feed cost	1.77	-17.59	4457	20.30	4688	18.06	14,326	84,674
PL cost	12.18	-28.33	4457	20.30	4688	18.06	14,326	84,674
Exchange rate	1.02	2.06	4457	20.30	4688	18.43	16,070	86,418

9.5 Discussion

Base case scenario

The assumptions used in the base case scenario represent the actual scenario of the experimental growout trials (Table 9.2). Under this scenario, *P. monodon* production results in a higher profit per ha ($70,348) compared to *P. esculentus* ($68,604), by a margin of $1,744/ha or about 2.5%. Although *P. monodon* consumes more feed, the feed is cheaper, and the prawns grow larger in a slightly shorter time, so despite the lower market price of *P. monodon*, the overall profitability was higher. Even so, the difference in profit was less than would be predicted when simply comparing the growth rates observed in the trials (Fig. 7.5). The higher price received for *P. esculentus* partly outweighed the lesser growth performance. However, there was a marked difference in the profit obtained by *P. esculentus* between years, with the 1999 crop, (profit $51,401) being less profitable than the 1997 crop (profit $68,604) by about $17,200/ha.

Overall, the cost-benefit analysis of the base case scenario supports the potential of *P. esculentus* to be grown with similar profitability to *P. monodon* (1997 trial), and provides the basis to identify improvements in specific variables to achieve equal profitability to *P. monodon*

Sensitivity analysis

Several parameters in the above cost-benefit analysis are subject to significant variability that may be beyond the farmers' control, and there are some variables that could not be estimated with a high level of certainty. Hence a sensitivity analysis was performed to predict for the effects of ranges of values for 27 combinations of survival, feed cost, feed conversion efficiency and exchange rates on the profitability of the 1997 *P. esculentus* crop (Table 9.4). This analysis describes the elasticity of profit with respect to these factors, thus permitting an evaluation of which factors to target for improving profitability. The analysis identifies survival (in terms of increased yield) and feed conversion efficiency (expressed also as or feed cost) as factors that are firstly potentially within the farmers' control, and secondly likely to impact proportionally on profitability.

Scenario analysis – critical values for the profitability of P. esculentus

A scenario analysis was used to identify the critical values of several parameters that would make *P. esculentus* as profitable as *P. monodon* (Table 9.6), resulting in several options to increase the profitability of growing *P. esculentus*. Some of these options are more achievable than others. For example, the effects of the currency exchange rates on price are out of the control of the farmer. Attempts to increase stocking rate while maintaining the survival, growth, size distribution and yield to the 1997 levels, or reductions in the cost of PL production are difficult to achieve. A reduction in the cost of the feed by 18%, or increasing feed conversion efficiency by 21% while maintaining equivalent growth and yield performance to that achieved in the 1997 trial may be possible. This would require further development of the specific *P. esculentus* diet, such that the performance observed in the laboratory trials could be achieved in a commercial environment.

However, improvement of the growth performance of *P. esculentus* is demonstrably possible with genetic improvement through selective breeding. An improvement in the maximum weight achievable in a growing season (α_E) by 1.97%, or increasing the growth rate (γ_E) by 4.85% is likely to be easily achievable. Hetzel *et al.,* (2000) have demonstrated that the realised heritability for improved growth in *P. japonicus* is 23%, and that the response to selection for faster growing animals is 21%. These values predict that selection for faster-growing *P. japonicus* would result in an 11% improvement in growth per generation for at least 3 to 5 generations. Furthermore, in commercial farm trials, Preston and Crocos (1999) have demonstrated a 13% improvement in growth and a 21% increase in value for second-generation selected stocks of *P. japonicus*.

The elements required for the selective breeding of *P. esculentus* are now in place. The major requirement is the capacity for closed cycle production of farm stocks to permit the selection of faster growing animals as broodstock to produce the next generation. This capacity has been developed and demonstrated for *P. esculentus* in the course of this project. It is now possible to select candidate broodstock at commercial harvest, on-grow these to spawning size, and mature and spawn them to produce a subsequent generation. It is expected that heritability and response to selection for growth in *P. esculentus* would be similar to that for *P. japonicus.*

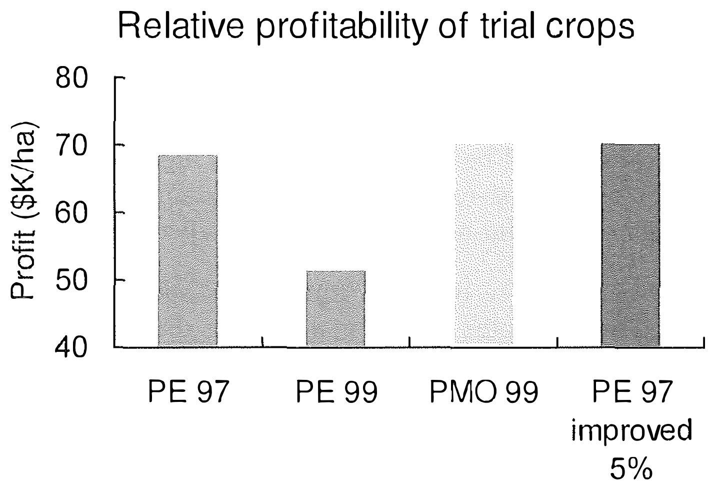


Figure 9.2. Relative profitability of crops grown in the trials. The right-hand bar illustrates the growth and market performance that would be achieved if the *P. esculentus* result in 1997 was combined with a growth improvement of 5%, ie. This would produce an equivalent profit to *P. monodon.*

Therefore, it is likely that selective breeding to achieve a 5% increase in growth for *P. esculentus* is a very achievable target, and that this gain would elevate the profitability of this species to be the equivalent of *P. monodon* (Fig. 9.2). Further gains in production efficiency through continued selective breeding in association with improved cost-effectiveness of the feed would ensure the viability of *P. esculentus* as an additional species to be grown by Australian prawn farmers.

10. Benefits

The outcomes of this project confirm the potential for *P. esculentus* to be grown as an additional species by Australian prawn farmers. This finding has several benefits for the Australian industry:

- The future growth of the Australian prawn aquaculture industry will benefit from the strategic opportunity to take up, and develop further, the production technology for an additional species, which has an established export market and which does not have the intense overseas competition that is the case for *P. monodon*. There is a niche market in Japan for *P. esculentus* created by a demand for a more strikingly coloured, and hence higher priced, prawn than the mass market "black tiger" prawn (*P. monodon*). This niche is created by consumers unwilling to pay the extremely high prices for *P. japonicus,* and so provides an opportunity for Australian producers.

- Farming of *P. esculentus* would be less problematic as regards spawner supply. Wild spawners are available year-round and in greater numbers, but even more importantly, production from pond-reared broodstock has been demonstrated.

- The superior growth performance of a diet formulation specifically tailored for *P. esculentus* has been demonstrated at a laboratory scale. Further development to achieve similar performance on-farm will provide the scope for further cost-effective improvements in growth.

- Development of novel approaches to increase the growth of *P. esculentus* in the early post-stocking stage will provide a means for "head-starting" the pond growout.

- Production efficiency of *P. esculentus* in the hatchery can potentially be improved by adopting the lower-temperature larval rearing protocol identified in this project.

- The development of the capacity for growing *P. esculentus* has enabled the commencement of research to evaluate the potential for stock enhancement of this species in the wild fisheries (FRDC 99/222). Stock enhancement initiatives would provide benefits to resource sustainability in wild fisheries, and, the additional market for seedstock would also benefit the farming industry.

- The project has quantified the cost-benefit of growing *P. esculentus* compared to *P. monodon*. This will provide farmers with a basis for production planning.

- The demonstration of the capacity for closed cycle production has confirmed the potential to achieve growth improvements, required for *P. esculentus* profitability to match *P. monodon*, by means of selective breeding.

11. Further development

Based on the outcomes of this project, we suggest three areas of further development to ensure that Australian farmers have the capacity to grow *P. esculentus* as an additional farmed species.

- The diet formulation developed specifically for *P. esculentus* in this project showed positive results in the laboratory experiments, but did not perform as well as expected in the commercial trials. Further development of the technology transfer process is required to enable the successful commercial-scale production of the project-formulated diet. A commercially produced feed is required that can achieve comparable performance in commercial ponds as was observed in the laboratory trials. The collaborative involvement of a commercial feed miller is needed to ensure the successful transfer of the diet formulation to a commercial product.

- Provision of natural-feed supplementation in tanks resulted in improvements in the growth of early stage juveniles. While there is a natural biota present in conventional growout ponds, the concept of introducing structures to increase the surface area for colonisation of natural biota may provide the means to further improve growth at the early stages.

- The cost benefit analysis identified the critical values for production parameters that would achieve equivalent profitability for *P. esculentus* as was observed for *P. monodon*. Development of selective breeding approach to improve on-farm growth performance using established techniques would ensure the improved growth performance required for *P. esculentus* to be equally as profitable as *P. monodon*.

12. Conclusion

This project has demonstrated the cost-benefit of farm production of *P. esculentus* to be comparable to that of *P. monodon*, has demonstrated the capacity for closed cycle breeding, and has demonstrated the superior growth performance of a formulated *P. esculentus* diet, at a laboratory scale.

The brown tiger prawn, *P. esculentus*, has been grown successfully and the product sold on the export market. The profitability of *P. esculentus* production was shown to be within 2.5% of *P. monodon* profitability for the 1997 trial where *P. esculentus* was fed a *P. monodon* diet supplemented with higher protein *P. japonicus* diet. The cost benefit analysis has defined the critical values of several parameters, which if achieved, would produce equivalent profitability for *P. esculentus* and *P. monodon*. Importantly, the inherently slower growth rate of *P. esculentus* compared to *P. monodon* is compensated for by the better market performance of *P. esculentus;* hence it is critical to focus on the profitability of production, and not simply the inherent growth rate of a species.

Improving the growth performance of *P. esculentus* by around 5% over the 1997 growth rate would produce equivalent profitability to *P. monodon.* The potential to achieve this level of improvement is available through selective breeding for faster growth, or by further development of the *P. esculentus* diet to produce on-farm growth performance equal to that achieved in the laboratory. The demonstrated closed cycle breeding during this project confirms the capacity for farm production from domesticated broodstock, and hence the opportunity to commence selective breeding for improved growth. Similarly, the project has identified approaches for further development of the diet to improve on-farm growth performance. In addition, other improvements to the efficiency of *P. esculentus* production, the optimal temperature for larval rearing and supplementary natural feeding at the nursery stage, have been developed in the course of the project and assist with the efficient production of *P. esculentus.*

The development of the culture of *P. esculentus* has enabled the commencement of research to evaluate stock enhancement of this species in wild fisheries (FRDC project (99/222), to provide benefits to resource sustainability in these fisheries.

The outcomes of this project confirm the potential for *P. esculentus* to be grown as an additional species by Australian prawn farmers. The opportunity to capitalise on these findings now rests with the Australian prawn farming community.

13. Acknowledgements

This research was funded by the Fisheries and Development Corporation. The farm production components were made possible with the cooperation of several prawn farming companies: Gold Coast Marine Aquaculture, Rocky Point prawn farm, Rossman's prawn farm, Truloff's prawn farm, and Seafarm. Dr Oscar Cacho, Agricultural Economist, University of New England, assisted with the cost-benefit analysis.

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APPENDIX 1: INTELLECTUAL PROPERTY

The intellectual property associated with the development of the *P. esculentus* diet is the subject of a confidentiality agreement between FRDC, CSIRO and Ridley Corporation.

APPENDIX 2: PROJECT STAFF

Peter Crocos	MSc	Project management, Design and supervision of growout and reproductive performance trials.	40%
David Smith	B App Sc	Diet development, Design and supervision of diet trials.	20%
Sandy Keys	BSc (Hons)	Growout trials, Reproductive performance trials.	100%
Simon Tabrett	BSc (Hons)	Diet development, Diet trials	20%
Nigel Preston	PhD	Industry liaison, project development	10%
Peter Rothlisberg	PhD	CSIRO Program Leader	5%