84/15

# FEASIBILITY OF INTENSIVE AQUACULTURE OF FRESHWATER CRAYFISH OF THE GENUS CHERAX

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# 1.0 INTRODUCTION

## 1.1 General:

In Western Australia, and now elsewhere, there has been considerable interest in marron farming for over two decades. Many schemes have come and gone and the highly optimistic attitude which once prevailed has gradually been replaced by a more realistic approach to marron aquaculture. While, for example, it was once considered that appropriate site selection would allow marron to be cultured to marketable size (120 g) on a yearly basis (Morrissy 1976), it was later realised that at least at intensive pond culture densities achievement of 120 g average weight in Western Australia was not possible even on a two-year schedule (Morrissy 1984(a)).

Most serious commercial interest in marron farming has been with pond and dam culture but there is still little clear advice to the would-be marron farmer. Proposed management and pond designs are yet to be tested as full-scale enterprises. Reasons cited for the failure of many marron farming schemes include predation by birds and other animals, cannibalism, climatic and weather variability and extremes, and, increasingly, operator inexperience. Underlying such explanations is the fundamental fact that pond and dam ecosystems are extremely complex and unpredictable. There is a growing appreciation that marron are sensitive organisms which are intolerant of environmental extremes.

Present commercial operations in Western Australia exploit two or more of the following aspects of marron aquaculture:

i) production of young-of-the-year, or 0+ marron, for sale as seed stock. At prices of up to 50 cents per marron (Western Australia) and $1 per marron (Queensland), production of these small marron (1-2 g) is clearly a very attractive proposition to farmers. The longer-term viability of this market will depend upon the success of;

ii) production of edible-sized marron, commonly termed "grow-out";

iii) tourism appeal; and

iv) consultation to other less-experienced operators.

The yabbie (a species of the same genus as the marron) has also been considered as a candidate for aquaculture, particularly in South Australia (Mills 1984). Although this species does not reach the large size of marron (150 g compared with reports of 2 kg), this may not be of relevance with a target size for harvest of perhaps between 50 and 100 g.

## 1.2 Philosophical considerations

A "maximum growth rate" for marron was derived from data from samples taken over a long period from a farm dam (Morrissy 1974). This became a standard by which marron growth rates in more intensive systems were assessed (Morrissy 1984). If growth rates did not compare favourably with this standard then the inference was drawn that the system used could not support commercial development of marron culture. We continue to have some doubts about the interpretation of data from which the growth curve was constructed, and assert that the commercial success or otherwise of any plant or animal production schemes will depend on the interaction of:

a) achievable survivorship;
b) achievable growth rate;
c) cost of resources used; and
d) value of final product.

A generalised picture of the relationship between the cost of resources and the value of production is given in Fig. 1.

There are several general features of this model worth mentioning. Firstly, there is a level of resource usage which gives unprofitable production, that is, below the break-even line (Region A). Secondly, there may be a range of resource usage which results in profitable production (Region B); somewhere in this region there is a point where maximum return on invested resources is obtained (X). Thirdly, beyond this region, the cost of production is greater than its final value (Region C), even though production may still increase with increasing investment. Finally, there will be a point at which the production curve flattens out; here the biological potential of the species has

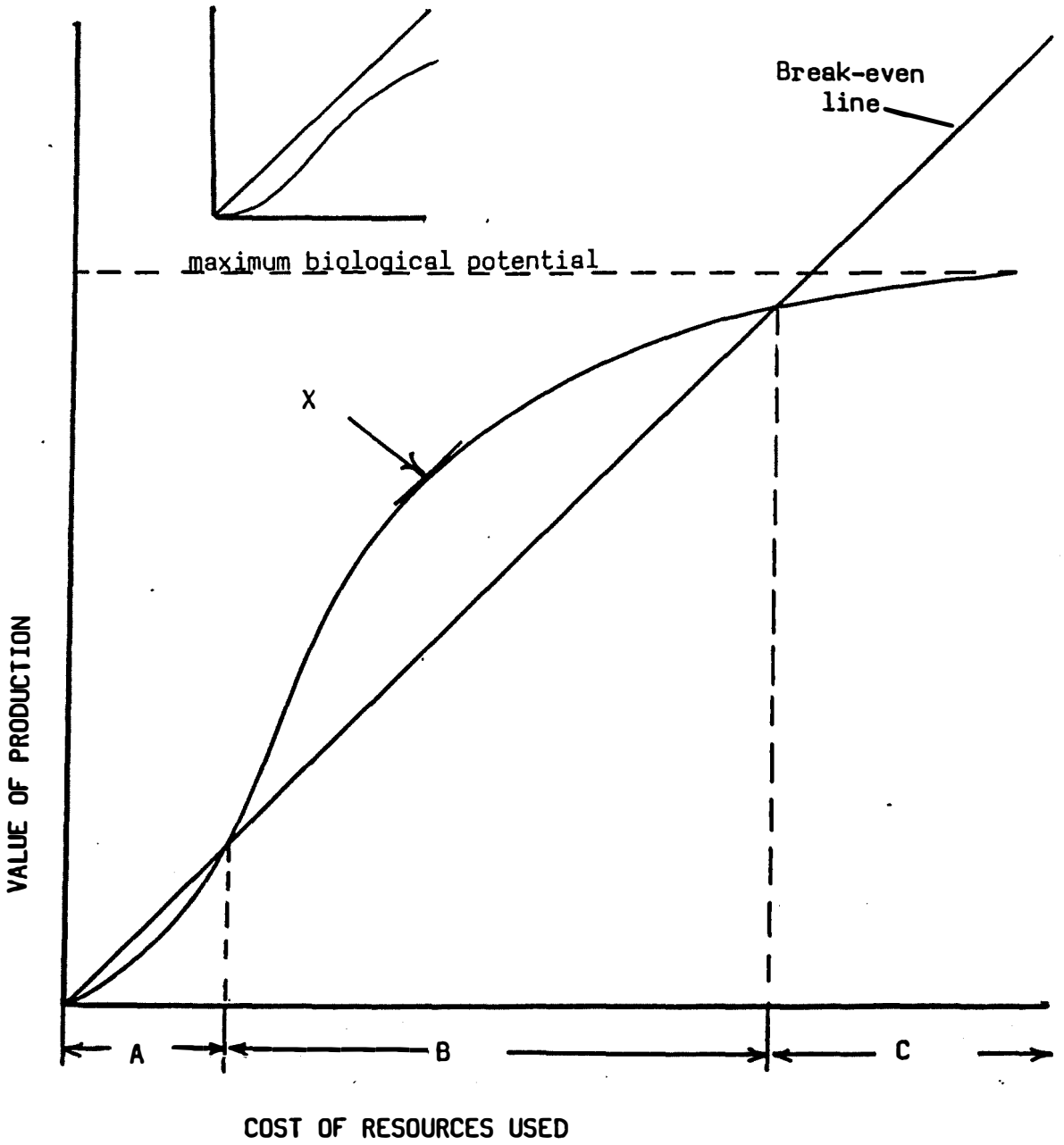



Figure 1: Conceptual model of the relationship between the value and cost of production generated by a biological system (largely "borrowed" from fishery production models).

been reached, and further investment of resources does not gain any increased production. It should be noted that in some cases the operation may be wholly unprofitable (see inset of Fig. 1), and also that while achievement of the biological potential of the species may be unprofitable, it may be possible to successfully exploit this species at a lower level of resource input.

## 1.3 Our approach:

Assuming that the market price of the product was outside our control, we considered it important to document the other elements influencing the ultimate feasibility of commercial culture, namely the production of crayfish (survivorship and growth) and the input of resources required. In addition to simply documenting these elements, research was aimed at maximising the former while minimising the latter.

Because of the already mentioned problems associated with the pond and dam culture of marron, and because such methods had already been the subject of research, we decided to investigate an alternative approach to the production of freshwater crayfish - that is, the intensive battery rearing of these animals. Using such a system it is possible to entirely eliminate threats of predation and cannibalism and to control many environmental factors between close limits. The concept of battery culture of crustaceans was not new - many schemes had been tried using the marine lobster Homarus particularly in the U.S. and the U.K., but despite years of research, efforts had apparently been unsuccessful.

We adopted the following constraints in the design of culture apparatus:

i) Simplicity of operation - endeavours were made to keep the design and maintenance of the apparatus as simple as possible. By so doing we hoped to reduce the vulnerability of the system to breakdown and to allow rapid and simple day to day operation.

ii) Ease of scale-up - it was important that our laboratory investigations were designed so that they could be scaled-up without gross changes to the environment provided for the

crayfish. If this were not the case, then extrapolations of commercial production based upon laboratory investigations would not be valid. A similar problem presents itself in extrapolating production data from small ponds (115 $m^2$ floor area) to commercial-sized operations (Morrissy 1979); a battery system is however more amenable to scale-up because the increase in size is due to an increase in number of units, rather than in the size of each unit.

Because of the paucity of data about growth of marron under controlled conditions, we were faced with an almost endless list of factors which at least potentially could have influenced crayfish production. Our choices of which factors to examine first were made after considering the following:

a) intuition;
b) literature reports on other species;
c) resource implications of the factor; and
d) the practicality of conducting a thorough investigation.

In the early part of the project we decided not to investigate diet as a factor despite the fact that the literature on crustacean aquaculture seemed almost preoccupied with this. This decision was made because (i) we believed the case for diet being the most important factor to be considered was flimsy, (ii) this factor was a very complex one to treat thoroughly, and (iii) there was already interest in the subject (Morrissy 1984(b)). However in the latter part of the project, with the publication of a "successful" crustacean ration (D'Abramo et al. 1981) and with this diet being made available to us (courtesy of Professor D'Abramo), we tested this against our locally produced diet in two growth trials.

There was also a paucity of knowledge about the growth of other locally available species of freshwater crayfish. As well as marron Cherax tenuimanus and yabbies C. destructor, the koonac C. plebejus and the gilgie C. quinquecarinatus were readily available for research, and the culture potential of these species was virtually unknown. At the inception of the project we thus decided to

investigate the growth performance of all four Cherax species; by the time the FIRTA support was available we had narrowed the selection down to the marron and the yabbie. Our reasons for not continuing with the other two species were largely due to logistic and time constraints. In short growth trials neither of these species seemed to have the growth potential of the marron or the yabbie, but further investigation would be required before they should be totally eliminated from consideration for aquaculture.

## 1.4 Funding and background research:

The project commenced in mid-1981; from its inception until 1984 it received support from within W.A.I.T. ($5,350). FIRTA support was obtained in 1984/1985 ($17,397) and 1985/1986 ($19,728). In addition, in 1984 funding from the Reserve Bank Rural Credits Development Fund was obtained ($3,675).

Findings for the three years of research prior to FIRTA support have been documented (Kowarsky et al. 1984). We will not reiterate them in detail here, but rather briefly outline major results to set the stage for the more detailed report following.

i) Tap water, despite thorough aeration and standing prior to use, was toxic to marron kept in flow-through conditions for longer than 5 days. The agent responsible was possibly copper. The battery system was connected to a supply of groundwater which was not conducted in copper pipes, and the problem disappeared.

ii) A culture apparatus using individual chambers with close control of water and food input was tested, but growth in this system was poor compared to that of marron free-ranging in an aquarium.

iii) Growth of marron individually confined to small stainless-steel cages within an aquarium did not differ from similar marron allowed to free-range in the same tank; mortality of the caged animals was considerably lower than those outside the cages. The system mentioned in (ii) above was abandoned in favour of a partitioned aquarium design.

iv) Much improved marron growth rates were obtained in the partitioned aquarium; there was also some evidence that the growth of juvenile yabbies was superior to that of marron of similar size, but that growth of gilgies was considerably slower than either of the other species.

## 1.5 Structure of the following report:

The work funded by FIRTA was conducted as a series of growth trials, each investigating the effects of different levels of one, two or at the most three factors. Some of this work has already been published (Kowarsky et al. 1985(a), 1985(b), 1985(c)).

For ease of reading we propose in this report to treat the material factor by factor, rather than in strict chronological order. The word "significant" is used throughout in its statistical context, referring to results occurring by chance factors alone with a probability of less than 5%.

# 2.0 MATERIALS AND METHODS

## 2.1 Accommodation:

The basic unit for the individual culture of marron and yabbies in all of the experiments was made from plastic boxes (ACI T-Series available from Makin Paper, Newcastle Street, Perth). Both the 2 l and 1.5 l boxes of this series were used in various trials, the same top dimensions and slightly tapered sides allowing these containers to neatly stack into each other, a property which was used in several designs. A diagram of one such accommodation unit is given in Fig. 2.

In all cases an airstone situated in a plastic tube provided an air-lift which circulated water through the unit. Units were placed on the bottom of a holding tank (with a capacity for 12 or 18 such units (Fig. 3(a)) with the water level maintained about 6 cm over the top of the lid, or fitted with legs so that the water level was about 3 cm below the lid (Figs 3(b) and 3(c) respectively).

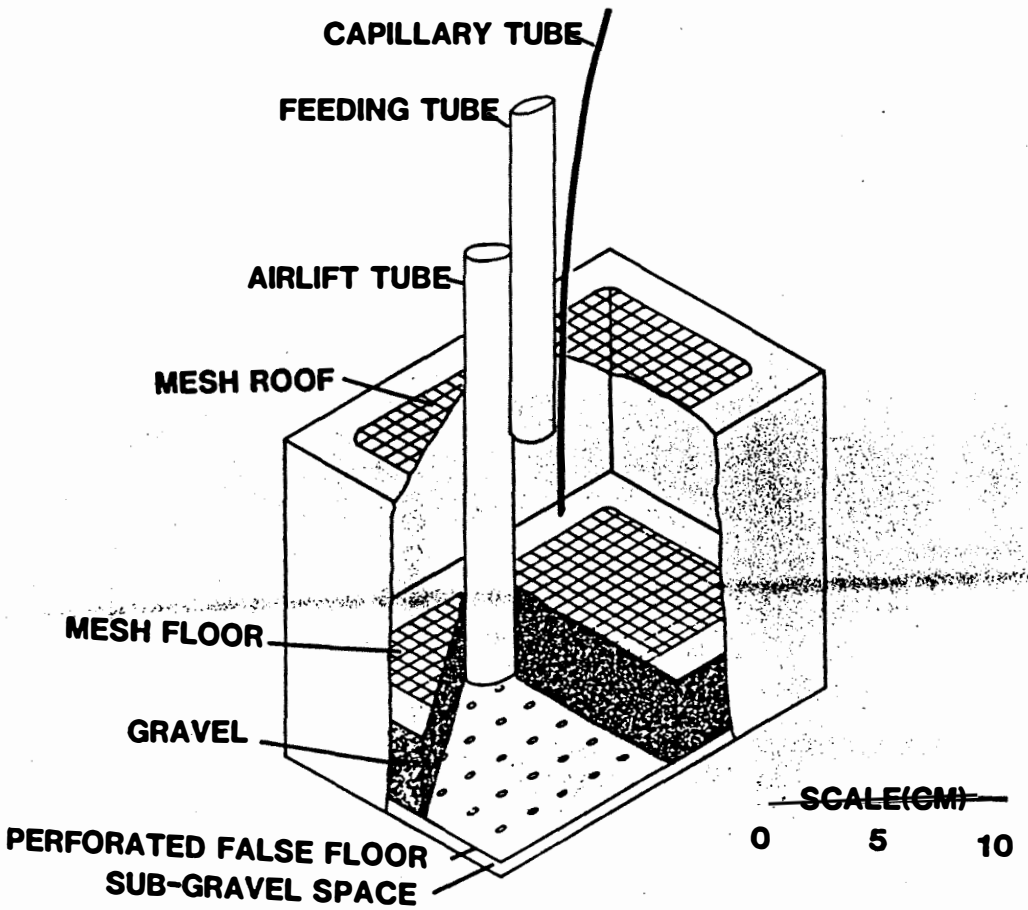



Figure 2: Diagram of accommodation unit for freshwater crayfish used in this research

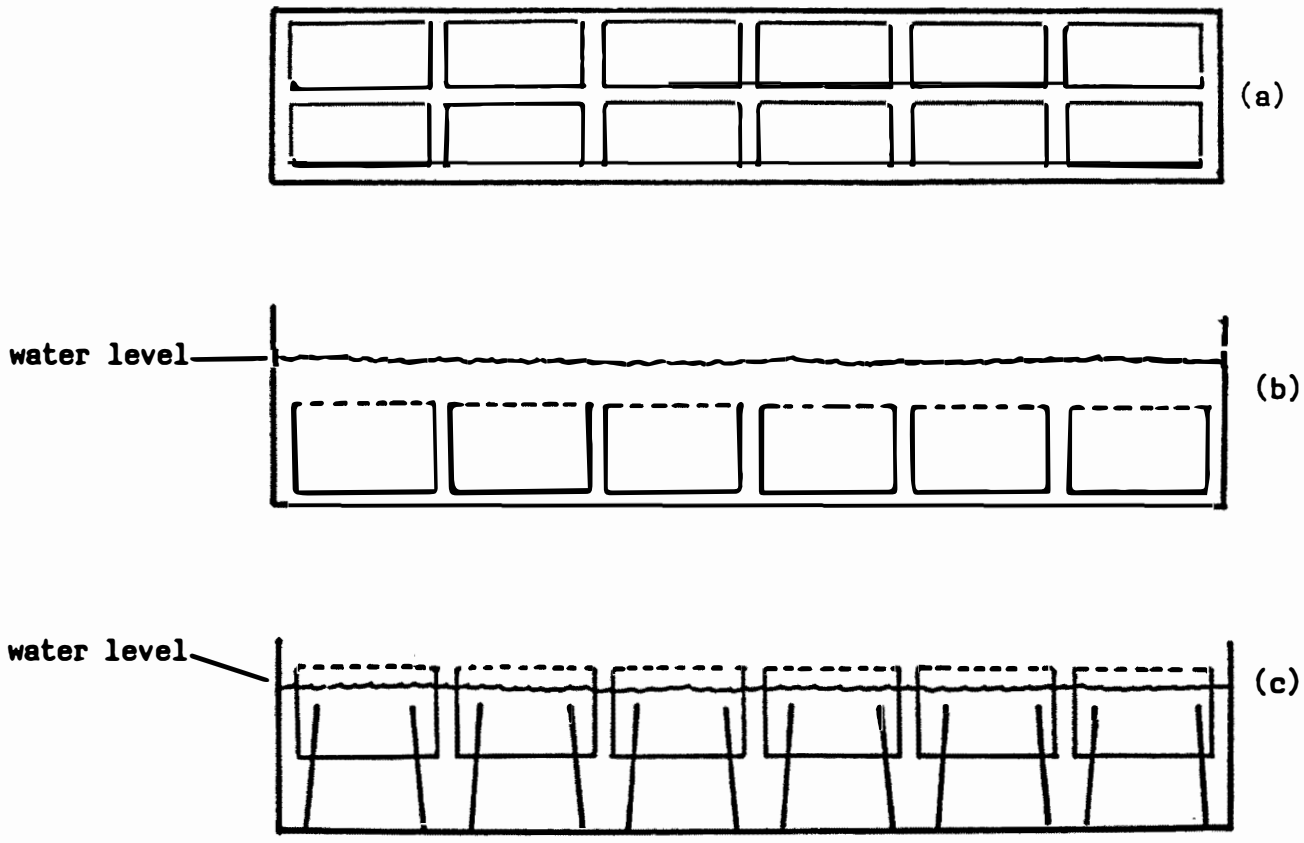



Figure 3: Diagrams (not to scale) of configuration of individual accommodation units within holding tank.

(a) Plan view
(b) Side elevation, units on tank floor, wholly immersed
(c) Side elevation, units raised on legs, partially immersed

Each unit received a capillary tube delivering water at a known rate. Variations to the general scheme described above were made by changing the following:

i) the presence or absence of a filter bed in each unit;

ii) where a filter bed was present, the depth of the bed and the type of gravel used (mean maximum diameter size of grains varying between 2.7 and 5.3 mm); and

iii) the size mesh used on the floor and lid of the containers (Nylex plastic mesh aperture size 3 mm, 6 mm and 12 mm).

A photograph of some experiments in progress is shown in Fig. 4.

## 2.2 Water calcium concentration:

Water for all experiments was provided from the W.A.I.T. Campus groundwater supply. Before use the water was thoroughly aerated. In cases where additional calcium was required, this was usually achieved by percolating the water before use through a plastic column (I.D. 55 mm x 1 m) which had been filled with commercially available shell grit; as this grit gradually dissolved it had to be periodically replaced. In one trial where higher calcium concentrations were required, this was achieved by adding a known concentration of $CaCl_2$ at a known rate to the water of the holding tank.

## 2.3 Container size:

To achieve a larger accommodation unit than the one described in 2.1 above, the end walls of two plastic boxes were removed and the boxes glued together to form a unit 260 mm long, compared to the standard 160 mm length. In all other respects the design of the longer containers was the same as those to which they were being compared.

## 2.4 Water temperature:

The airconditioning system of the experimental room combined with evaporative cooling due to aeration of the tanks kept water temperatures generally below 20°C. Aquarium heaters placed in each holding tank were adjusted until the holding tank water temperature was maintained at 21°C, or in one trial at 25°C.

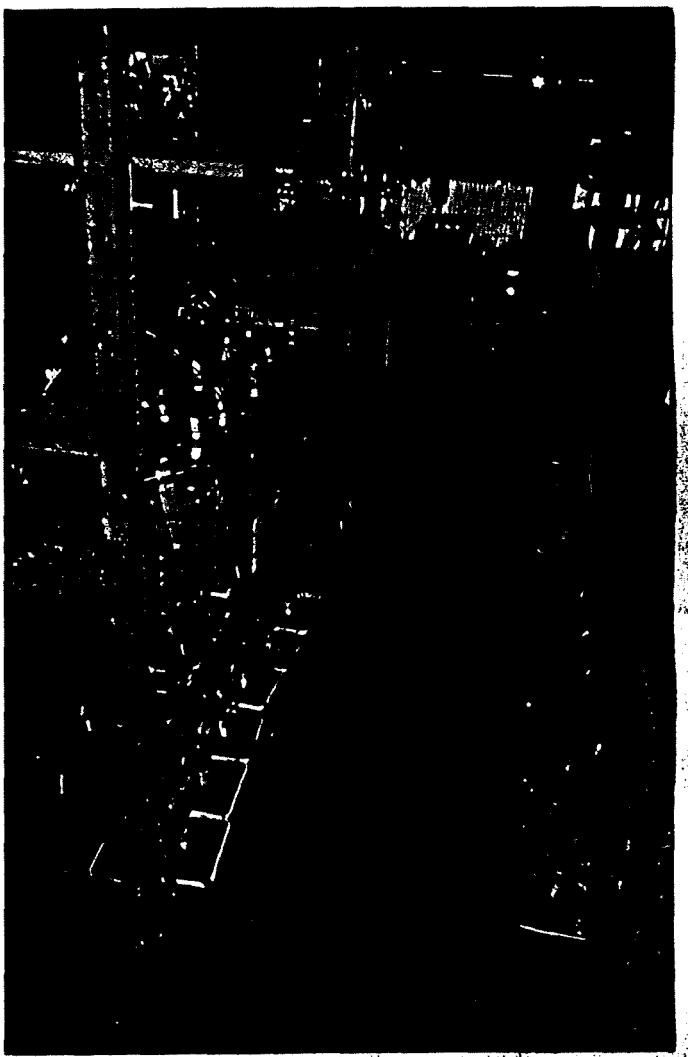


Figure 4: Photograph of laboratory showing a section of the experimental battery culture apparatus

## 2.5 Diet

Formulations of the two experimental rations are given in Appendix A. Food was usually administered in the pelletised form; in some trials coarsely broken pellets ("crumbles") were used. The appearance of these diets is shown in Fig. 5.

Control of ration size was effected in two ways:

a) where small quantities of food were required, pellets were manually cut to a length giving a known average weight (0.2 g), and the correct amount of food was dispensed by counting out the determined number of pellets;

b) for larger quantities, standard measuring spoons were calibrated to determine the average weight of pellets or crumbles held by a level spoonful. From this data the combination of spoons delivering the quantity of food closest to that required was determined.

Several feeding schedules were used. Schedules 1 and 2 involved daily inspection of the unit, and food administration only if food from previous feeding had disappeared. The feeding rates of Schedules 1 and 2 were approximately 10% and 5% (wet weight of food expressed as percentage of wet body weight) respectively. Later feeding schedules involved daily feeding, irrespective of the presence of unremoved food. Feeding rates for Schedules 3, 4, 5 and 6 were 8%, 4%, 2% and 1% respectively. With all feeding schedules, the actual ration to be given was determined by the wet weight of the animal at the start of each 50-day period.

The food conversion ratio for each animal was calculated by summing the total wet weight of food given and dividing this number by the total wet weight growth increment for the period under review.

## 2.6 Control of water flow rate:

Water from a constant-head reservoir was gravity fed through 13 mm piping past all accommodation units. Delivery of required amounts to

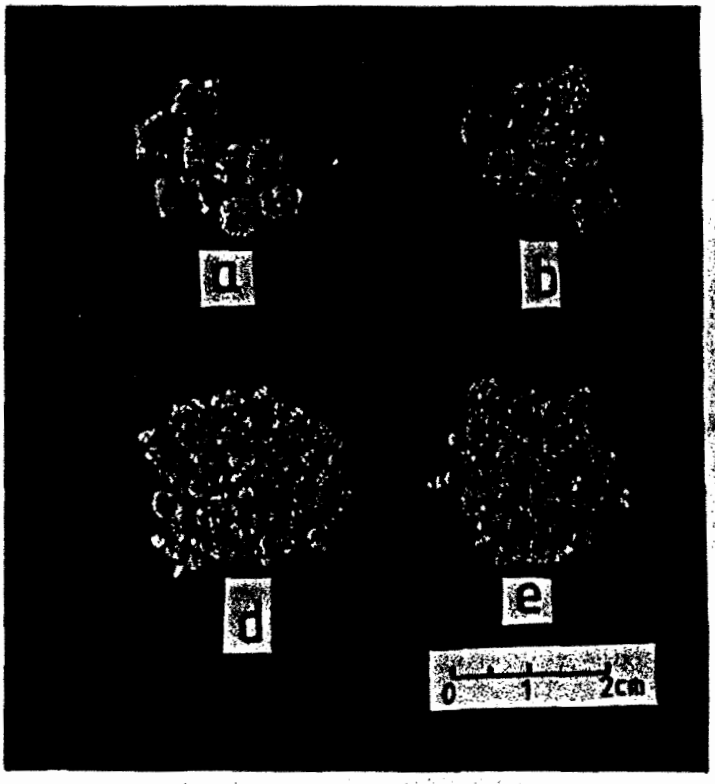



**Figure 5: Experimental diets used in growth trials**

(a) Diet 1 pellets
(b) Diet 2 pellets
(d) Diet 1 "crumbles"
(e) Diet 2 "crumbles"

each unit was effected through a combination of choice of bore and length of capillary delivery tubing, and use of taps appropriately placed.

## 2.7 Water quality assay:

Water was assayed at intervals for oxygen concentration (Winkler titration), pH, calcium and ammonium (all with ion selective electrodes).

## 2.8 Light intensity:

Light intensity at the water surface of several tanks was measured using a Quantum light meter.

## 2.9 Photoperiod control:

Experimental tanks were surrounded by a framework over which opaque black plastic was spread. Fluorescent lights within this light-proof structure were controlled by time switches to allow for correct day-length settings. Inspection of units was timed to occur during "day" periods.

## 2.10 Product appeal:

Comparisons of several attributes of cooked crayfish tail were made in controlled tests. In all cases the crayfish were immersed in boiling water and cooked for 3 minutes after the water had returned to the boil, then cooled immediately in running water. Following peeling and deveining, the flesh was placed in sealed containers and refrigerated overnight at 5°C. The flesh was removed from the refrigerator 2 hours before the tests were conducted. Small portions (approximately one third of the tail) were arranged on paper plates which had been divided into three sectors, each sector being coded with a Greek letter. Each person was given a plate with three pieces of crayfish on it, and asked to assess each piece on the following criteria by marking the appropriate position on a 50 point undifferentiated scale:

a) General appearance: very unpleasant - very pleasant
b) Flavour pleasantness: very unpleasant - very pleasant
c) Shell fish (crustacean) flavour strength: nil - very strong
d) Chemical flavours: nil - very strong
e) Unusual flavours: nil - very strong
f) Eating exture: very tough - very tender
g) Eating texture: very unpleasant - very pleasant
h) Overall rating: totally unacceptable - totally acceptable

Subjects were also asked to describe unusual flavours, and to make any other comments.

Four tasting experiments were conducted as follows:

| | EXPERIMENT (number of subjects) | | | |
|---|---|---|---|---|
| BATCHES | 1(21) | 2(12) | 3(21) | 4(21) |
| EM Diet 1, 650 days | X | | X | |
| EM Diet 2, 650 days | X | X | | |
| EM Diet 2, 400 days | | X | | |
| EM Diet 1, 400 days | | X | | |
| EM Diet 1, 350 days | | | | X |
| PM | X | | | X |
| EY Diet 1, 300 days | | | X | |
| PY | | | X | X |

Coding: P - Pond reared E - Experimental (reared in battery)
M - Marron Y - Yabbies

Table 1: Comparisons made in four taste-testing trials of pond-reared and battery-reared marron and yabbies. The three batches compared in each experiment are indicated by "X". The number of days refers to the period crayfish were maintained in the battery.

## 3.0 RESULTS AND DISCUSSION

### 3.1 Survival:

Survival of marron in the longest running experiment (650 days) was 88%. Survival of yabbies under the more favourable calcium treatment (see below) in the longest running experiment (450 days) was 100%. Similar survivorship occurred in shorter term experiments.

Some deaths were due to escape from the containers due to flaws in their fabrication. Most deaths, however, were coincident with, and most likely caused by, hypoxic conditions which in turn were associated with one or more of the following:

i) poor water circulation through the container due to clogging of the grit filter and/or mesh floor;
ii) poor water circulation due to ineffective air-lifts;
iii) build-up of uneaten food with a consequently high B.O.D. (Biological Oxygen Demand) leading to hypoxic conditions; and
iv) poor water quality due to failure of the water delivery system.

In most cases deaths were also associated with moulting; a separate investigation of marron metabolism (Kowarsky *et al.* 1986) provided evidence that these animals, like other crustaceans, have elevated metabolisms at the time of moulting.

### 3.2 Growth

#### 3.2.1 Effect of water calcium concentration

A strikingly significant effect of water calcium concentration on the growth of yabbies was demonstrated in two independent trials (Fig. 6).

Growth in the elevated calcium treatment of each trial was similar, despite the fact that the mean calcium concentration in the second trial was 32 ppm compared to 9 ppm in the first (control treatment calcium concentrations were 3-4 ppm). This suggests that a plateau may have been reached with respect to the effect of calcium concentration on yabbie growth, and further raising the calcium levels would not result in further increases in growth rate. Changes in pH occurred

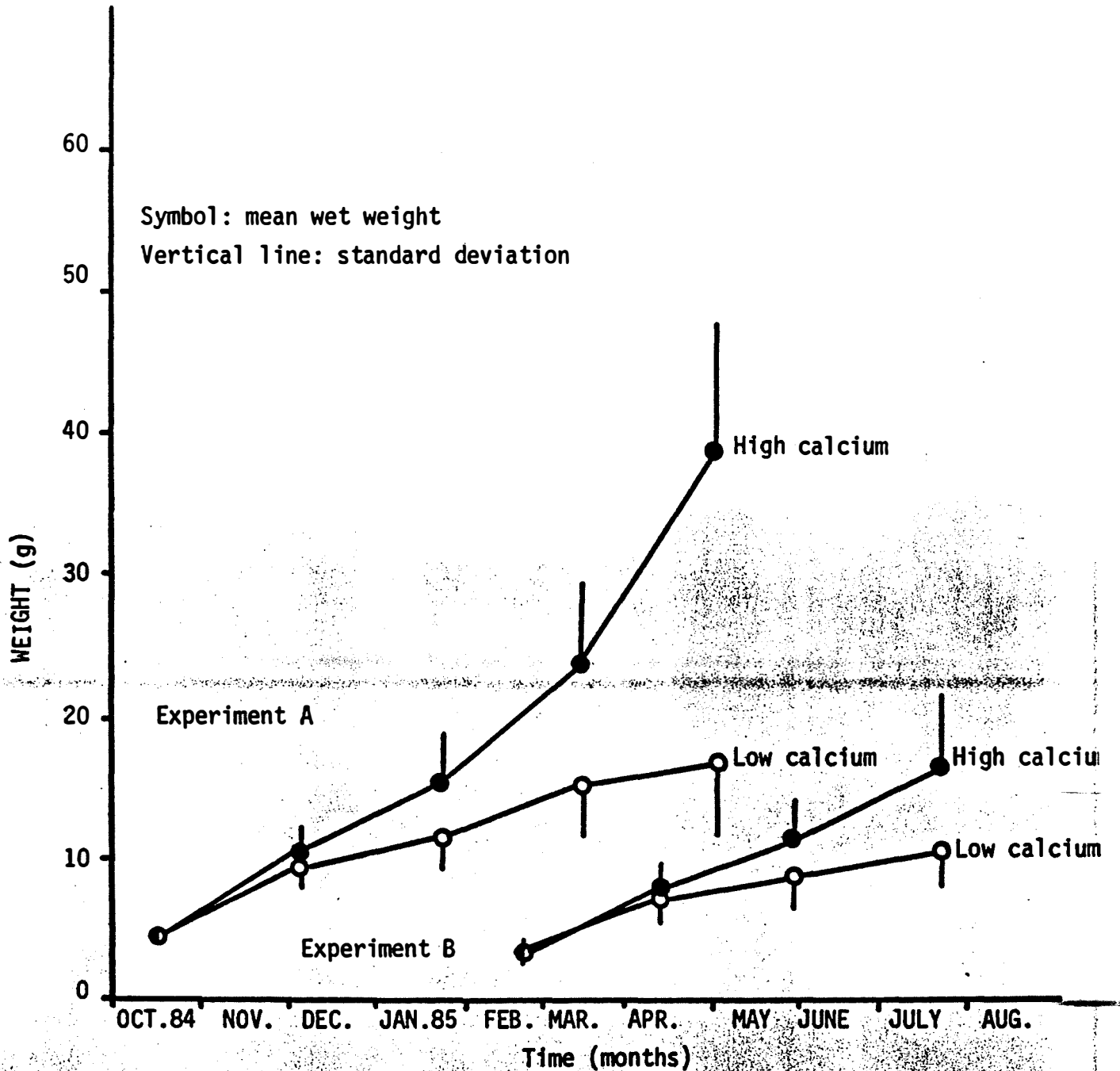



**Figure 6: The results of two experiments investigating the effect of elevated calcium levels on the growth of juvenile yabbies in individual culture.**

with changes in calcium concentration (7.6 compared to 7.2 in the first trial, 7.9 compared with 7.4 in the second). We did not attempt to more closely determine the precise agent leading to changes in growth.

In the case of marron, no such effect on growth was detected. Marron kept for 300 days in bore water (calcium level 4 ppm) and calcium enhanced water (calcium level 9 ppm) had very similar final mean weights (22.8 g (N=12) and 23.6 g (N=11) respectively). We note here that this investigation was conducted before either water flow rate or temperature (see later sections) had been optimised - it would be useful to again test affects of water calcium concentration on marron growth under more optimal levels of these other factors.

There is little information available in the literature regarding effects of calcium concentration on marron or yabbie growth. Morrissy (1974) reported that ecdysial frequency (and presumably growth rate) of marron was less at 75 ppm than at 20 ppm calcium. A study of marron production in several farm dams led to the conclusion that optimal calcium concentrations could be in the range 20-30 ppm (Morrissy 1970; Morrissy 1974); however in a subsequent study other factors were apparently more important in influencing the biomass of marron (Morrissy 1974).

All further yabbie growth trials reported here used calcium enhanced water (about 9 ppm), while all further marron growth trials used bore water (3-4 ppm calcium).

### 3.2.2 Effect of gender:

Fig. 7 shows the significant superiority of male yabbies over female yabbies with respect to growth.

A similar early and marked manifestation of differences between male and female marron did not occur. However, a difference did emerge when, at the end of the longest running growth trial (650 days), data from non-differing treatments were pooled and sorted with respect to gender (Table 2).

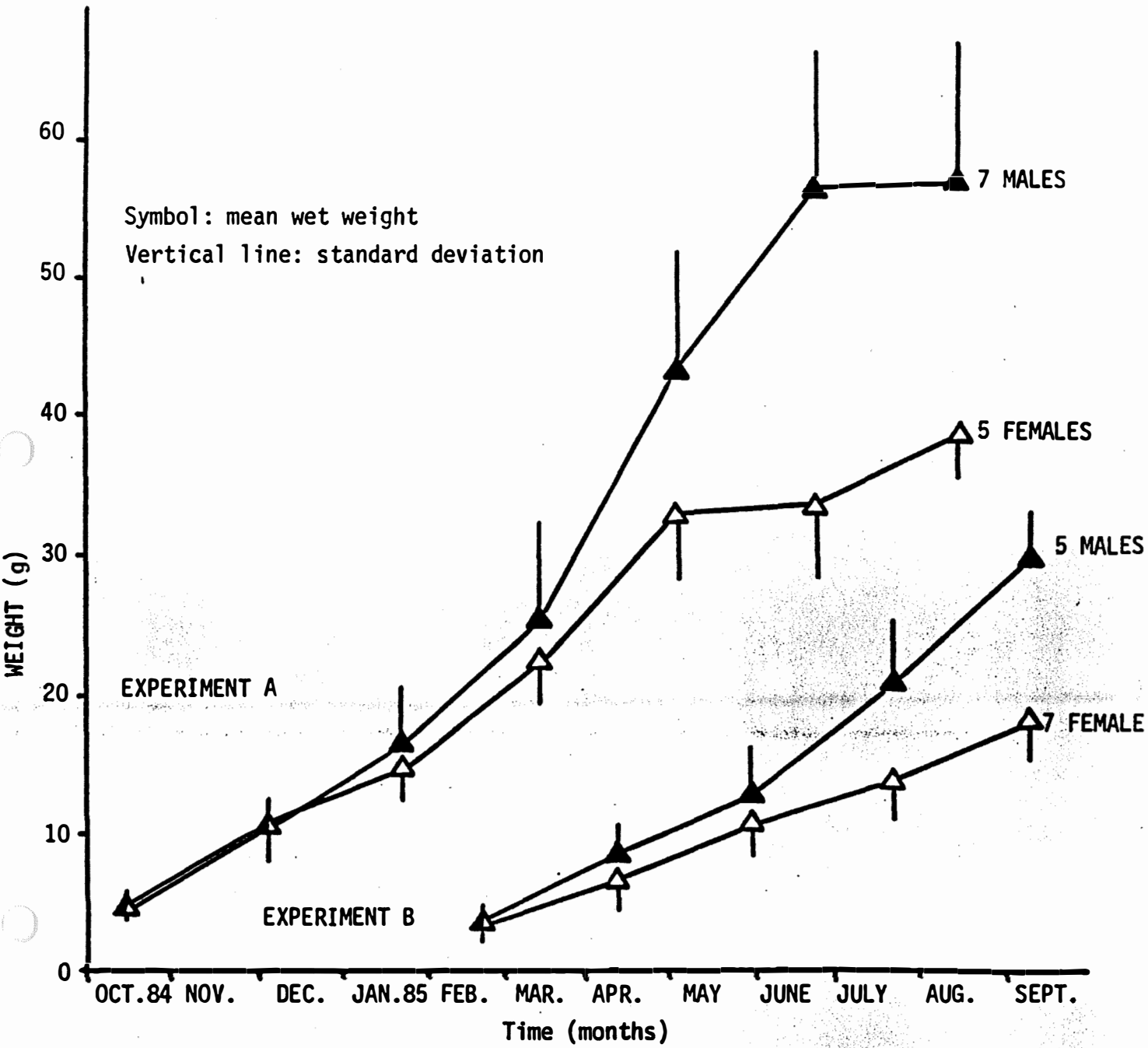



**Figure 7: Comparison of the growth of male and female juvenile yabbies kept in similar conditions in individual culture in two experiments.**

| MALES | FEMALES |
|---|---|
| 70.6 ± 22.2 (17) | 53.3 ± 21.4 (16) |

Table 2: Mean ± s.d. wet weights (g) of male and female juvenile marron after 650 days in individual battery culture. Number of individuals in each sample indicated in parenthesis.

There were two other comparatively long-term growth experiments with marron. The first of these was conducted over 400 days, but the small numbers in each group when divided by treatment and gender precluded reasonable comparison of male and female growth rates. The second growth trial was over 350 days, but the sexes of marron used in this trial were not determined. In shorter-term trials no male-female differences in growth were apparent.

Lake and Sokol (1986) cite references indicating that mature male yabbies grew faster than mature female yabbies, and also present new data supporting this observation. From our work it is clear that the superior growth rate of yabbie males was manifest from an early stage (around 10 g wet weight). We could not find any reference to male/female growth differences in marron.

In the light of the above findings it may be advantageous to use only male crayfish in growout schemes, extensive and semi-intensive as well as battery systems. But before this strategy is adopted for ponds and dams, production trials comparing performances of males and females kept seperately should be conducted. An additional advantage in stocking water bodies with only males may be the prevention of overbreeding, overstocking and runting which may otherwise occur. Against such possible advantages must be weighed the cost of (i)

discarding juvenile females (although some of these could be utilised as future broodstock) and (ii) labour in sorting the animals before use (low power microscopes are necessary for sexing small (1-2 g) animals.

In all subsequent growth trials involving yabbies, only males were used, and all subsequent yabbie data reported here is from males only. In the case of marron, however, mixed sex samples were used throughout the experimental period and are reported here. While it was not practical to separate and analyse male and female marron data separately (due to too small-sized sub-groups) we have examined the data and none of the significant findings following appear to be the result of bias because of differing sex-ratios of marron under differing treatments.

### 3.2.3 Effect of water turnover and ration size:

Growth data from juvenile marron subjected to two levels of water turnover and three levels of ration size for 200 days are shown in Fig. 8.

A significant effect of water turnover rate was found by the first 50 days of the trial; however there was no detected effect of ration size on marron growth even after 200 days.

Juvenile yabbies were also subjected to two levels of water turnover treatment, this time in conjunction with testing of Diets 1 and 2. In this 150-day trial there was no effect of diet, but like the marron experiment above, there was a marked significant effect of water turnover rate on yabbie growth (Fig. 9).

We are unable to offer an explanation of why both marron and yabbies showed such superior growth under the slower water turnover treatment. Examination of the water quality parameters measured revealed no marked or consistent difference between the two flow treatments. We note that superior growth of lobsters under static and near static conditions has been reported (Wadley et al. 1982).

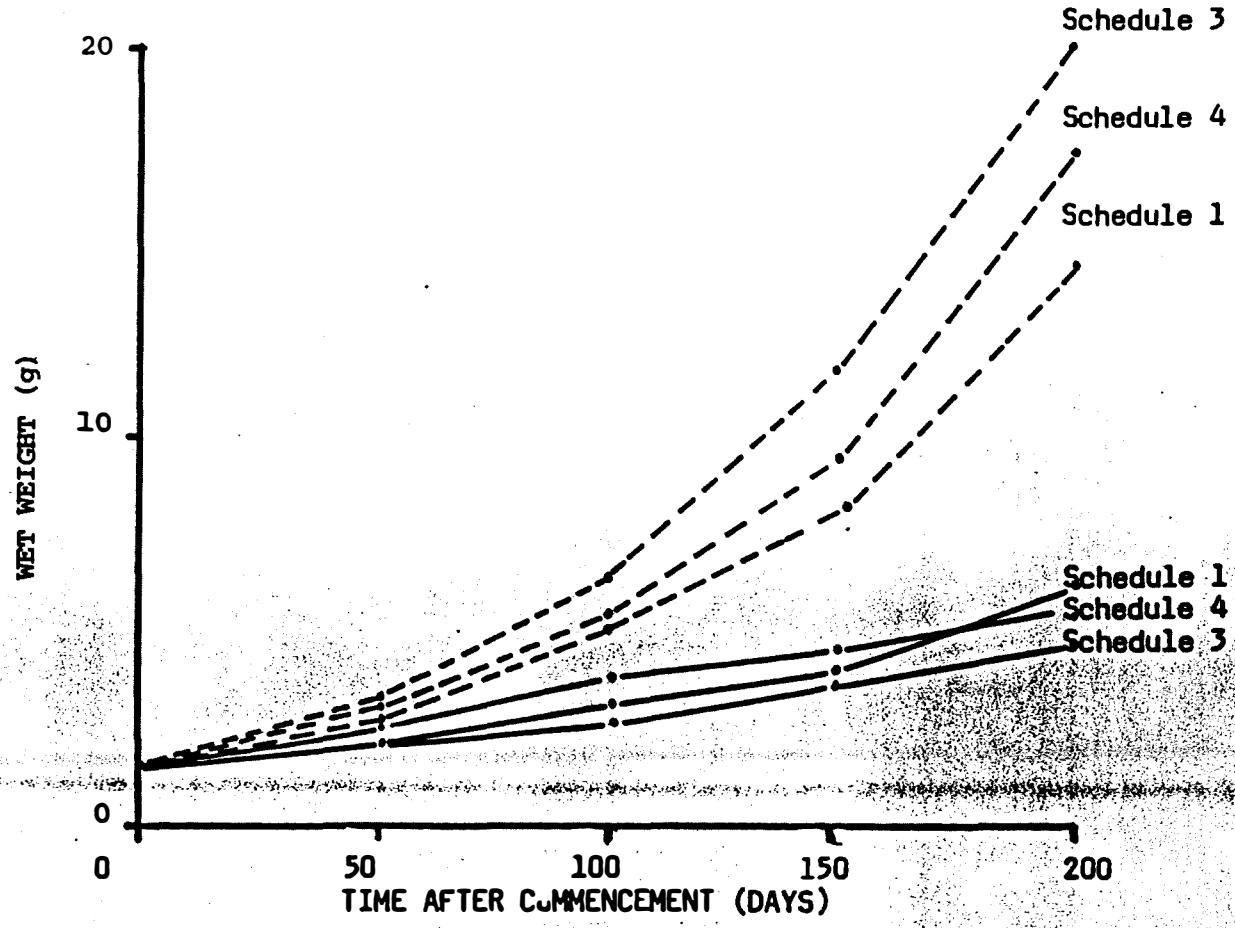



Figure 8: Growth trial with juvenile marron in individual culture with three feeding schedules and fast (continuous line) and slow (broken line) water flow treatments. Mean wet weight of sample in each treatment indicated.

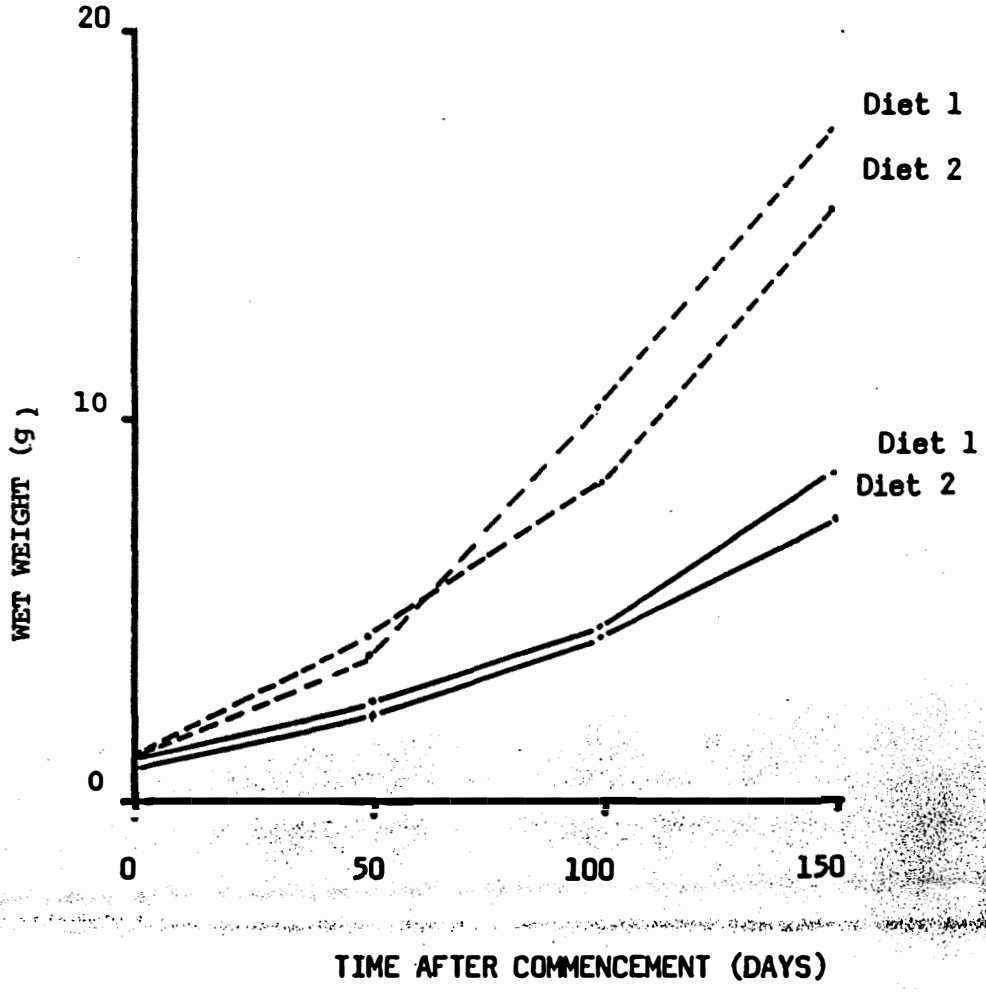



Figure 9: Growth trial with juvenile male yabbies in individual culture with two diet treatments and fast (continuous line) and slow (broken line) water flow treatments. Mean wet weight of sample in each treatment indicated.

In all subsequent marron growth trials, the slower water turnover treatment was used. As the yabbie finding was only obtained near the end of the research period, other yabbie data reported here was obtained under the higher flow treatment.

### 3.2.4 Effect of diet and temperature:

With respect to yabbies, we reiterate the finding of no significant difference in growth of juveniles fed Diet 1 and those fed Diet 2 in a 150-day trial mentioned in the previous section. All yabbie growth trials were conducted at a nominal temperature of 21°C; in the light of a report of optimal growth of yabbies at about 28°C (Milla 1984), and the temperature effect on growth found for marron (see below), it is likely that better growth rates could have been achieved had we used higher temperature conditions for yabbies.

Two experiments investigating the effect of diet on marron were conducted. The first, at a nominal temperature of 21°C, was run over a period of 200 days using marron of mean weight 20 g from a previous trial (Table 3).

| | | DAY OF EXPERIMENT | |
|---|---|---|---|
| | | 50 | 200 |
| DIET 1 | Weight (g) | 23.9 ± 3.7 | 60.5 ± 6.8 |
| (N=4) | % weight increment | 17.5 ± 15.4 | 197.0 ± 13.4 |
| DIET 2 | Weight (g) | 28.2 ± 2.5 | 65.4 ± 7.6 |
| (N=5) | % weight increment | 41.7 ± 3.9 | 228.6 ± 22.7 |

Table 3: Mean ± s.d. values for weight and percentage weight increment for marron kept under two diet treatments for 200 days. Appendix A contains the formulations for the experimental diets.

By day 50 of this experiment, animals fed Diet 2 were significantly larger than those given Diet 1. Although significant differences in mean weight disappeared subsequently, when growth was expressed in terms of the total weight increment as a percentage of initial weight the significant difference persisted up to the end of the trial.

The second experiment investigated effects of two levels of temperature (21°C and 25°C) as well as the two experimental diets on juvenile marron growth (initial wet weight 1.5 g). Mean weights of marron at the end of the 100 day trial are shown in Table 4.

| | NOMINAL TEMPERATURE | |
|---|---|---|
| | 21°C | 25°C |
| DIET 1 | 4.1 ± 0.9 (5) | 6.1 ± 1.6 (6) |
| DIET 2 | 5.1 ± 0.6 (6) | 5.8 ± 0.9 (6) |

Table 4: Mean ± s.d. wet weight of groups of juvenile marron kept under two temperature and two diet treatments for 100 days. Number of survivors of initial 6 in each treatment is indicated in parenthesis.

A two-way analysis of variance on the above data revealed a significant effect of temperatures only, with no significant interaction between the two variables. When the data for 21°C was analysed separately, a significant difference between the two diet treatments was found.

The results of these two experiments indicate that superior growth of marron occurred with Diet 2 at 21°C, but that no difference between the diets was manifest at the higher temperature treatment, where growth rates superior to those found at the lower temperature (irrespective of diet) were achieved.

The literature reveals little in the way of rigorous tests of effects of temperature on marron growth; one summary of seasonal growth in relation to temperature in farm dams (Fig. 2 of Morrissy 1976) appears to indicate that best growth occurred in the range 19°-21°C, with considerably inferior growth occurring when the temperature was in the 22°-24°C range.

It would be worthwhile to conduct a longer-term study of marron growth at 25°C; we would anticipate that an improvement to the overall growth rate (see 3.2.7 below) would occur. Because the incipient lethal temperature for marron was found to be around 31°C (Morrissy 1976), it is unlikely that much better growth could be achieved by maintaining marron at temperatures greater than 25°C.

### 3.2.5 Effect of container size

Controlled experiments with marron (mean initial weight 39 g, duration of trial 250 days) and yabbies (mean initial weight 47 g, duration of trial 150 days) comparing growth in standard containers (160 mm long) and enlarged containers (260 mm long) did not reveal any growth differences. We note the report that lobster growth was affected from very small size by the dimensions of the container (Schleser 1974; Goyert and Avault 1978) and we point out here that we have not conducted trials using small (1-2 g) crayfish. We also note the report that total floor space rather than floor shape influenced lobster growth (Schleser 1974). Our own subjective impression of marron and yabbie behaviour when confined in our containers was that optimal space usage would be achieved by using rectangular rather than square containers. Large animals aligned themselves along the longer axis of the container and did not appear to be constrained by the narrower width dimension.

The largest marron grown in our standard containers weighed 134 g; this represented the upper extreme of considerable variation in size. To achieve a mean weight of 120 g (present minimum legal size) marron substantially heavier than 120 g would have to be produced. It is possible that such sizes may be subject to growth inhibition due to container dimensions. To minimise such effects, two strategies could be adopted:

a) use selective culling of animals as market size was reached, rather than waiting for the batch average to reach this size. The additional labour coats could be offset by avoiding possible growth inhibition, freeing space in the system and minimising residence time in the system;

b) continue research aimed at minimising variation between individuals.

### 3.2.6 Effect of photoperiod:

A summary of data from the 100-day trial investigating photoperiod is given in Table 5 below.

| | PHOTOPERIOD | |
|---|---|---|
| | 16 hours light/ 8 hours dark | 8 hours light/ 16 hours dark |
| Initial weight (g) | 1.5 ± 0.2 | 1.4 ± 0.2 |
| Final weight (g) | 5.7 ± 0.8 | 5.3 ± 1.0 |
| Percentage weight increment | 276 ± 41 | 267 ± 52 |

Table 5: Mean ± s.d. values for two groups of 9 juvenile marron kept in individual culture for 100 days under two photoperiods.

There was no significant difference between the growth performance of the two groups of marron. We note that an effect of photoperiod has been found on the moult cycle duration of the spiny lobster Panulirus argus (Quackenbush and Herrnkind 1983), with short days shortening the overall moult cycle. We note also that larval lobsters Homarus americanus were found to survive better and develop faster under very short days (Aiken et al. 1982).

While in the wild marron are generally cryptic during the day, and active foragers at night, we have observed that in the laboratory these animals, and yabbies, are active at all times of the day and apparently irrespective of the intensity of lighting. In the individual containers, sections of plastic pipe were provided as shelter for young crayfish. These were utilised by small animals, but by the time crayfish were between 10-20 g weight, the shelters did not appear to be used frequently, and they were usually removed.

### 3.2.7 Overall growth rates:

Best growth rates achieved by marron and yabbies in this study are compared with that found for the lobster Homarus elsewhere (Fig. 10).

Although marron growth performance improved through the course of this research, the best growth curve achieved fell well short of the maximum growth rate reported for this species (Morrissy 1984(b) based on Morrissy 1974). We are aware of claims of very high growth rates of marron kept in pond culture in Queensland. While we do not believe that we have reached the full potential of marron growth in our trials, we have some doubts about the validity of the interpretation of field data for the W.A. pond trials, and we have not yet seen any raw data from which the Queensland claims have been inferred. However, there is general consensus that at realistic stocking densities achievement of the reported maximum growth rate of marron in Western Australian conditions is impossible with present technology (Bennison 1984; Morrissy 1984(a)); even claims from commercial interests (see Fig. 11 below) fall short of achieving commercial size (120 g at present) within one year.

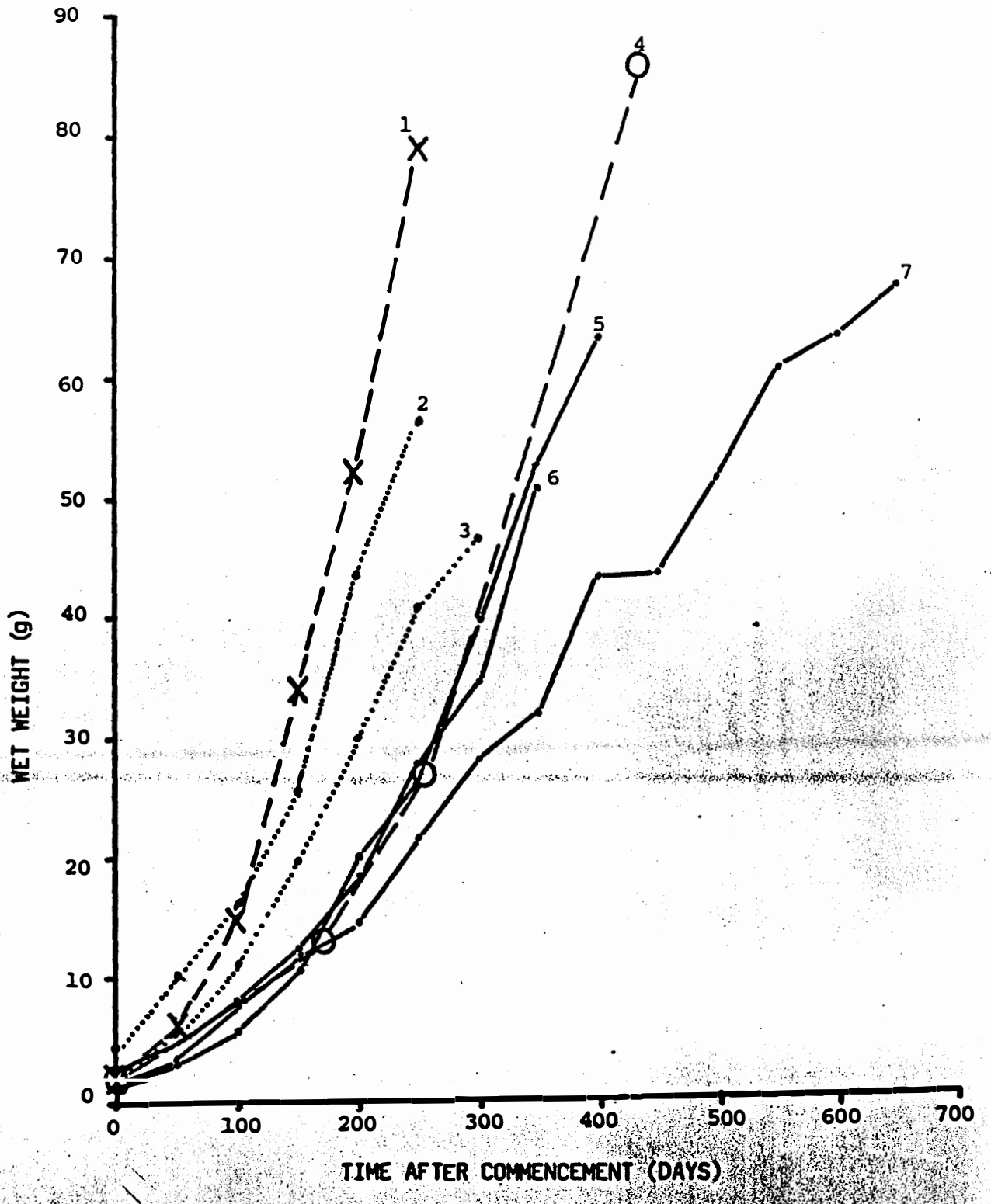



**Figure 10: Comparison of best growth rates achieved in this study with those reported for marron and Homarus elsewhere.**

1 - maximum growth rate for marron from Morrissy (1984(b))
2 - male yabbies, this study, trial commenced 31/8/84
3 - male yabbies, this study, trial commenced 29/7/85
4 - Homarus gammarus in battery culture, from Beard et al. 1985
5 - mixed sex marron, this study, trial commenced 24/4/85
6 - mixed sex marron, this study, trial commenced 25/6/85
7 - male marron, this study, trial commenced 31/8/84

Marron on the plate faster

Figure 11: Article appearing in The West Australian Thursday February 27 1986.

We would expect that with longer term experiments at 25°C, and with the use of male marron only, further improvement of the growth curve for this species in battery culture would occur. On the basis of growth thus far achieved, the time to reach mean size of 120 g could be extrapolated to about 2 years, providing that the "plateau" in the growth curve of yabbies did not occur with marron.

Growth of yabbies in the battery was of the same order as those kept in ponds by Mills (1984). As with the marron, we would expect that more optimal conditions (slower flow rate, probably higher temperature) would result in more rapid growth of yabbies in the battery situation.

Cause for some concern is the flattening of the growth curve found for male yabbies, and for females of both species. Field studies of yabbies do not support the idea that they had reached maximum size (see studies by, and cited by, Lake and Sokol 1986). In the case of marron there is certainly evidence of these animals far exceeding the weights achieved here. During preparation of marron for product appeal trials, we noticed that some females had large eggs present in their bodies. It is possible that the slowing of growth remarked upon here was related to the early development of gonads. If this were the case, avoidance of external conditions likely to trigger gonadal development would be advantageous to the crayfish culturist.

Little is known about the factors influencing the maturation of the gonads of marron. Trials varying both temperature and photoperiod simultaneously were reported to induce earlier than usual spawning (Morriasy 1983), but the design of these trials makes it difficult to gain clear insight into the causes of the earlier events. In the American lobster, Aiken and Waddy (1985) in controlled experiments were unable to demonstrate any effect of photoperiod on spawning.

## 3.3 Food conversion:

The food conversion ratios for a group of five marron kept under favourable conditions for 400 days were calculated (Table 6).

| PERIOD OF EXPERIMENT | | |
|---|---|---|
| DAY 1 - DAY 200 | DAY 201 - DAY 400 | DAY 1 - DAY 400 |
| 3.6 ± 1.4 | 2.8 ± 0.1 | 3.0 ± 0.4 |

Table 6: Mean ± s.d. food conversion ratios for five juvenile marron kept under favourable treatments in battery culture for 400 days. Mean initial wet weight = 1.3 g, mean final wet weight = 65.4 g.

We point out that the measurement of food conversion ratio in this instance is made on the amount of food given to the individual, rather than the amount of food ingested by each animal which is much more difficult to quantify. Thus an apparent increase in efficiency in the second half of the experiment may have been due, at least in part, to our becoming more efficient in the distribution of food rather than the larger animals becoming metabolically more efficient.

Using information from determinations of moisture content of both marron and the food pellets, we calculate that a value of 3.0 (wet weight basis) would be approximately equivalent to a food conversion ratio of 13.5 (dry weight basis, assuming that food was 10% moisture, marron were 80% moisture content), or 2.7 (dry weight food - wet weight animal).

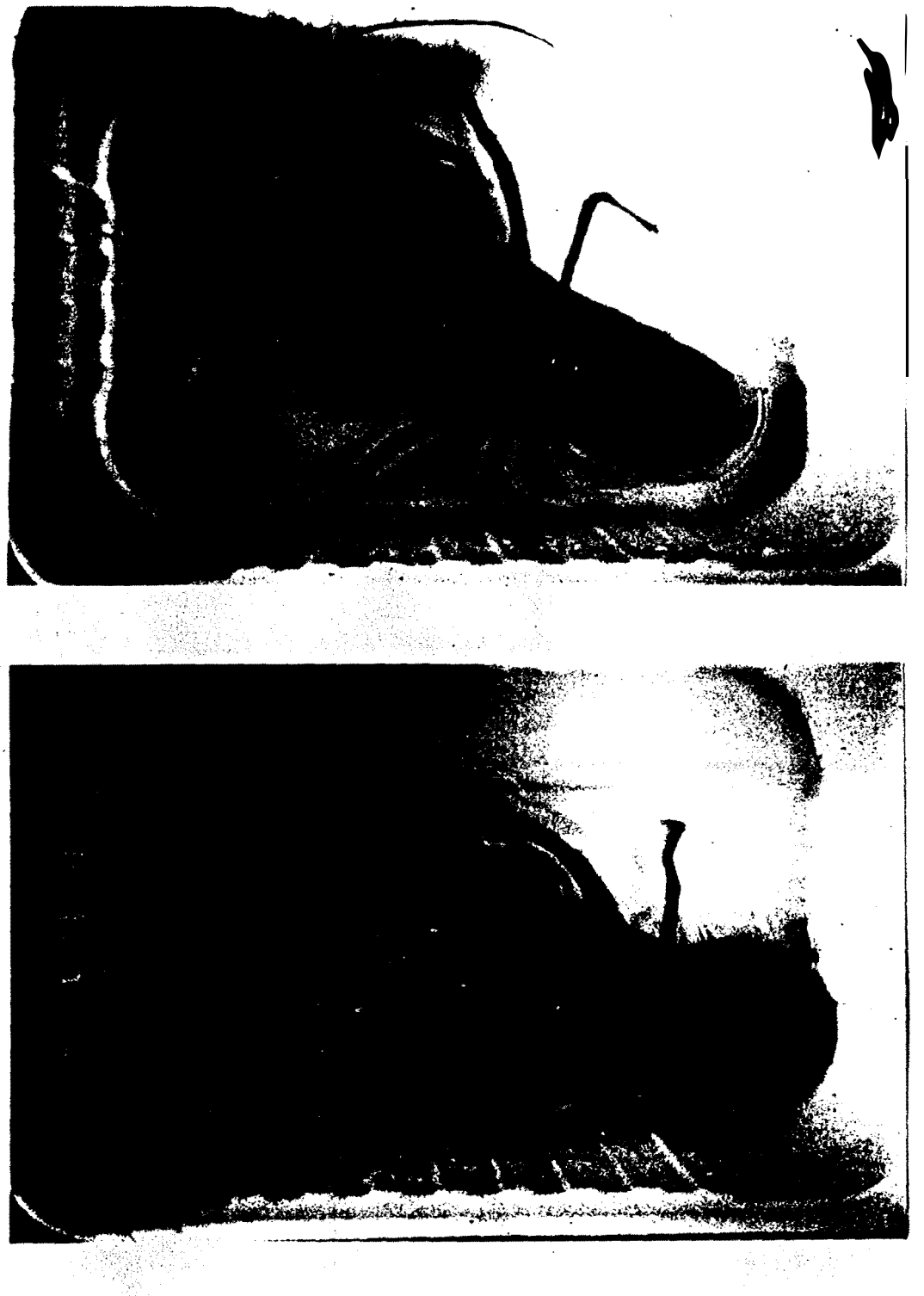
Because yabbie growth virtually ceased after 250 days, calculation of food conversion ratios for this species was restricted to this period. A group of 7 male yabbies had a mean food conversion ratio of 4.7 (s.d. = 0.7) (wet weight basis).

Values of the same order have been found in other species of cultured crustaceans (e.g. Beard et al. 1985). Knowledge of the food conversion ratio enables us to determine the cost of food needed for the production of a given sized animal. For example, assuming that the food conversion ratio to produce a 120 g marron is 3.5, 3.5 x 120 = 0.42 kg of food would be required to produce this marron. Given a food cost of approximately $650/tonne, this quantity would cost 27 cents. At present market value of 120 g marron of around $30/kg, each marron would return $3.60 - it is unlikely, therefore, that the cost of such food would be a major obstacle to the commercial viability of marron production.

## 3.4 Product appeal:

One-way analyses of variance performed on scores for each of the eight criteria for each of the four experiments revealed only one significant difference - for the criterion of "General Appearance" in Experiment 1. A Scheffe test showed that the difference found was between the flesh of pond grown marron and experimental marron fed Diet 1 - in that experiment there was no difference between the pond marron and experimental marron fed Diet 2. Note that in Experiment 4, another comparison between pond marron and experimental marron fed Diet 1 did not reveal any difference.

On the basis of the above trials it would be reasonable to conclude that there was very little difference between any of the products tested i.e. pond marron, pond yabbies, experimental marron and experimental yabbies were products of similar appeal. This does not mean, however, that these products had similar appearances, either live or cooked. Live pond marron were very dark, almost black shelled, while live pond yabbies were a somewhat lighter brown colour. In the battery system, crayfish of both species had markedly lighter exoskeletons (Fig. 12). In experimental marron the shell had a strongly blue-purple hue, while in the case of experimental yabbies the shell was more clearly blue. These obvious differences in appearance of live animals were reflected in the appearance of the unshelled cooked animals (Fig. 13) and the shelled tails (Fig. 14).



(a)

(b)

Figure 12: Comparison of the appearance of live marron (a) and yabbie (b) after rearing in battery culture. Each animal weighed approximately 70g and was fed Diet 1.

Figure 13: Appearance of cooked but unshelled freshwater crayfish: left to right - battery yabbie, pond marron, aquarium yabbie, battery marron.

Figure 14: Appearance of cooked and shelled tail meat of freshwater crayfish;
left to right - battery yabbie, pond marron, aquarium yabbie, battery marron.

There is no doubt that the pond marron and yabbies, when cooked, more closely resembled the cooked appearance of other edible crustaceans than the battery-reared crayfish. If the difference in appearance of battery-reared crayfish influences the market acceptance of these products, it will be important to direct research into restoring a more natural look to the battery-reared animal. While there has been a report of diet influencing shell appearance (Morrissy 1984(b)), controlled investigations of factors affecting the degree and hue of pigmentation in the exoskeleton of marron and yabbies remain to be done.

## 4.0 REVIEW OF PROJECT

Apart from the specific findings already detailed, this research project has demonstrated two important points relevant to the battery culture of marron and yabbies. Firstly, it has shown that it is clearly feasible to maintain these animals for extended periods in confined conditions with acceptable mortality. Secondly, it has shown that the growth of these crustaceans is extremely sensitive to the prevailing environmental conditions, and that to optimise growth it is necessary to carefully control these conditions.

While from the practical viewpoint the results to date are encouraging, we stress that the research is by no means complete, and results presented here should not be used as a model for commercial production. As already noted at particular points during the presentation of results, further research needs to be undertaken to investigate and optimise levels of several environmental factors. As the effects of a particular factor become clearer, it will often be necessary to re-investigate effects of other factors to determine the extent, if any, of interaction occurring.

But no matter for how long laboratory studies in this field are carried out, such work will never confront and solve the practical problems associated with a necessarily much larger commercial operation. These problems, largely engineering in nature, include provision of services to each animal (water, food, oxygen, waste

removal) and the maintenance of environmental conditions between defined limits, for a large scale project. Given successful automation of most aspects of the daily care of battery crayfish, by far the most significant running cost will be that associated with energy use to maintain the required environmental conditions, in particular, temperature. Indeed, the manner in which these problems of scale-up are solved will probably determine the financial viability of a would-be commercial battery operation.

It is therefore highly desirable at this stage to move battery research from the laboratory level to the level of a pilot plant so that the opportunity to resolve problems of scale-up can be taken.

## 5.0 SUMMARY

a) Juvenile marron and yabbies were maintained in an experimental battery culture system for extended periods (over 12 months) with high survivorship.

b) Water calcium concentration was an important influence on yabbie growth, but no such effect was detected for marron.

c) In both marron and yabbies, males showed a superior growth rate to females.

d) In both marron and yabbies, superior growth occurred under slower water turnover conditions.

e) With marron, superior growth was found with Diet 2 than with Diet 1 at 21°C C; there was no difference at 25°C. No difference in growth due to diet was found in yabbies.

f) Growth of marron fed approximately 4% wet body weight daily did not differ from others fed twice that amount.

g) Growth of marron at 25°C was superior to those kept at 21°C.

h) No effects of container size on the growth of marron or yabbies was detected.

i) No effect of photoperiod on marron growth was detected.

j) Extrapolation from best growth rates achieved for marron suggested that present minimum legal size (120 g) could be reached in about 2 years. Yabbie growth virtually ceased at 50-60 g after 250 days.

k) Marron food conversion ratios were approximately 3:1 (wet weight basis); for yabbies the figure was 4.7:1.

l) Comparison of the appeal of the cooked flesh of pond and battery marron and yabbies in four experiments using eight criteria for judgement showed only one significant difference present. This was using the criterion of "General Appearance"; the score for pond marron was significantly greater than for a group of battery marron. There were clear differences in the appearance of the live, cooked and shelled flesh of pond marron and yabbies versus battery crayfish.

m) We recommend that further research be conducted, both following specific points from the present work, and also investigating the practicality of scaling up from the laboratory investigation to a pilot production plant.

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## APPENDIX A: Formulation of diets used in growth trials

DIET 1 (made up, and calculated nutrient analysis, courtesy of Wesfeeds Ltd, Sevenoaks St., Bentley, W.A.)

| Raw material | Percentage by weight (on "as is" basis) |
|---|---|
| Wheat | 11 |
| Fish meal | 10 |
| Soyabean meal | 25 |
| Soya full fat | 50 |
| Mono/di calcium phosphate mix | 4 |

Calculated nutrient analysis

| Nutrient | Percentage of dry weight |
|---|---|
| Crude protein | 39.05 |
| Fat | 10.33 |
| Fibre | 3.82 |
| Calcium | 1.22 |
| Total phosphorous | 1.52 |

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DIET 2 (made up, and nutrient analysis, courtesy of Professor Louis D'Abramo, Department of Wildlife and Fisheries, Mississippi State University)

| Raw material | Percentage of dry weight |
|---|---|
| Sybean meal | 25 |
| Fish meal | 12 |
| Rice bran | 15 |
| Shrimp meal | 25 |
| Nutribinder | 15 |
| Corn distillers dried grains with solubles | 4.3 |
| Tuna oil | 3.0 |
| Phytosterol premix[a] | 0.5 |
| Vitamin premix[b] | 0.2 |

[a]Phytosterol: B-sitosterol, 63.2%; campesterol, 32.2%; stigmasterol, 4.6%.

[b]Vitamin premix: Thiamin, 1.01%; riboflavin, 1.32%; pyridoxine, 0.9%; nicotinic acid, 8.82%; folic acid, 0.22%; vitamin B12, 0.001%; pantothenic acid, 3.53%; menadione, 0.2%; ascorbic acid, 33.07%; vitamin A, 4,409,200 (IU)/kg; vitamin D3, 2,204,600(IU)/kg; vitamin E, 66,138 (IU)/kg; athoxyquin, 0.66%.

Proximate nutrient analysis

| Nutrient | Percentage of wet weight |
|---|---|
| Moisture | 13.9 |
| Ash | 10.6 |
| Crude protein | 32.3 |
| Fat (acid hydrolysis) | 8.4 |
| Crude fibre | 4.6 |
| Nitrogen-free extract | 30.2 |

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