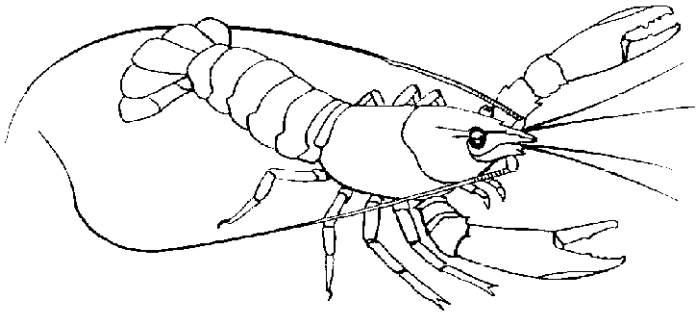
ProductionTechnology for Redclaw Crayfish (Cherax quadricarinatus)



FINAL REPORT

Project 92/119
Fisheries Research and Development Corporation

July, 1996

C.M. Jones and I.M. Ruscoe

DPI
QUEENSLAND
DEPARTMENT OF
PRIMARY INDUSTRIES

FISHERIES
RESEARCH &
DEVELOPMENT
CORPORATION

Freshwater Fisheries & Aquaculture Centre
Walkamin, Australia

C.M. Jones and I. Ruscoe

July 1996

FINAL REPORT

PRODUCTION TECHNOLOGY FOR REDCLAW CRAYFISH (*CHERAX QUADRICARNATUS*)

Fisheries Research and Development Corporation, Project 92/119

**Freshwater Fisheries and Aquaculture Centre,
Department of Primary Industries
Walkamin Q 4872, Australia**

TABLE OF CONTENTS

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

TABLE OF FIGURES

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

TABLE OF TABLES

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

EXECUTIVE SUMMARY

This research and development project aimed to define specific guidelines for the aquaculture production of redclaw crayfish, *Cherax quadricarinatus*. This aim was achieved, and a comprehensive list of such guidelines is now documented.

Redclaw crayfish aquaculture was a small industry when this project was initiated, generating less than 40 tonnes of product per year. Production technology was undefined and extremely variable across the industry. Now, in 1996, production has risen to around 100 tonnes and a more consistent and appropriate approach is applied to production. This is due to a large extent to the technologies developed by this project, the full benefits of which are still flowing to industry.

Armed with a 'best practice' approach, the redclaw aquaculture industry is poised for significant expansion, which will enable it to more fully exploit the excellent export opportunities which have been clearly identified for the product.

Information generated both directly and indirectly from the conduct of this project includes:

- optimal farm design characteristics have been defined
- economies of scale have been investigated and a size of 3 to 4 hectares of growout production area identified as minimum for commercial viability
- optimal pond specifications are 1,000 square metres (50m x 20m), 1.2 to 2 metres depth, V-shape batters
- artificial shelters have been identified as essential, they should be abundant, at least one shelter per $4m^2$, synthetic mesh bundles are optimal
- aeration is essential, airlift pump system is suitable and most cost-effective, minimum specification for $1,000m^2$ pond is 6 x 90mm diameter airlifts, an air supply of around 80 l/min per airlift, a pressure of 0.4 kPa, and an air injection level of no less than 80cm; continuous operation is optimal
- a managed juvenile production program or nursery phase separate to growout is essential, involving selected broodstock stocked at a rate of 100 to 200 females per pond, with a male/female ratio of no more than 1 to 4; a culture period of 3 to 4 months is necessary to achieve a mean size of juveniles of 5 to 15g
- two critical factors in juvenile production are shelter and food; shelter is provided in the form of synthetic mesh bundles, a managed bloom of zooplankton provides

- the best food, careful water quality management, involving regular applications of soluble fertilisers is required

- growout must involve active stock management, including stocking with known numbers of advanced juveniles of at least 5g mean weight, maximum size range at stocking should be 10g, stocking density of between 5 and 15 per m^2 is optimal

- careful handling of stock is critical, maximum growout period should be 6 months to minimise the possibility of un-managed reproduction, at harvest stock must be graded and re-distributed as breeding stock, market grades, further growout or cull and discard.

- An acceptable diet formulation for redclaw has been defined, several commercial diets are now available which represent the optimal specification as currently defined, approximately 20% protein, grain-based

- optimal feeding practices have been defined, including broadcasting of feed over the entire pond, frequency of 3 to 5 times per week is adequate, preferably at dusk, use of a feeding schedule is critical

- pond environment must be actively managed, weekly monitoring of pH, dissolved oxygen and secchi, monthly monitoring of hardness, alkalinity and ammonia, all measurements made at the water / soil interface on the bottom

- benthos must be well managed, involving liming, applications of nitrate and aeration, pH should be kept above 7.0 through regular applications of lime, nitrogenous fertilisers such as urea and ammonium phosphates (eg DAP) should be avoided in preference to nitrate fertilisers, plankton abundance must be maintained, particularly for juvenile production

- drying of ponds between crops is essential to sterilise and re-vitalise the bottom, 1 to 2 weeks until cracks appear

- protection against birds, rats, and eels, and any other potential predator must be provided, complete enclosure netting and fencing is essential, economic analysis indicated that the cost of netting (including materials and installation) is equivalent to 15% of one crop

- harvesting with flow trap is most efficient, should involve 95% drainage of the pond over 24 hours from dawn to dawn, set up centrally in the pond, both the flow trap and the last remaining water must be well aerated, stock should be quickly removed and transported to clean water in tank system, care must be taken to minimise crushing, maximum of 15kg of stock per transport container

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

- breeding stock must be carefully selected, significant improvements can be achieved through good broodstock selection, biggest weight for age and healthiest crayfish from each harvest should be used for breeding

- small crayfish which are known to be slow growing should be culled and discarded

- recognised river stocks of redclaw are genetically and morphologically very similar, however, production characteristics vary significantly, Flinders and Gilbert River strains display several economically advantageous characteristics

- polyculture of redclaw and silver perch is feasible, economic return is potentially greater than monoculture of either species, silver perch less than 200g have minimal impact on recruitment of juvenile crayfish

ACKNOWLEDGEMENTS

We wish to acknowledge the assistance of the many people who assisted in the conduct and successful completion of this project.

All the staff, technical and administrative, of the Freshwater Fisheries and Aquaculture Centre, Walkamin assisted in various ways. In particular, we acknowledge the committment of Jo Grady, Dave Bull, Ian Wallace and Greg Jennings for assistance with establishment and maintenance of the pond and laboratory trials. Millin Curtis provided invaluable help with extension of information to industry. Garry Morrison and Tracy Fitzgerald of Athmaize Pty Ltd provided assistance with the development of redclaw diets. We are grateful to Chris Barlow, Dr Kevin Williams, and Dr. Ray McClain for discussions concerning the results and critical comment on the conclusions drawn from this research. We thank Joanne White for statistical advice and analyses, and Anthony Roelofs for conducting histological work.

Special acknowledgement and appreciation is extended to the redclaw aquaculture industry and its many participants who have provided strong support and enthusiasm for our endeavours. We trust that their support will be repaid by increased production and profitability.

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

1. Introduction

Redclaw (*Cherax quadricarinatus*) is an endemic, tropical freshwater crayfish, which first gained prominence as a substitute for West Australian marron which had been trialled unsuccessfully as an aquaculture species in south-east Queensland. Commercial cultivation of redclaw first began in the mid 1980's (Hutchings, 1987, Jones, 1988), and although limited production was achieved at that time, it was clear that the species displayed many advantageous aquaculture attributes.

In 1988, the Department of Primary Industries Queensland received Commonwealth Reserve Bank funding to conduct a two year assessment study of redclaw. This work, completed in 1989 (Jones, 1990) confirmed and evaluated the significant potential of redclaw. Subsequent evaluations have supported, and indeed highlighted this potential (Gillespie, 1990; Rouse, et al., 1991; Treadwell, et al., 1991; 1992, Jones and Barlow, 1992).

The Australian Bureau of Agricultural and Resource Economics identified redclaw as one of three key species, out of 43 evaluated, with the most significant aquaculture potential in Australia (Treadwell, et al., 1992, Treadwell, et al.,1992). A more recent and comprehensive economic assessment (Hinton, 1994) has supported the commercial viability of redclaw aquaculture.

On the strength of the recognised potential, over 50 aquaculture licenses had been issued by January 1993. However, at the same time production had reached only 40 tonnes per annum, with a value of around one million dollars.

The discrepancy between potential and development was attributed to the lack of aquaculture experience and knowledge in the private sector and the lack of established and proven technologies. Despite the outstanding biological potential of redclaw, the farming technology applied to its cultivation was variable, often inefficient and in some cases totally inappropriate.

1.1 Economics

Treadwell et al (1991) established that from an economic perspective, redclaw farming is less risk affected and more likely to produce a profitable return than most of the other aquaculture species in production or being developed in Australia. An average internal rate of return (IRR) of 12% and a 90% probability of achieving in excess of 5% IRR provided and excellent basis for investment. A more comprehensive economic assessment conducted by Hinton (1994) supported the earlier results. These statistics are far more favourable than those of Salmon farming for example, which is a well established industry. With appropriate investment and technological support, redclaw

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

aquaculture has the potential to be a more profitable and successful industry than many existing Australian aquaculture industries.

1.2 Geographic Potential

Previous research (Jones, 1990) indicated the broad geographic potential of redclaw. Its cultivation is well suited to the northern half of Australia and has real potential throughout tropical regions of the world. Furthermore, unlike mariculture which is restricted to the coast and constrained by competing demand for coastal resources, redclaw can be farmed over broad regions where freshwater is available.

1.3 Market

Established and substantial demand for freshwater crayfish exists in both Europe and the USA where native species have been consumed for many centuries. Two factors have increased the potential for redclaw to realise some and possibly a great proportion of this demand. Firstly, disease (crayfish plague) introduced from America to Europe last century has effectively wiped out all European production of native species and thus increased the demand for imports. Secondly, the aquacultured American species which are the most widely available, are small in size and less preferred than the large Australian species.

European demand is mostly centred in Italy, Spain, Sweden and France and totals some 10,000 tonnes per annum (Huner, 1989). Production of crayfish in the USA is over 50,000 tonnes per annum, the bulk of which is grown and consumed in Louisiana and neighbouring states. Increasing demand in the big cities on both east and west coasts is likely to be more successfully satisfied with the larger and sweeter Australian crayfish according to marketing experts (Rogers, 1991).

Although unaccustomed to freshwater crayfish, the seafood markets of south-east Asia and Japan are also well suited to redclaw. Of particular significance to redclaw is the demand these markets express for live product. Redclaw is extremely tolerant to air-exposure and can be successfully transported live with minimal expense and high survival over long distances.

The established demand for freshwater crayfish worldwide and the wide acceptance and reputation of redclaw in the established markets supports the likelihood of a large scale, export-oriented production industry in Australia.

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

1.4 The Issue

In many ways, the promotion of redclaw has overtaken production development. Through public and media interest, the image of redclaw has risen to one of wide familiarity and acceptance on both a national and international scale. While this image is constructive and deserved, it has obscured the immediate need for further development of production techniques and investment. The industry's main objective is to achieve consistent, predictable and profitable production. This will depend to a large extent on appropriate production-oriented research. This report details the findings from a three-year production technology research program.

1.5 Objectives

- To evaluate the biological characteristics of recognised stocks of redclaw, and assess their relative suitability for cultivation
- To investigate the nutrition of redclaw through studies of digestive physiology, natural food availability and comparative feeding trials
- To develop standard growout techniques in relation to pond preparation, stocking density and size, pond management and harvesting
- To investigate the feasibility of polyculturing redclaw and silver perch

1.6 Direct Benefits / Beneficiaries

The primary benefit of this research is the availability of technology which results in significantly improved yields and therefore profitability over what was achieved previously. Through application of methods and techniques defined by the research, it is feasible for individual redclaw aquaculturists to increase their yield by an average of 100%. Although additional practitioners have entered the industry since this research was initiated, production has increased by a factor of between 2 and 2.5, due to a large extent to the availability of technologies generated by this research.

Direct beneficiaries of the research are existing and prospective redclaw crayfish farmers. However, on a broader perspective, the research will have considerable value to farmers of other Australian freshwater crayfish (yabbies and marron). This has been borne out by recent invitations to address yabbie and marron growers in South Australia and marron growers in Western Australia, where findings of this research were presented (Jones, 1996). Additional beneficiaries are likely to be the existing agricultural community for which redclaw may prove to be a commercially attractive alternative or additional crop.

There are likely to be flow-on benefits to associated industries including stock feed manufacturers, fertiliser companies, general agricultural supply businesses.

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

1.7 Research Components

1.7.1 Strain Comparison

It is clearly evident that within the distribution of redclaw, different 'strains' are recognised (Hutchings, 1987, Austin, 1986, 1995, Fielder, 1990) which are purported to be of varying superiority and suitability for cultivation. As has been the case with other intensive animal production candidates, it is of great importance that the differences are described and quantified and their basis (genetic or otherwise) is investigated so the industry can proceed with confidence that the best stock is being developed. Clearly, such investigations will also provide an appraisal of the potential for cross-breeding and its important implications.

1.7.2 Nutrition Studies

Development of formulated diets is critical to increased production as was clearly illustrated in the development of intensive prawn aquaculture through the 1970's and 80's. Industry has identified this issue as one of critical importance. A series of comparative production trials examining existing commercial diets and formulated experimental diets was undertaken.

1.7.3 Husbandry

Variability in yields of redclaw can be predominantly attributed to inconsistency in the basic techniques applied. Issues such as pond preparation, stocking density, size at stocking and so forth vary between and within individual farms, reflecting the inexperience of the operators and the lack of established husbandry practices. These operational techniques can only be effectively established for the expedient benefit of the industry through appropriate production trials. A facility which will accommodate several trial treatments with replication was established as part of this project.

1.7.4 Polyculture

While aquaculture development in Australia has focused on monoculture, the effectiveness of polyculture, as exemplified most impressively by Chinese and South-east Asian aquaculturists, cannot be ignored. The priority of this project was to establish the production technology of redclaw alone. However, its suitability for polyculture with a finfish is clear. Specific advantages of the Silver Perch (*Bidyanus bidyanus*) include:

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

- basic growout technology established
- small-mouthed and unlikely to consume crayfish larger than 5g
- consumption of juvenile redclaw an advantage to fish production and as a control of excessive redclaw reproduction
- performs well on a pellet diet, the uneaten portion of which would benefit redclaw production
- hardy and tolerant of similar water quality conditions as redclaw
- market demand established

1.7.5 Results

The bulk of this research took the form of discrete trials. A separate account of each including individual introduction, materials and methods, results and discussion is presented below. Additional results and discussion of redclaw production technology are provided in the General Discussion.

1.7.6 Publications

A list of publications arising from this project is presented in Appendix 10.1.

1.8 References

Austin, C.M. (1986) Electrophoretic and morphological systematic studies of the genus *Cherax* (Decapoda: Parastacidae) in Australia. Ph.D. Dissertation, University of Western Australia, Perth.

Austin, C.M. 1995. The definition and phylogenetic position of the genus *Cherax* (Decapoda: Parastacidae). Freshwater Crayfish, 8:12-31.

Fielder, D.R. 1990. Research to focus on future needs. In: Macreadie, M. (ed) Australian Fisheries: Aquaculture Special: Redclaw. Australian Government Publishing Service, Canberra, Vol.49(11):44-45.

Gillespie, J. 1990. Redclaw - a hot new prospect. In: Macreadie, M. (ed) Australian Fisheries: Aquaculture Special: Redclaw. Australian Government Publishing Service, Canberra, Vol.49(11):2-3.

Hinton, A. 1994. Redclaw Farming - An Economic Perspective. In: Redclaw Crayfish Aquaculture. Choices: New Opportunities for the Atherton Tablelands. Department of Primary Industries, Queensland, Mareeba:22-35.

Huner, J.V. 1989. Overview of international and domestic freshwater crawfish production. Journal of Shellfish Research, 8(1):259-265.

Hutchings, R. 1987. Exciting new crayfish. Austasia Aquaculture, 1(12):12-13.

Jones, C.M. 1988. Aquaculture potential of the freshwater crayfish *Cherax quadricarinatus*: Research objectives and preliminary results. In: Evans, L.H. and O'Sullivan, D. (eds) Proceedings of the First Australian Shellfish Aquaculture Conference, 1988. Curtin University of Technology, Perth:73-78.

Jones, C.M. 1990. The Biology and Aquaculture Potential of the Tropical Freshwater Crayfish, *Cherax quadricarinatus*. In: Queensland Department of Primary Industries Information Series, QI90028: . Queensland Department of Primary Industries, Brisbane:109p.

Jones, C.M. 1996. The Redclaw Experience? Lessons for Marron Aquaculture. In: Evans, L.H. and Whisson, G. (eds) Proceedings of the Marron Growers Association Open Seminar, May 25 1996, Perth, Australia. Marron Growers Association of Western Australia, Perth:9-20.

Jones, C.M. and Barlow, C.G. 1992. The Australian redclaw - a rosy outlook. Infofish International, 2:44-47.

Rogers, D. 1991. So you want to sell your crays in the US. Austasia Aquaculture, 5(6):23-24.

Rouse, D.B., Austin, C.M. and Medley, P.B. 1991. Progress toward profits? Information on the Australian crayfish. Aquaculture Magazine, 17(3):46-56.

Treadwell, R., McKelvie, L. and Maguire, G. 1991. Discussion Paper 91.11: Profitability of selected aquacultural species. Australian Bureau of Agricultural and Resource Economics, Canberra.

Treadwell, R., McKelvie, L. and Maguire, G.B. 1992. Potential for Australian Aquaculture. Australian Bureau of Agricultural and Resource Economics, Canberra.

2. Evaluation of six diets fed to redclaw, *Cherax quadricarinatus* (von Martens), (Decapoda: Parastacidae) held in pond enclosures

2.1 Abstract

Five formulated pelleted diets and one natural diet were fed to redclaw crayfish held within 9m^2 cages fixed to the bottom of an earthen pond in a 6x4 randomised block experiment. Crayfish were stocked at a mean weight of 9.7 ±0.13 and a density of 6.7 per m^2 in June and harvested 5 months later in November. Formulated diets varied considerably in composition, particularly crude protein which ranged from 18 to 42%. A sixth natural diet consisted of a combination of whole rice, lupin seed and raw potato. Food was provided to each cage 3 times per week to excess.

Numbers harvested from each cage were severely affected by escape and to a lesser extent by water rat predation. In excess of 500 of the 1,440 experimental crayfish were captured outside the enclosures. Considerable growth was achieved in all cages, with one of the pellet diets significantly out-performing all others. Size at harvest from this superior diet averaged 45.8g. Average size for the other five diets ranged from 31.3 to 38.5g. The mean size of escaped crayfish was 49g. Due to the significant reduction in density in each cage because of losses attributed to escape and predation, the nutritional value of each diet was not completely tested. Nevertheless, the results suggest that at the densities which prevailed at harvest, the total protein level of the diet is of minimal significance, and other characteristics including those of a non-nutritional nature may be of greater importance. This supports the notion that a simple diet formulation which feeds the benthic microbial biomass is required for redclaw aquaculture, rather than a nutritionally complete diet formulation which feeds the animal.

2.2 Introduction

Development of an aquaculture industry in Queensland based on the redclaw crayfish, *Cherax quadricarinatus*, has progressed with limited success since the late 1980's. Current annual production is in the order of 60 to 80 tonnes. A primary constraint to consistent and commercially acceptable production rates and therefore to further industry development, has been a lack of information on suitable nutrition and appropriate feeding practices for this species. While it is clear from previous studies (Jones, 1990) that redclaw is generally omnivorous, selection and delivery of appropriate food has been uncertain. Economic analysis (Hinton, 1994) has indicated that a semi-intensive approach over a full 12 month growing season is necessary for commercial production of redclaw. Consequently, the application of a forage based feeding strategy using a planted cereal crop as applied to *Procambarus clarkii* culture

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

in the southern USA, is not appropriate. An effective, formulated ration is necessary, as is used for most other semi-intensively aquacultured crustaceans. However, its development has been confounded by a lack of information on the nutritional requirements of redclaw. Several commercial redclaw pellets are available and have been used with varying success by redclaw producers. An assessment of three of these pellets and a simple organic diet was chosen as a starting point for nutritional research within an overall aim of developing an optimal ration for pond production of redclaw.

The unsuitability of the Crustacean Reference Diet, as assessed by Morrissy (1989) for marron (*C.tenuimanus*), required the definition of an alternative 'control'. Two diets were chosen; the first a commercially successful penaeid diet used locally for the culture of *Penaeus monodon*, and secondly, a 'redclaw reference diet' formulated as a best guess diet, according to documented nutritional information for freshwater crayfish.

2.3 Materials and Methods

As the aim of this research was to provide practical solutions to the commercial industry, assessment of the chosen diets was made in a 'typical' earthen pond. While the nutritional research of freshwater crayfish conducted under controlled laboratory conditions is essential to a complete understanding of total nutritional requirements (D'Abramo et al., 1988), it provides little guidance to the development of practical feed formulations for a pond reared omnivore.

In the absence of sufficient individual ponds for replicated trials, enclosures within a pond were chosen as the experimental facility. This method has an advantage over separate ponds, where natural variability between replicates can mask treatment effects (Maguire and Hume, 1982). Cage enclosures were fabricated from a 20mm (stretched) nylon, monofilament netting. Each cage consisted of a box 3m by 3m by 1.6m deep with no top. Cages were secured to the pond floor by corner ropes tethered to fixed steel poles and by a 3m x 3m x 10mm steel frame placed inside the cage. The cage floor was thus firmly held against the pond floor, giving experimental animals direct and complete access to the soil over the entire $9m^2$ floor area. The top corners were also secured to the steel poles. Twenty-four cages were used to accommodate 6 treatments with 4 replicates in a randomised block design. The treatments consisted of 3 commercial crayfish diets (4mm pellets), a simple organic diet, consisting of successive fortnights of whole rice, whole lupin (*Lupinus albus*) seed, chopped raw potato, and two control diets, the first a commercial *Penaeus monodon* diet (2mm pellet) and an experimental redclaw reference diet (Table 2.1) formulated according to documented nutritional information concerning freshwater crayfish (D'Abramo and Robinson, 1989; Brown, 1990; Reigh et al., 1990; Huner, 1991; Lochmann et al., 1992; Reigh et al., 1993) and amino acid analysis of redclaw abdominal muscle (Table 2.6).

These diets represented crude protein levels ranging from 10% to 40% (Table 2.2). Initial feeding rate was 5% of body weight per day, provided in 3 feeds per week. Subsequent feeding rate was adjusted according to estimated growth and mortality, on the basis of periodic sampling and by observations for uneaten feed. While feeding rate was varied throughout the study, equal quantities of feed were provided to all cages at each feeding. Sixty crayfish of between 5 and 15g (mean = 9.7 ±0.13) were stocked into each cage, representing a density of 6.7 per square metre.

Table 2.1. ***Composition (percent dry weight) of redclaw reference diet.***

Ingredient	%
Wheat 10%	25.0
Meat meal 50%	4.0
Cottonseed meal 38%	10.0
Limestone	0.6
Linseed (solvent)	1.0
Fish meal 50%	21.0
Soybean meal (full fat roasted)	32.0
L-threonine	0.1
Lysine mono HCL	0.5
DL Methionine	3.9
Carboxy methyl cellulose	1.2
Barramundi premix (vitamin & mineral)	0.7
	100

Table 2.2 ***Proximate composition statistics for six diets fed to redclaw crayfish.***

Diet	Description	Crude Protein	Fat	Crude Fibre	C	N	C:N
1	Commercial crayfish pellet	20.5	2.7	6.0	35.9	3.1	11.6
2	Commercial fish pellet	36.0	5.2	2.7	37.4	5.2	7.2
3	Commercial crayfish pellet	21.0	3.3	2.9	35.6	3.0	11.9
4	Reference diet formulated by DPI	36.5	4.9	4.8	39.8	6.1	6.5
5	Commercial prawn pellet	44.7	9.3	5.6	42.4	6.7	6.3
6	Lupin seed	16.4	3.3	24.7			>20
6	Whole rice	9.3	1.8	10.6			>20
6	Raw potato	9.9	0.4	3.0			>20

The pond used was approximately 2,000 square metres in total area, and was prepared by application of lime at 1 tonne per hectare, diammonium phosphate fertiliser at 200kg per hectare, and grass hay pellets at 1 tonne per hectare. Each cage was

furnished with an airlift pump, providing aeration and water circulation for 12 hours each night. In addition, an abundance of shelter was provided in each cage in the form of stacks of agricultural pipe, and bundles of synthetic mesh.

Crayfish were stocked on the 11/6/93 and harvested on the 16/11/93. Sampling of the crayfish was performed at 60 days, 120 days and at harvest, 158 days after stocking. All crayfish were retrieved for the day 60 sample, by removing each cage entirely from the pond. As this proved to be extremely laborious and resulted in some losses of experimental crayfish, a sub-sample of each cage population was taken at day 120 by retrieving crayfish from the shelters. The final sample was taken by draining the pond and removing all crayfish from each cage. For each sample, the weight and sex of each crayfish was recorded.

Correlation analysis of harvest number and mean harvest weight was performed by calculating Spearman's rank correlation coefficient (Siegal, 1956). Harvest size data were analysed using analysis of variance. Regression analyses were also performed on growth data for each diet to permit comparison of growth characteristics.

2.4 Results

All water quality parameters were maintained at acceptable levels (Jones, 1990) throughout the period of the trial (Table 2.3). There was considerable difficulty with the maintenance of the planktonic bloom due to significant seepage and the persistence of filamentous algae. However, this did not impact adversely on the trial.

Table 2.3 ***Water quality statistics over the 158 day period of the redclaw nutrition trial.***

Statistic	Secchi (cm)	Maximum Temperature (°C)	Minimum Temperature (°C)	Dissolved Oxygen (ppm)	pH
mean	100	25.2	20.8	7.1	8.0
maximum	140	31.5	25.0	12.7	9.5
minimum	80	22.0	17.5	5.2	6.7

Survival data were confounded by significant escape and some predation of the crayfish. This was due primarily to water rats (*Hydromys* spp.) which tore holes in the cages, predating some crayfish and facilitating escape of others. Removal of all cages on day 60 revealed that losses ranged from 0 to 48 crayfish per cage. To avoid the influence of variable density on growth, these losses were made up (to 60 crayfish per cage), by replacement crayfish of the same mean size as the survivors from each cage. Survival was not measured at the day 120 sample, and no further replacement of losses was made. Because true survival at harvest (day 158) was confounded by the

replacement at day 60 and further escape/predation, survival data were not analysed. The number of crayfish remaining in each cage at harvest is presented in Table 2.4. A total of 548 escaped crayfish were retrieved outside of the cages at harvest when the pond was drained.

Although there was considerable variability in numbers harvested from each cage (Table 2.4), there was no significant correlation ($r = -0.003$, $p = 0.989$) between harvest number and mean harvest weight, suggesting that density did not influence growth. Consequently, no further consideration of density was given in the analysis of growth data (Table 2.5). Figure 2.1 depicts the mean size throughout the culture period, for each of the six diets.

Crayfish grew well on all diets and in all cages, their mean weight progressing from 10g at stocking to between 25 and 65 grams at harvest in the 5 month culture period. There was considerable individual variability in growth with some crayfish in excess of 100g at harvest. The growth achieved with all diets was within a range typically attained by commercial farmers and considered commercially viable.

Two-way analysis of variance indicated that the within-treatment (i.e. between replicates) variance was not significant ($p > 0.01$), and that between treatment variance was significant ($p < 0.001$). Replicate data were therefore pooled for further analysis. Figure 2.2 presents the mean harvest weight for the six diets. Data for the escaped crayfish are included.

Table 2.4. ***Number of redclaw harvested from cages after 158 days.***

	Replicate 1	Replicate 2	Replicate 3	Replicate 4	Mean
Diet 1	3	3	38	37	20.3
Diet 2	1	17	16	3	9.3
Diet 3	1	9	6	58	18.5
Diet 4	11	0	7	10	7
Diet 5	2	0	3	6	2.8
Diet 6	0	44	0	6	12.5

Table 2.5. ***Mean weight (g) of redclaw (replicates pooled) over a 158 day culture period fed six diets. Escape represents crayfish which escaped from experimental enclosures.***

Diet	Day 0 Stocking	Day 60	Day 120	Day 158 Harvest
1	9.5	17.6	35.4	45.8
2	9.4	17.2	30.9	34.1
3	9.8	17.5	32.4	38.5
4	9.6	15.7	33.0	34.1
5	10.1	17.8	28.1	31.3
6	9.6	15.0	30.3	34.7
Escape				49.0

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

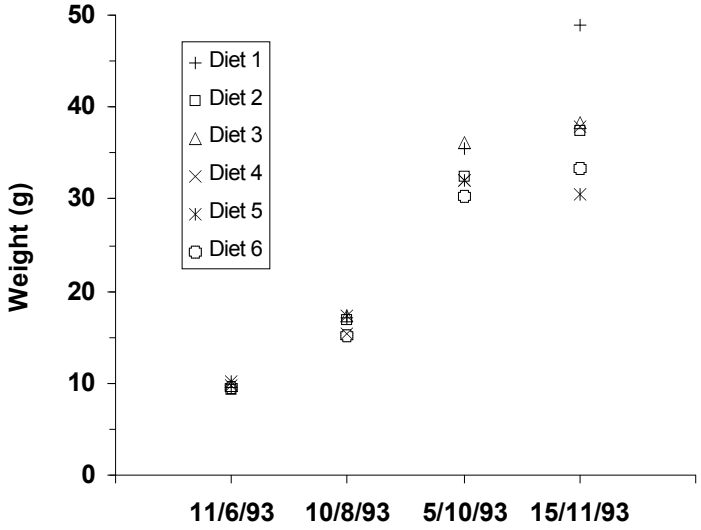


Figure 2.1 ***Mean weight (g) of* C. quadricarinatus *throughout a 158 day period, cultured in an earthen pond using six diets.***

Analysis of variance of harvest weight (replicates pooled) indicated that the escapees and those crayfish fed Diet 1 grew to a significantly ($p < 0.01$) larger size than those fed the other five diets, for which there was no significant difference.

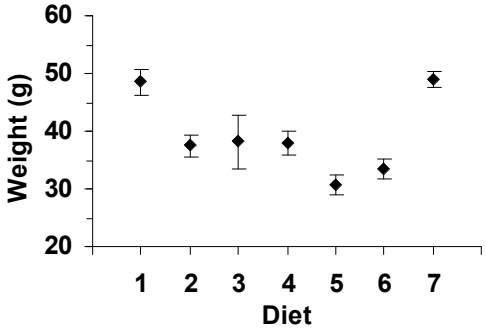


Figure 2.2 ***Mean harvest weight (±SE) for* C. quadricarinatus *cultured in an earthen pond over 158 days and fed six diets. Diets are described in the text. Data for 7 represent escaped crayfish captured outside of the cages at harvest.***

2.5 Discussion

The escapees growth is understandable given that their density was in the order of one crayfish per several square metres. To explain the superior growth achieved with Diet 1 is not immediately clear. What is clear is that the level of protein, and the general nutritional balance of the diet was not important (Table 2.2). Diet 5, the commercial prawn diet, was a high protein, carefully formulated crustacean diet, which should, from a purely nutritional perspective, be an effective diet for redclaw. Similarly, the reference diet (Diet 4) was specifically formulated on the basis of documented information regarding freshwater crayfish nutrition, and on amino-acid analysis of the redclaw. Both these diets performed poorly relative to the other diets which were lower in protein, less formulated and much cheaper.

Examination of the amino-acid profiles for the five formulated diets (Table 2.6) in comparison with the profile for whole redclaw, supports the contention that the nutritional balance of the diets was unrelated to their performance. The two diets

Table 2.6 ***Amino Acid profile of the five pellet diets and approximate amino-acid composition of redclaw.***

Amino Acid	Diet 1	Diet 2	Diet 3	Diet 4	Diet 5	Redclaw
Aspartic Acid	16.1	28.1	16.1	30.3	37.3	30
Threonine	6.3	11.1	6.1	12.4	16.0	12
Serine	8.6	15.1	8.5	15.0	18.7	15
Glutamic Acid	36.0	49.5	33.3	50.6	68.4	50
Proline	11.3	27.2	13.4	16.3	22.3	15
Glycine	9.0	36.4	15.8	20.1	24.8	20
Alanine	9.1	23.0	11.0	17.2	23.3	20
Cystine	3.2	4.2	5.6	4.9	5.3	
Valine	8.2	15.9	8.3	14.5	20.3	15
Methionine	3.5	5.1	5.2	26.0	9.6	25
Isoleucine	6.8	8.6	5.6	12.4	17.7	15
Leucine	13.7	23.7	11.9	23.2	31.0	25
Tyrosine	5.5	6.8	4.9	9.5	13.9	15
Phenylalanine	8.7	14.3	8.6	15.0	19.4	15
Lysine	8.0	22.8	9.0	23.4	27.9	25
Histidine	5.1	9.4	4.8	9.5	13.8	10
Arginine	13.9	20.2	16.3	22.5	24.2	25

which most closely matched the amino-acid profile of the redclaw, Diets 4 and 5, performed poorly.

This suggests that the crayfish in the experiment made little direct use of the feed provided, and obtained the bulk of their nutrition from the natural productivity of the pond benthos. Such an outcome has been reported for several species in similar pond-

based trials (Smitherman et al., 1967; Maguire and Hume, 1982; Moriarty, 1986; New, 1990;). This is in contrast with the results of laboratory and tank studies where formulated diets are consumed and their relative nutritional efficacy can be determined. While such studies can provide useful information, they also emphasise the limited value of trials conducted under artificial conditions where the objective is to determine practical diets for pond-reared species. This limitation has been implied, or recognised and expressed in many studies of freshwater crustaceans (Smitherman et al., 1967; Fair and Fortner, 1981; Levinton, et al., 1984; Morrissy, 1984; D'Abramo, et al., 1988; D'Abramo and Robinson, 1989; Brown, 1990; Huner, 1991; Lochmanm et al., 1992; Reigh, et al., 1993).

Results of this study suggest that the feeds provided were processed through the 'natural' organic decomposition pathways and may have contributed indirectly to the nutrition of the crayfish. The excellent growth of the escaped crayfish suggests that this contribution was not essential. However, these crayfish were represented by a density of around 1 crayfish per $4m^2$ and therefore had access to an abundance of natural food provided primarily by the organic and inorganic fertilisation during pond preparation. Clearly, at the densities prevailing in the cages, the diets provided would have made a significant contribution to the benthic biomass and subsequently to the crayfish.

In this context Diet 1 clearly provided a contribution superior to the other five diets. The reasons why are not clear, and are clouded by the complexities of the organic decomposition process (Levinton et al., 1984; Moriarty, 1986; Bowen, 1987; Mann, 1988). This hypothesis suggests that to provide suitable nutrition to pond-reared redclaw, a shift in objective is necessary from feeding the crayfish directly to feeding the benthic detrital 'system', and consequently the nature of the diet must be assessed from a different perspective.

Firstly, some assessment must be made of what constitutes the 'natural' food of redclaw in an earthen pond. It is reasonable to assume that this food consists primarily of microbially enriched organic particles, as has been established for other benthos-feeding species (Schroeder, 1978; Suren and Lake, 1989; Day and Avault, 1986; Moriarty, 1986; Bowen, 1987; Mann, 1988; Boon, 1990; McClain et al., 1992a; 1992b; Morrissy, 1984). The characteristics of organic materials which maximise the availability of microbial biomass have been investigated to some extent for the cultivation of *Procambarus clarkii*.

In examining the various forages used in the cultivation of *P. clarkii*, the carbon to nitrogen ratio (C:N) of the material has been flagged as an indicator of how nutritious it is (Goyert and Avault, 1977; Chien and Avault, 1980; 1983; Day and Avault, 1986). A C:N of 17:1 is considered optimal. However, McClain et al. (1992a) suggested that the C:N is a rough guide at best, and may be misleading in this regard because the detritus

is made up of a variety of particles which may differ widely in their C:N ratio. The C:N ratios of the six diets in this trial proved to be of little guidance (Table 2.2).

The C:N of Diets 2, 4 and 5 were quite low (<7.2), due to their high protein nature. The organic diet (Diet 6) consisted of three materials all with C:N ratios over 17. While this diet is likely to have decayed at a reasonable rate and provided a suitable substrate for microbial activity, it did not perform well. It is possible that the lupin seed component included an inhibitory factor which affected the crayfish directly, or the colonisation of microbes. *Lupinus albus* is known to have non-specific growth inhibitors (Williams, 1981). Diets 1 and 3 both had C:N ratios of around 12, and were therefore closest to the recognised optimum of 17. However, only Diet 1 produced superior growth.

A more likely explanation for the superiority of Diet 1 is the source of carbohydrate and the level of fibre. Unlike the other two crayfish diets (Diets 2 and 3), the carbohydrate source of Diet 1 was primarily maize, rather than wheat. It is possible that maize provides a superior substrate for microbial colonisation than wheat. In addition, Diet 1 had a crude fibre level considerably higher than the other diets. While fibre has been shown to be of limited value as a direct nutritional source for freshwater crayfish (Reigh et al., 1990), it may benefit microbial colonisation (Schroeder, 1978).

Some economic consideration must also be given in the assessment of the relative performance of the diets. In addition to their poor performance, Diets 4 and 5 cost in excess of A$1,500 per tonne and their use cannot therefore be justified. However, at a commercial cost of less than A$500 per tonne, Diet 1 is quite cheap and therefore represents a good diet for pond production of redclaw. Its characteristics provide a reasonably good starting point for further development of an optimal redclaw ration.

These assessments of the results of this feeding trial are certainly not conclusive, however, they do suggest that under current redclaw aquaculture management practices (i.e. earthen pond culture at relatively low densities), provision of adequate nutrition is likely to be more a pond or benthos management issue than development of a formulated diet. The selection of materials which maximise the microbial fauna and flora of the pond benthos is an avenue which requires further exploration.

In regard to the development of a formulated diet (i.e. a totally nutritionally complete redclaw food), it is likely to be of greater relevance to more intensive redclaw farming, either in ponds or tanks, where the natural background cannot provide a suitable, or sufficient source of food. As current commercial practice does not support this approach, further development of such a diet is not warranted at this time.

Future pond trials will examine experimental rations with particular reference to the source of carbohydrate and level of fibre, and measuring the nature and abundance of the benthic microbial biomass as well as crayfish survival and growth.

2.6 References

Boon, P.I. 1990. Organic matter degradation and nutrient regeneration in Australian freshwaters. II. Spatial and temporal variation, and relation with environmental conditions. Archives Hydrobiolgie, 117:405-436.

Bowen, S.H. 1987. Composition and nutritional value of detritus. In: Moriarty, D.J.W. and Pullin, R.S.V. (eds) Detritus and microbial ecology in aquaculture. ICLARM Conference Proceedings 14, 420p. International Center for Living Aquatic Resources Management, Manila Philippines.

Brown, P. 1990. Review of crayfish nutrition. Crustacean Nutrition Newsletter, 6(1):68-69.

Chien, Y.H. and Avault, J.W., Jr. 1980. Production of crayfish in rice ponds. Progressive Fish-Culturist, 42(2):67-71.

Chien, Y.H. and Avault, J.W., Jr. 1983. Effects of flooding dates and type of disposal of rice straw on the initial survival and growth of caged juvenile crayfish, *Procambarus clarkii*, in ponds. Freshwater Crayfish 5: 344-350.

D'Abramo, L.R., Reed, L. and Heinen, J.M. 1988. A Culture system for nutritional studies of crustaceans. Aquaculture, 72:379-389.

D'Abramo, L.R. and Robinson, E.H. 1989. Nutrition of crayfish. Reviews in Aquatic Sciences, 1:711-728.

Day, C.H. and Avault, J.W., Jr. 1986. Crayfish *Procambarus clarkii* production in ponds receiving varying amounts of soybean stubble or rice straw as forage. Freshwater Crayfish 6: 247-265.

Fair, P.H. and Fortner, A.R. 1981. The role of formula feeds and natural productivity culture of the prawn *Macrobrachium rosenbergii*. Aquaculture, 24:233-243.

Goyert, J.C. and Avault, J.W.Jr. 1977. Agricultural by-products as supplemental feed for crayfish, *Procambarus clarkii*. Trans. Amer. Fish. Soc., 106:629-633.

Hinton, A. 1994. An economic perspective of redclaw farming. In: Proceedings of the Redclaw Farming Workshops (Jones, C.M. & Curtis, M.C., eds.), pp.52-65. February 12-17, 1994. Queensland Department of Primary Industries, Walkamin, Queensland.

Huner, J.V. 1991. The use of manufactured feeds in Louisiana crawfish ponds. Crustacean Nutrition Newsletter, 7(1):32-33.

Jones, C.M., 1990. The Biology and Aquaculture Potential of the Tropical Freshwater Crayfish *Cherax quadricarinatus*. Queensland Department of Primary Industries Information Series QI90028 109pp.

Levinton, J.S., Bianchi, T.S. and Stewart, S. 1984. What is the role of particulate organic matter in benthic invertebrate nutrition? Bulletin of Marine Science, 35:270-282.

Lochmann, R., McClain, W.R. and Gatlin III, D.M. 1992. Evaluation of practical feed formulations and dietary supplements for red swamp crayfish. Journal of the World Aquaculture Society, 23(3):217-227.

Maguire, G.B. and Hume, I.D. 1982. A study of the nutritional requirements of school prawns *Metapenaeus macleayi* (Haswell) in some Australian brackish water farming ponds. Aquaculture, 29:261-278.

Mann, K.H. 1988. Production and use of detritus in various freshwater, estuarine, and coastal marine ecosystems. Limnology and Oceanography, 33(4):910-930.

McClain, W.R., Neill, W.H. and Gatlin III, D.M. 1992a. Nutrient profiles of green and decomposed rice-forages and their utilization by juvenile crayfish (*Procambarus clarkii*). Aquaculture, 101:251-265.

McClain, W.R., Neill, W.H. and Gatlin III, D.M. 1992b. Partitioning the contributions of forage-based production system components to weight gain of juvenile crayfish (*Procambarus clarkii*). Aquaculture, 101:267-281.

Moriarty, D.J.W. 1986. Bacterial productivity in ponds used for the culture of penaeid prawns. Microbial Ecology, 12:259-269.

Morrissy, N.M. 1984. Assessment of artificial feeds for battery culture of a freshwater crayfish, marron (*Cherax tenuimanus*) (Decapoda : Parastacidae). Department of Fisheries and Wildlife of Western Australia Report, No.63:1-43.

Morrissy, N.M. 1989. A standard reference diet for crustacean nutrition research. IV. Growth of freshwater crayfish *Cherax tenuimanus*. Journal of the World Aquaculture Society, 20(3):114-117.

New, M.B. 1990. Freshwater prawn culture: a review. Aquaculture, 88(2):99-143.

Reigh, R.C., Braden, S.L. and Craig, R.J. 1990. Apparent digestibility coefficients for common feedstuffs in formulated diets for red swamp crayfish, *Procambarus clarkii*. Aquaculture, 84:321-334.

Reigh, R.C., Braden, S.L. and Laprarie, R.J. 1993. Substitution of soybean protein for fish protein in formulated diets for red swamp crawfish *Procambarus clarkii*. Journal of the World Aquaculture Society, 24(3):329-338.

Schroeder, G.L. 1978. Autotrophic and heterotrophic production of microorganisms in intensely manured fish ponds, and related fish yield. Aquaculture, 14:303-325.

Siegal, S. 1956. Nonparametric Statistics for the Behavioural Sciences. International Student Edition. McGraw-Hill Kogakusha Ltd., Tokyo.

Smitherman, R.O., Avault, J.J.W., de la Bretonne, J.L. and Loyazamo, H.A. 1967. Effects of supplemental feeding and fertilizer on production of red swamp crawfish, *Procambarus clarkii*, in pools and ponds. Proceedings of the Annual Conference of the southeastern Association of Fisheries and Wildlife Agencies, 21:452-458.

Suren, A.M. and Lake, P.S. 1989. Edibility of fresh and decomposing macrophytes to three species of freshwater invertebrate herbivores. Hydrobiologia, 178:165-178.

Williams, K.C. 1981. Lupins and Triticale as alternative feeds. pp. 111-122 in Proceedings Poultry Information Exchange, Broadbeach Queensland, 15-17 November 1981. Queensland Department of Primary Industries, Conference and Workshop Series 81010.

3. Evaluation of six diets fed to redclaw, *Cherax quadricarinatus* (von Martens) (Decapoda: Parastacidae), under laboratory conditions.

3.1 Introduction

Commercially successful aquaculture of redclaw crayfish *Cherax quadricarinatus*, is now being achieved throughout the State of Queensland, albeit on a small scale. Several constraints to the industry's further development have been identified including the availability of a cost-effective diet.

Previous studies by Jones (1990, 1995) have indicated that for earthen pond culture the most effective diets do not necessarily have a high protein content and that redclaw obtain a substantial proportion of their nutrient requirements from natural food materials available in the pond. These natural food materials are presumed to be mostly microbial flora and fauna associated with the decaying organic fraction of the benthos.

The habit of redclaw of ingesting natural food materials confounds the assessment of experimental diets. Nevertheless, as commercial aquaculture of redclaw is practised in earthen ponds, a commercially acceptable diet will have to perform in that environment. Reigh and Ellis (1994) found that superior diets as assessed in laboratory experiments for *Procambarus clarkii*, were not superior when assessed in typical commercial earthen pond conditions.

To eliminate the availability of natural food materials to provide a more accurate assessment of the six diets previously trialed with redclaw (Jones, 1995), a relatively sterile environment was required. It was hypothesised that this may also reveal the relative importance of the natural food fraction of the redclaw diet.

3.2 Materials and Methods

The experiment was conducted at the Freshwater Fisheries and Aquaculture Centre, Walkamin (17.1°S, 145.5°E). A block of eighteen 80l glass aquaria housed within an enclosed hatchery was used as the experimental facility. Six diet treatments were applied in a randomised block design with 10 crayfish per aquarium, representing a density of 30/m^2. While this density was somewhat higher than that applied to the pond study (Jones, 1995), it was considered necessary given the small scale of each experimental unit and to maintain statistical rigour. Three replicates were used for each treatment.

The treatments consisted of 5 pellet diets (4 commercial formulations and 1 experimental reference formulation) and a simple organic diet (consisting of alternate fortnights of whole rice, whole lupin seed, chopped raw potato). These diets represented crude protein levels between 10% and 40%. Formulation details of the experimental reference diet are presented in Table 3.1. Proximate composition details of all diets are listed in Table 3.2. An initial feeding rate of 5% of body weight per day was applied, provided in 3 feeds per week. This rate was adjusted on the basis of observation. Food was provided between 3 and 5pm and all uneaten material and excreta were removed each morning.

Table 3.1 ***Composition (percent dry weight) of redclaw reference diet.***

Ingredient	%
Wheat 10%	25.0
Meat meal 50%	4.0
Cottonseed meal 38%	10.0
Limestone	0.6
Linseed (solvent)	1.0
Fish meal 50%	21.0
Soybean meal (full fat roasted)	32.0
L-threonine	0.1
Lysine mono HCL	0.5
DL Methionine	3.9
Carboxy methyl cellulose	1.2
Barramundi premix (vitamin & mineral)	0.7
	100

Table 3.2 ***Proximate composition statistics for six diets fed to redclaw crayfish.***

Diet	Description	Crude Protein	Fat	Crude Fibre	C	N	C:N
1	Commercial crayfish pellet	20.5	2.7	6.0	35.9	3.1	11.6
2	Commercial fish pellet	36.0	5.2	2.7	37.4	5.2	7.2
3	Commercial crayfish pellet	21.0	3.3	2.9	35.6	3.0	11.9
4	Reference diet (DPI)	36.5	4.9	4.8	39.8	6.1	6.5
5	Commercial prawn pellet	44.7	9.3	5.6	42.4	6.7	6.3
6	Lupin seed	16.4	3.3	24.7			>20
6	Whole rice	9.3	1.8	10.6			>20
6	Raw potato	9.9	0.4	3.0			>20

A centralised upflow sand filter was established to which all aquaria were connected. A flow rate was maintained to ensure the volume of water in each tank was replaced 6 times per hour. Filter sand was backflushed regularly. Water was continuously aerated. Crayfish habitat was provided in the form of two bundles of an open weave

synthetic mesh (Oyster Mesh, Southcorp Industrial Textiles) placed in each tank with a weight. Each mesh bundle was of an equivalent size, and was made from 6 strips (1m x 100mm) of material tied together across their longitudinal centres. The sides of each aquarium were covered with black plastic and the top screened with a translucent plastic mesh. Light levels in each aquaria were uniform and likely to be equivalent to a normal pond situation.

Water temperature of the tank system was maintained at approximately 25°C with a 1Kw immersion heater placed in the filtration reservoir. The photoperiod was maintained at 14L:10D with a time switch attached to two fluorescent ceiling lights which were dimmed with a layer of shade-cloth material. Water quality parameters including pH, maximum and minimum temperature, ammonia and nitrite were measured once per week.

Experimental crayfish were harvested from a pond at the Freshwater Fisheries and Aquaculture Centre. Crayfish were chosen on the basis of their size (approximately 10 g) and condition as gauged by their robustness and possession of all limbs. Individual weights and sex were determined and recorded. Size frequency distributions of crayfish stocked are presented in Figure 3.1.

The experiment was run over a 24 week period from 20/6/94 to 22/11/94. Because individual crayfish were not identifiable, growth was expressed as individual weight at harvest minus the mean weight of each tank when stocked. Survival was expressed as the proportion of crayfish alive at harvest.

Mean growth, survival and biomass for the 6 treatments were compared with analysis of variance. Residuals were examined to determine any requirement for data transformations. In all cases residuals were uniformly distributed and no transformations were applied. Pairwise comparisons of means were made with the Least Significant Difference test.

3.3 Results

Conditions remained generally conducive to the maintenance of redclaw throughout the trial period. Water quality data are summarised graphically in Figure 3.2. A significant spike in ammonia (0.5ppm) in mid-August and in temperature in mid-September had no appreciable effect on the experimental stock. However, human intervention in late September led to the displacement of the mesh covers on several tanks, resulting in the escape and loss of experimental animals. Consequently, one replicate was lost to each of diets 1, 2, 3 and 6.

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

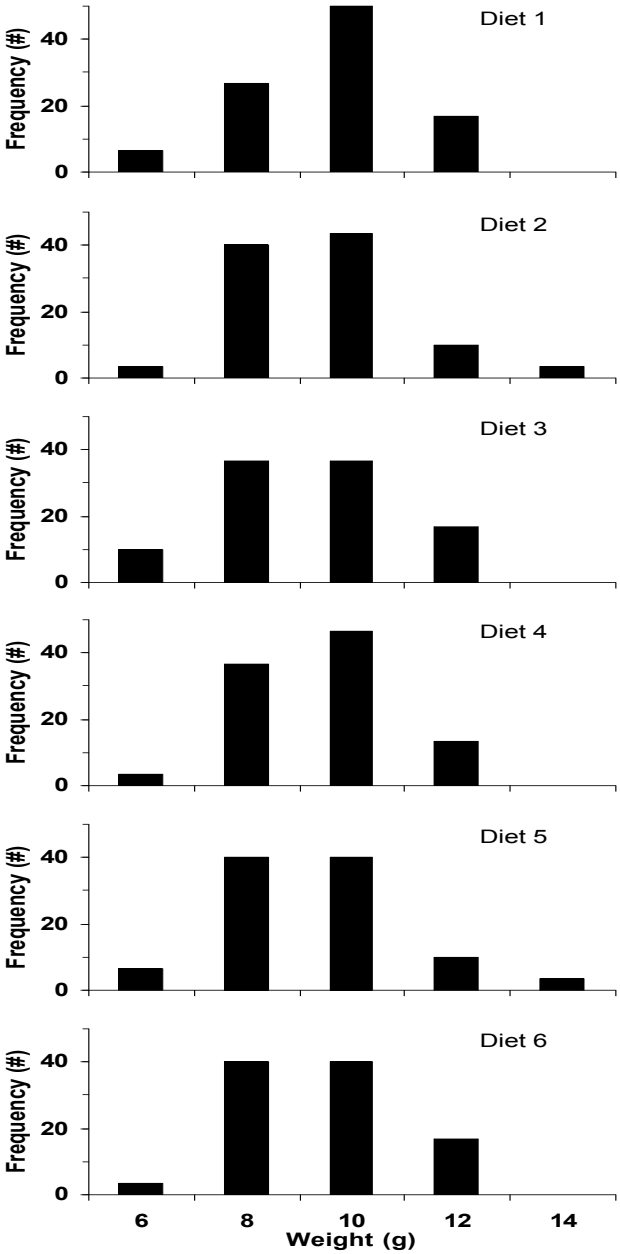


Figure 3.1 ***Size frequency distributions for redclaw stocked to feeding trial.***

Approximately 660g of diets 1 through 5 was provided to each tank over the culture period. Due to the high moisture content of raw potato (90%), quantities 5 times the amount of the pellet diets were applied. Quantities of rice and lupin seed were equivalent to the pellets. Over the trial period, 1130g of the organic diet was applied.

Statistics in relation to the size and number of crayfish at harvest for each tank are detailed in Appendix 10.2. Survival of crayfish in the aquarium system was generally good. Survival for each diet is depicted in Figure 3.3. Analysis of variance indicated no significant variability ($p > 0.05$).

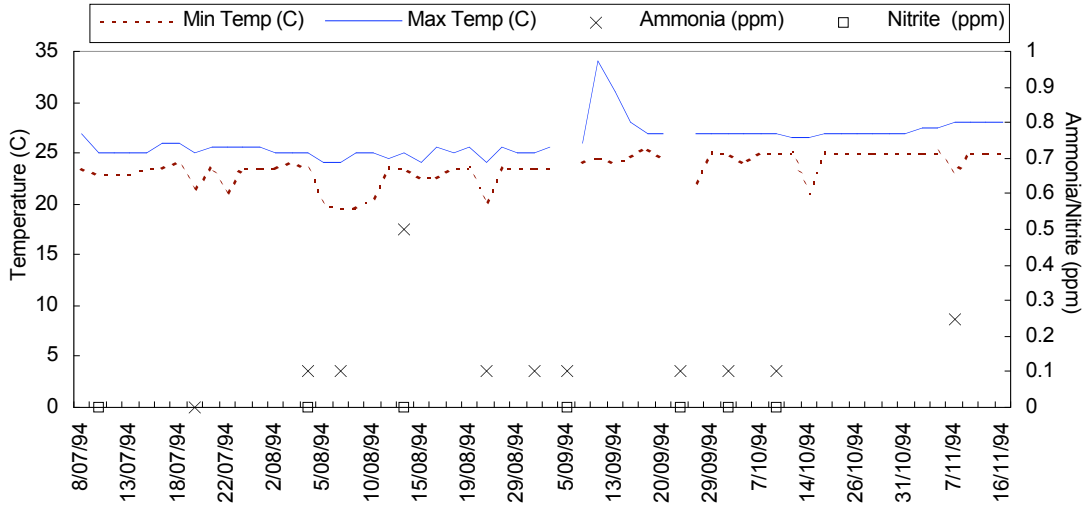


Figure 3.2 ***Summary of water quality over the 24 week period of redclaw feeding trial in aquaria.***

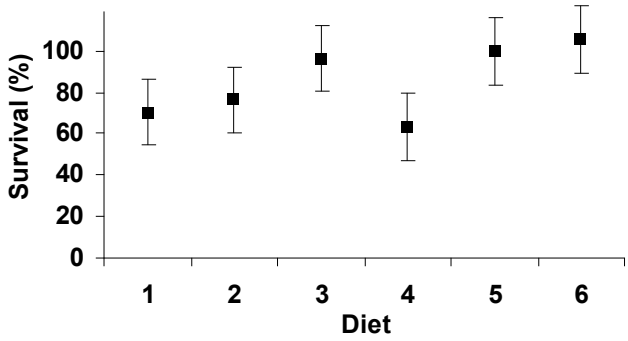


Figure 3.3 ***Mean survival (±SE) of redclaw fed 6 different diets in aquaria.***

Mean weight at harvest is illustrated in Figure 3.4. Analysis of variance of mean growth indicated significant variability ($p < 0.01$). Pairwise comparison of means are presented in Table 3.3. The simple organic diet (# 6) generated significantly less growth than all other diets. Differences among the other diets were less clear, although the reference diet (#4) and diet 1 generated greater growth than diets 2, 3 or 5.

Closer examination of growth data for each sex revealed no significant variability in survival between sexes ($p > 0.05$), but highly significant variation in growth ($p < 0.01$). Females were consistently larger than males as illustrated in Figure 3.5.

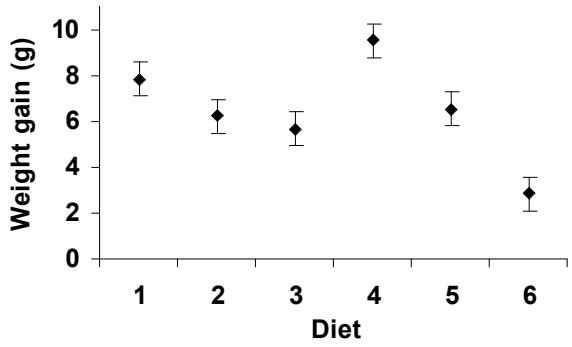


Figure 3.4 ***Mean growth (±SE) of redclaw fed 6 different diets in aquaria.***

Table 3.3 ***Mean growth of redclaw fed 6 different diets in aquaria. Means underscored by the same line are not significantly different (p > 0.05).***

	Diet					
	4	**1**	**5**	**2**	**3**	**6**
Mean	9.53	7.80	6.52	6.23	5.65	2.84

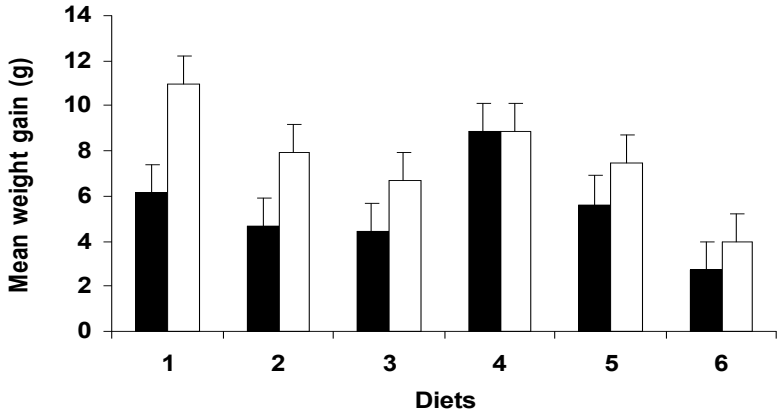


Figure 3.5 ***Mean growth (+SE) of male (solid) and female (open) redclaw fed 6 different diets in aquaria.***

A plot of growth for each diet from stocking to harvest is presented in Figure 3.6. Growth curves for the same six diets as generated from the pond trial (Jones, 1995) are included for comparison.

Biomass (total weight of crayfish harvested from each cage) was not significantly different between diets ($p > 0.05$). Size frequency distributions of harvest weight (Figure 3.7) provide a more detailed picture of size at harvest.

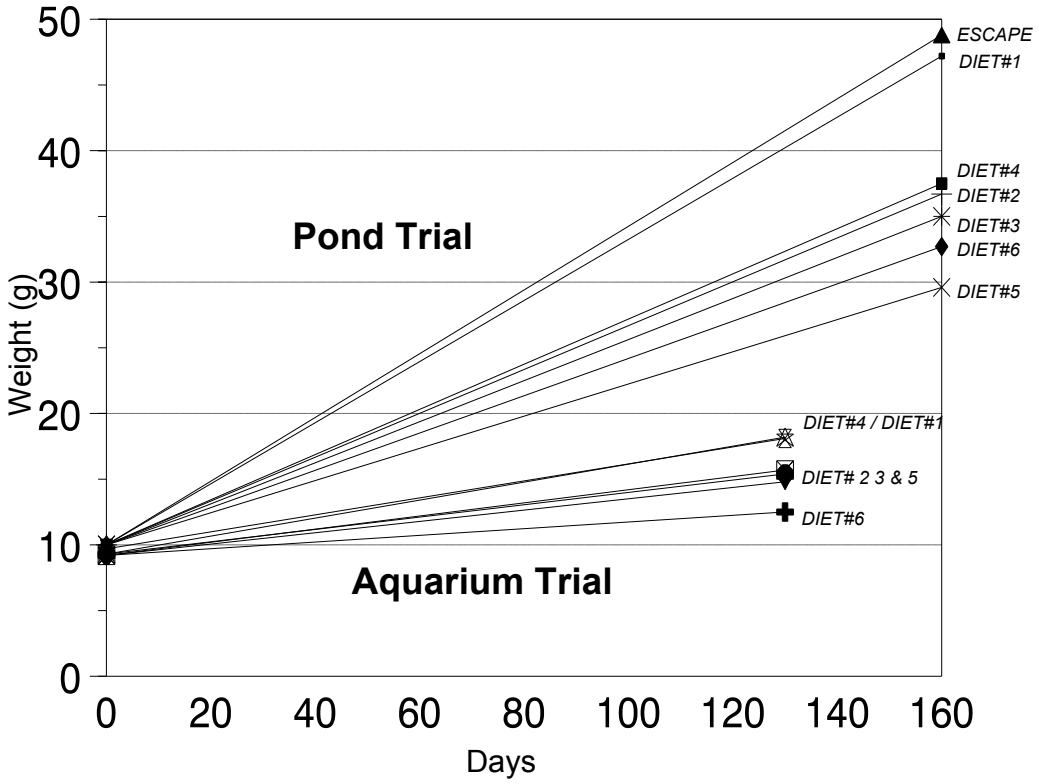


Figure 3.6 ***Growth curves for redclaw from stocking to harvest (mean weight) fed 6 different diets in aquaria and in an earthen pond. Details of the pond study are reported in Jones (1995).***

3.4 Discussion

Despite a substantial body of research aimed at nutrition of freshwater crayfish (D'Abramo and Robinson, 1989; Reigh, et al., 1989; 1993; Reigh, 1990; Reigh and Ellis, 1994; Brown, 1995), development of formulated diets which are cost-effective, nutritionally balanced, and which perform well under typical commercial conditions in earthen ponds, has had limited success (Brown, 1995). To date, investigations concerning redclaw nutrition have been conducted, necessarily, at a reasonably coarse

level. Results of this trial provide further useful information which will contribute to the development of a suitable formulated feed for redclaw.

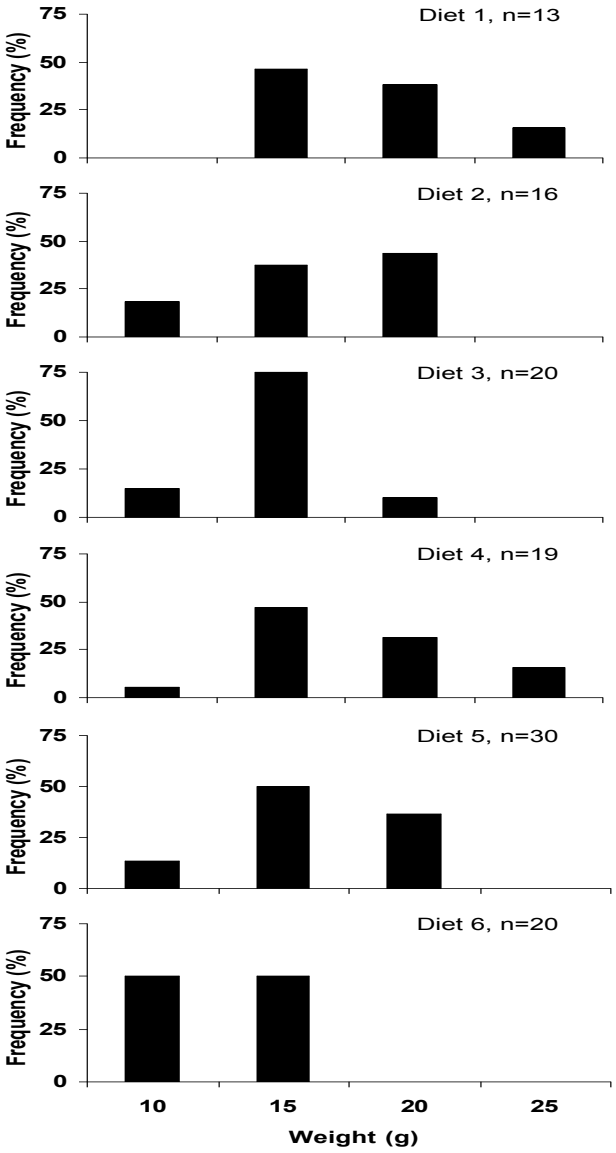


Figure 3.7 ***Size frequency distributions for redclaw after a 24 week culture period in aquaria, fed 6 different diets.***

Despite the absence of benthos and natural food organisms in this trial, as were available in the earthen pond environment of the preceding trial (Jones, 1995), Diet 1 again performed very well, although fractionally less well than the reference diet (#4) which generated the best growth.

The simple organic diet (#6) was clearly inferior to the other diets. It was surmised by Jones (1995) that the organic materials in the earthen pond environment provided an acceptable base for colonisation by micro-organisms and thereby rendered the material suitably nutritious. However, the simple organic diet, which did not perform well in the pond study (Jones, 1995), was clearly even more inadequate in the aquaria where such colonisation could not occur.

The mean size at harvest provides a fixed measure of the relative performance of the diet, however, the size frequency distribution gives a more comprehensive assessment of size. Only diets 1 and 4 supported growth to the 25g size class. However, with the exception of the simple organic diet (#6) all size distributions were reasonably similar in shape. Although growth was significantly different among diets, when combined with survival to generate biomass data, no significant differences between diets were measured. However, the growth trends suggest more significant differences may have eventuated over a longer period.

This trial supported the findings of the preceding trial (Jones, 1995) suggesting that redclaw does not have a specific requirement for high levels of protein, and can be successfully cultured on a diet primarily composed of materials of plant origin. Although the reference diet (#4) included a substantial proportion of fish meal and had a crude protein level of 36.5%, Diet 1 which also performed well, was entirely composed of non-animal materials. As no microbial enrichment could have occurred in the culture system, the trial provided a direct assessment of the diets nutritional adequacy.

Given the proven efficacy of the commercial penaeid diet (#5) for its designated species (*Penaeus monodon*), it is uncertain why it did not sustain better crayfish growth. Reasons for the comparatively poor performance of Diet 3, which had a similar crude protein level to Diet 1 and was similarly composed of non-animal materials, were also unclear.

While specifically high protein levels appear to be un-necessary, the composition of the protein required is likely to be important. The disparate performance of Diets 1 and 3, which were in a general sense quite similar, suggests that specific quantities of particular amino-acids may be required. Clearly, other gross nutritional factors are also likely to be important. These include relative digestibility's of components, fat content and composition, vitamin and mineral requirements. Future investigations should examine these factors under controlled nutritional conditions, where treatment factors are varied while other nutritional factors are held constant.

This aquarium-based trial also provided additional insights into the cultivation of redclaw. Despite the provision of ideal redclaw culturing conditions from the perspective of water quality, uniform high temperature, low incident light, abundant shelter etc., the growth over the trial period compared very poorly with that achieved in the preceding pond study with the same diets (Figure 3.6). This provides a relative

measure of the magnitude of the natural food fraction in the diet of redclaw under earthen pond culture conditions. Presumably, other aspects in addition to the diet are likely to have contributed to the poor growth of redclaw in the aquarium system, although the nature of such factors is not clear. All the crayfish harvested from the trial were healthy with minimal indication of stress, often manifested in fluid filled blisters on the uropods and telson. Nevertheless, the relatively sterile environment and in particular, the lack of sediment are likely to be antagonistic to redclaw condition and growth.

In the pond study, redclaw grew to a size 100 to 200% larger, over an equivalent period, to that achieved in aquaria. On this basis, as much as 50 to 70% of the growth of redclaw grown under pond conditions (as described by Jones, 1995) may be surplus to that provided directly by the pellet diet. While some of this proportion may be attributable to non-dietary factors, the bulk of it is likely to be generated from nutrition provided by other materials (natural food organisms) available in the pond.

Superior growth of females in this study was surprising. For all diets excepting the reference diet (#4), females grew to a significantly greater size than males. Several studies of freshwater crayfish have documented substantially greater growth for males (Aiken and Waddy, 1992). Studies of redclaw (Curtis and Jones, 1995; Jones and Ruscoe, 1996) have shown faster male growth and larger maximum size of males. However, the superiority of male growth has always been documented for relatively large (adult) sizes. In this study, growth was monitored over a reasonably small range to a maximum of around 25g. Juvenile female redclaw may grow faster than their male counterparts up to maturation to compensate for faster male growth after maturation.

These results also provide a useful assessment of the efficacy of tank-based systems for the culture of redclaw. Intensive to super-intensive culture systems for *Cherax* species have been suggested and pursued by many commercial operators throughout Australia. In Queensland, at least one company promotes and supplies redclaw aquaculture kits based on above ground tanks or in some cases, plastic-lined in-ground pools. Based on the results of this trial, such systems are not likely to achieve economically acceptable growth, particularly in light of their high establishment and operating costs. Maintaing healthy crayfish and achieving reasonable survival over a substantial time frame is not problematic, however, generating reasonable growth rates certainly is.

3.5 References

Aiken, D.E. and Waddy, S.L. 1992. The growth process in Crayfish. Reviews in Aquatic Sciences, 6(3):335-381.

Brown, P.B. 1995. A review of nutritional research with crayfish. Journal of Shellfish

Research, 14:561-568.

Curtis, M.C. and Jones, C.M. 1995. Observations on monosex culture of redclaw crayfish *Cherax quadricarinatus* von Martens (Decapoda: Parastacidae) in earthen ponds. Journal of the World Aquaculture Society, 26(2):154-159.

D'Abramo, L.R. and Robinson, E.H. 1989. Nutrition of crayfish. Reviews in Aquatic Sciences, 1:711-728.

Jones, C.M. 1990. The Biology and Aquaculture Potential of the Tropical Freshwater Crayfish, *Cherax quadricarinatus*. In: Queensland Department of Primary Industries Information Series, QI90028: . Queensland Department of Primary Industries, Brisbane:109p.

Jones, C.M. 1995. Evaluation of six diets fed to redclaw, *Cherax quadricarinatus* (von Martens), held in pond enclosures. Freshwater Crayfish, 10:469-479.

Jones, C.M. and Ruscoe, I. 1996. Production Technology for Redclaw Crayfish (*Cherax quadricarinatus*). Final Report FRDC Project 92/119. Fisheries Research and Development Corporation, Canberra

Reigh, R.C. 1990. Crawfish nutrition and feeding. In: Reigh, R. (ed) Proceedings of the Louisiana Aquaculture Conference 1990. LSU Agricultural Center, Baton Rouge, Louisiana.:61-64.

Reigh, R.C. and Ellis, S.C. 1994. Utilization of animal-protein and plant-protein supplements by red swamp crawfish, *Procambarus clarkii*, fed formulated feeds. Journal of the World Aquaculture Society, 25:541-552.

Reigh, R.C., Braden, S.L. and Craig, R.J. 1989. Apparent digestibility coefficients for common feedstuffs in formulated diets for red swamp crayfish, *Procambarus clarkii*. Aquaculture, 84:321-334.

Reigh, R.C., Braden, S.L. and Laprarie, R.J. 1993. Substitution of soybean protein for fish protein in formulated diets for red swamp crawfish *Procambarus clarkii*. Journal of the World Aquaculture Society, 24(3):329-338.

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

4. Assessment of carbohydrate source in five diets fed to redclaw, *Cherax quadricarinatus* (von Martens) (Decapoda: Parastacidae), under earthen pond conditions

4.1 Introduction

Aquaculture of redclaw crayfish, *Cherax quadricarinatus*, in Australia amounts to around 80 tonnes per annum (Curtis and Jones, 1995). Although this production base is small, given the excellent aquaculture attributes of redclaw, it provides a solid foundation for the growth of a substantial industry. The most advanced practitioners are now achieving yields in excess of 2 tonnes per hectare per year averaged over their commercial operation (Lobegeiger, 1995). Experimental yields have exceeded 3.5 tonnes per hectare (Jones and Ruscoe, 1996). While economically acceptable yields are being achieved with existing technology, there are likely to be significant gains made through the further development of formulated diets. Just as aquaculture production of penaeids increased substantially after nutritional breakthroughs in the early 1970's, a significant acceleration of redclaw aquaculture production may follow the development of a more effective formulated diet.

Previous studies (Jones, 1990; 1995) have suggested that diets provided to redclaw in earthen ponds are not all consumed directly, and that the redclaw gain a substantial proportion of their nutrition by ingesting natural foods, mostly microbial flora and fauna associated with the decaying organic fraction of the benthos. The diet provided may contribute to this organic substrate, supporting the colonisation of micro-organisms and thereby sustaining the crayfish indirectly. Consequently, the diets which perform best are those that contribute most to the microbial fauna. Jones (1995) suggested that the source of carbohydrate may be a key element in this respect. Consequently, this experiment was conceived to assess the relative efficacy of five diets identical in all respects with the exception of the primary source of carbohydrate.

D'Abramo and Robinson (1989) indicated that crayfish are likely to be able to effectively utilise large amounts of dietary carbohydrate. However, the premise of the proposed investigation, that the carbohydrate may contribute to the availability of natural microbial food organisms, is more in line with the forage-base approach developed for *Procambarus clarkii* (D'Abramo and Robinson, 1989; Avault and Brunson, 1990; McClain et al., 1992; Brown, 1995), and more recently for *Cherax destructor* (Chavez and Mitchell, 1995; Mitchell et al., 1995).

Specific objectives of this experiment were to determine the effect of different sources of dietary carbohydrate on growth and survival of redclaw under earthen pond conditions, and to provide information for the development of experimental diets for further testing.

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

4.2 Materials and Methods

The trial was conducted in cage enclosures within a 2000m^2 earthen pond at the Freshwater Fisheries and Aquaculture Research Center, Walkamin in Northern Australia (17.1°S, 145.5°E) over the period December 1994 to May 1995.

Cages were fabricated from a 9mm extruded plastic mesh. Each cage consisted of a box 4m x 4m x 1.8m high with no top or bottom. Cages were secured to the pond floor by burying the bottom margin of the cage approximately 300mm into the pond soil. The four corners of the cages were secured to steel poles, placed inside the corners and driven deeply into the pond bottom. Ninety millimetre PVC pipe was attached to the top margin of each cage to prevent crayfish escape.

The pond was prepared with applications of dolomite at the rate of 1,000kg/ha, di-ammonium phosphate at 250kg/ha and mulching hay at 1,000kg/ha. Additional applications of fertilisers were used throughout the experiment to maintain a plankton bloom. Water was maintained at a constant depth of between1.3m and 1.8m for all cages. New water was added only to match losses due to evaporation and seepage. Dissolved oxygen, pH, secchi depth and maximum and minimum temperatures at the pond bottom were measured two times per week.

Each cage was furnished with a single 100mm diameter PVC airlift pump (Jones and Curtis, 1994) to provide aeration and water circulation. Air was injected at 0.435kPa through a perforated 12mm polythene pipe at a depth of 1 metre within the 100mm pipe. Airlift pumps were operated continuously throughout the experiment.

Twenty-four cages were used to accommodate 6 treatments with 4 replicates, arranged in a randomised block design. The treatments consisted of 5 experimental diets, identical in composition with the exception of the primary carbohydrate source and a control treatment diet for which a proprietary commercial crayfish diet (Athmaize) was used. The Athmaize crayfish diet was evaluated as the best of six diets compared previously by Jones (1995).

Experimental diets were prepared at the Freshwater Fisheries and Aquaculture Centre. The composition of each of the five experimental diets is listed in Table 4.1. All diet ingredients were measured on an electronic balance and placed in a food mixer (Hobart A120). A volume of hot (80°C) bore water was then added to the mixture, equal to 50% of the weight of the initial ingredients. The mixture was then blended for 15 minutes. The mixture was fed through a mincing attachment on the food mixer, fitted with a 5mm dye. The extruded noodles were laid onto aluminium trays and dried for 24 hrs in a drying oven at 40°C. The dried noodles, once removed from the trays, broke into pellets of between 3 and 6mm length. Each diet was made in 5kg lots and stored in sealed plastic bags in a refrigerated cold room at 5°C, until used.

Each cage was furnished with an equivalent amount of two artificial shelter types. The first consisted of bundles of plastic oyster mesh (Southcorp Industrial Textiles Pty Ltd) (similar to that used for onion bags) attached to rope, and secured to the pond bottom with a concrete weight. Each mesh bundle was of an equivalent size, and was

Table 4.1 ***Composition (%) of five experimental diets trialled for redclaw under earthen pond conditions. Diet 1 (Athmaize® crayfish pellet) was used as a control.***

Ingredient	Diet 2	Diet 3	Diet 4	Diet 5	Diet 6
Maize	50.2				
Wheat		50.2			
Sorghum			50.2		
Lupin				50.2	
Barley					50.2
Cottonseed Meal 38%	10	10	10	10	10
Sunflower 35%	12	12	12	12	12
Soybean 45%	10	10	10	10	10
Limestone	10	10	10	10	10
Bentonite	4	4	4	4	4
CIAL Aqua Food Binder	0.5	0.5	0.5	0.5	0.5
Feed Oil	0.1	0.1	0.1	0.1	0.1
Molasses	3	3	3	3	3
Fish Premix	0.2	0.2	0.2	0.2	0.2
TOTAL	100	100	100	100	100

made from 20 strips (1m x 100mm) of material tied together across their longitudinal centres. Due to the buoyant nature of the mesh, the bundles floated up from their anchor points, such that they simulated large, rooted macrophytes. These habitats therefore provided an abundance of edges, the benefits of which have previously been suggested (Smith and Sandifer, 1979; Jones, 1995b). Four of these mesh bundles were placed in each cage, equivalent to one per $4m^2$. The second shelter type was a fixed structure comprised of twenty-four 250mm lengths of 80mm diameter corrugated polythene agricultural pipe (brand), placed in a 3-high by 8-across stack. Steel fencing clips were applied at both ends of each pipe length where they lay against those adjacent, to hold the structure together. A 240mm x 640mm piece of rigid plastic mesh (6mm, Nylex Pty Ltd) was attached across the open ends of the pipe stack on one side, so that only one end of the pipes was accessible to crayfish. One pipe on the bottom row was filled with concrete to provide weight to ensure the shelter remained upright and on the pond floor. Four pipe stack shelters were provided to each cage.

The water level in the pond was maintained such that the depth of water in each cage was no less than 1.2m and no more than 1.6m. There was no water exchange.

Juvenile redclaw stock for this trial were harvested with a flow trap (Jones, 1994) from ponds which had been stocked 4 months previously with Flinders River

broodstock. Crayfish were chosen on the basis of their size (15 to 25 g) and condition as gauged by their robustness and possession of all limbs. Each cage was stocked with 120 juvenile redclaw (7.5 crayfish/m^2) with a mean weight of approximately 20 grams. Individual weight and sex were determined and recorded.

Table 4.2 ***Feeding schedule for forecasting feed requirements for pond trial of six diets. Actual refers to actual amounts applied.***

Week	Size (g)	Stock #	Biomass (g)	Rate (%)	Food/day dry wt(g)	Food/feed (3x / wk) per cage (g)	Actual per cage (g)
1	20.0	120.0	2400.0	3.3	79.2	185	175
2	21.5	118.8	2554.2	3.2	80.9	189	175
3	23.1	117.6	2718.3	3.0	82.7	193	180
4	24.8	116.4	2893.0	2.9	84.5	197	170
5	26.7	115.3	3078.8	2.8	86.3	201	170
6	28.7	114.1	3276.6	2.7	88.2	206	170
7	30.9	113.0	3487.2	2.6	90.1	210	175
8	33.2	111.8	3711.2	2.5	92.0	215	175
9	35.7	110.7	3949.7	2.4	94.0	219	180
10	38.3	109.6	4203.4	2.3	96.1	224	185
11	41.2	108.5	4473.5	2.2	98.1	229	185
12	44.3	107.4	4760.9	2.1	100.3	234	190
13	47.6	106.4	5066.8	2.0	102.4	239	190
14	51.2	105.3	5392.4	1.9	104.7	244	195
15	55.0	104.2	5738.8	1.9	106.9	250	200
16	59.2	103.2	6107.5	1.8	109.3	255	205
17	63.6	102.2	6499.9	1.7	111.6	260	210
18	68.4	101.2	6917.6	1.6	114.0	266	215
19	73.5	100.1	7362.0	1.6	116.5	272	220
20	79.0	99.1	7835.0	1.5	119.0	278	
21	85.0	98.1	8338.4	1.5	121.6	284	
22	91.3	97.2	8874.2	1.4	124.3	290	
23	98.2	96.2	9444.3	1.3	127.0	296	
24	105.5	95.2	10051.1	1.3	129.7	303	
25	113.5	94.3	10696.9	1.2	132.5	309	

Initial feeding rate was calculated as 3.5% of body weight per day, provided in 3 applications per week. A feeding schedule was generated (Table 4.2) which accounted for number and size of crayfish stocked, estimated growth and mortality rates, and feeding rate as a proportion of biomass. Actual feeding rate was then adjusted on the basis of observation. Food was introduced on three non-consecutive days each week between 3pm and 5pm.

The experiment was run over a 19 week period from 21/12/94 to 3/5/95. Because individual crayfish were not identifiable, growth was expressed as individual weight at

harvest minus the mean weight of each cage when stocked. Survival was expressed as the proportion of crayfish alive at harvest.

Mean growth, survival and biomass for the 6 treatments were compared with analysis of variance. Residuals were examined to determine any requirement for data transformations. In all cases residuals were uniformly distributed and no transformations were applied. Pairwise comparisons of means were made with the Least Significant Difference test.

Table 4.3 ***Proximate composition of grains used as the primary carbohydrate source in five experimental diets for redclaw.***

Grain	Name	Water	Crude Protein	Lipid	Crude Fibre	NFE	Ash	Ca	Phosphorus
Barley	*Hordeum vulgare*	12.4	10.5	1.8	5.6	67.1	2.6	0.05	0.37
Maize	*Zea mays*	12.2	9.6	3.9	2	70.8	1.5	0.02	0.28
Sorghum	*Sorghum bicolor*	11.2	10.6	3	1.9	71.4	1.9	0.08	0.27
Rice	*Oryza sativa*	11.2	8.3	1.6	9.4	65.1	4.4	0.07	0.26
Wheat	*Triticum aestivum*	12.1	12	1.7	2.5	70	1.7	0.05	0.36
Lupin	*Lupinus albus*	9.4	25.9	5.4	13.0		2.8	0.20	0.30

Table 4.4 ***Proximate analyses for experimental diets as used for feeding trial on redclaw.***

Diet	Carbohydrate source	Ash	Protein	Fat	Ca	P	Moisture
1	'commercial'	13.7	19.9	3.4	3.34	0.48	10.4
2	maize	15.9	19.1	2.6	2.29	0.45	7.0
3	wheat	15.5	22.3	1.5	2.11	0.47	6.3
4	sorghum	15.1	20.5	2.4	2.11	0.44	8.4
5	lupin	16.5	30.8	5.2	2.20	0.44	8.0
6	barley	16.3	20.6	1.5	2.16	0.43	7.0

4.3 Results

Conditions remained relatively stable and conducive to redclaw production throughout the term of the trial. Water quality data are summarised in Figure 4.2. Reasonable numbers of redclaw were harvested from each cage, with the exception of cage 4 where a split in the cage mesh facilitated the escape of most crayfish. Data from this cage were eliminated from further analysis. Summary statistics of harvest for each cage are presented in Appendix 10.3. The total quantity of food provided to each cage over the 19 week trial period was 3.565kg Analysis of variance of survival, growth and biomass increase indicated no significant variability ($p > 0.05$) between diets. Means (±SE) for these variables for each diet are presented in Figures 4.3 to 4.5. While statistical significance was not evident, there was a strong indication of superior growth for diet

1, and superior biomass increase for diet 3, that may have become more significant over a longer culture period.

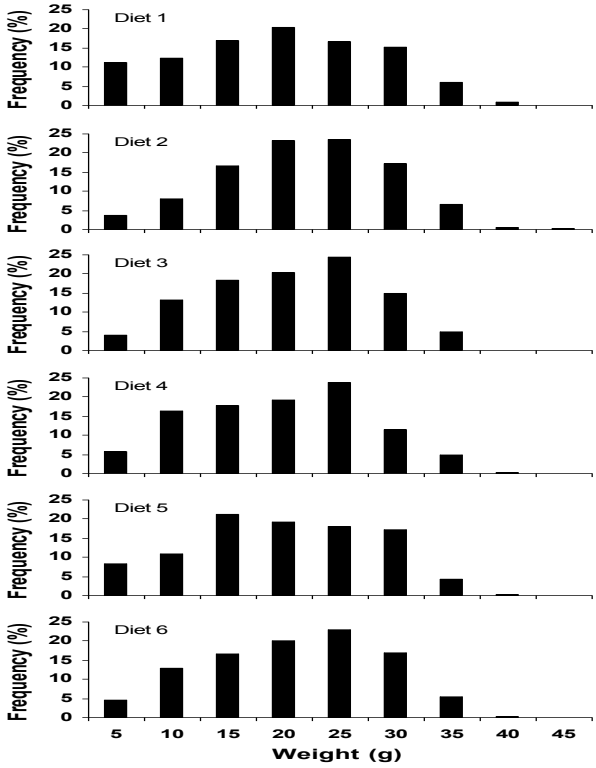


Figure 4.1 ***Size frequency distribution for crayfish at time of stocking.***

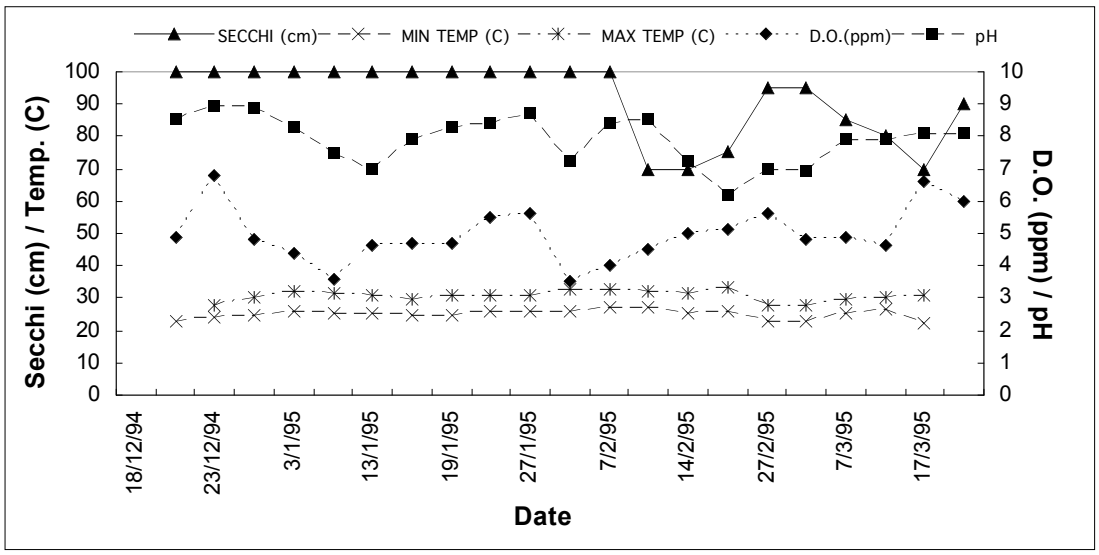


Figure 4.2 ***Summary of water quality parameters over culture period for carbohydrate assessment trial for redclaw.***

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

Analysis of variance of survival and growth factored for gender indicated no significance ($p > 0.05$) for survival between diets, but highly significant variation for growth ($p < 0.01$). Growth of males was consistently much greater than that of females as illustrated in Figure 4.6. Size frequency distributions of harvested crayfish for each diet are presented in Figure 4.7.

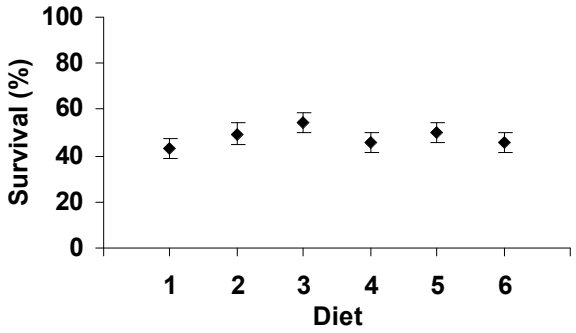


Figure 4.3 ***Mean survival (±SE) for redclaw fed six diets in an earthen pond over 5 months.***

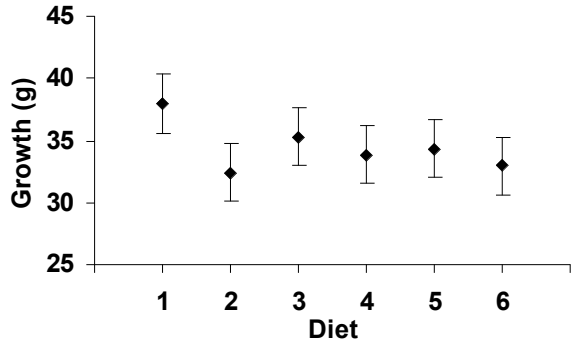


Figure 4.4 ***Mean growth (±SE) for redclaw fed six diets in an earthen pond over 5 months. Crayfish were stocked at approximately 20g.***

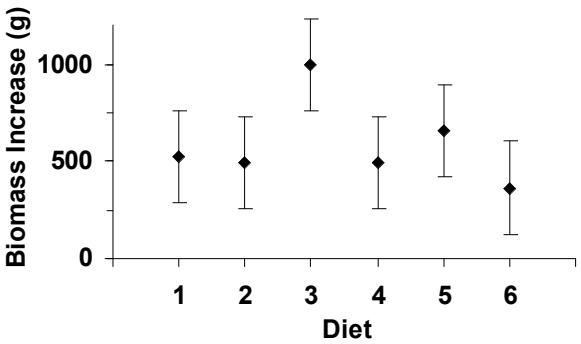


Figure 4.5 ***Mean biomass increase (±SE) for redclaw fed six diets in an earthen pond over 5 months.***

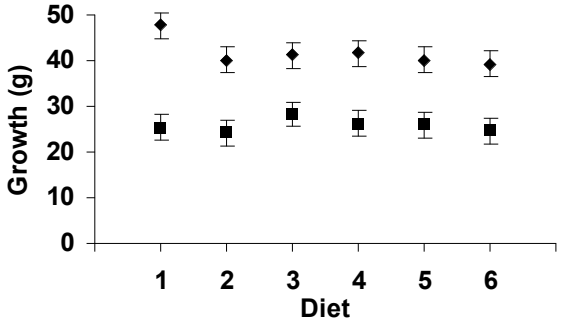


Figure 4.6 ***Mean growth (±SE) for male (diamond) and female (square) redclaw cultured in an earthen pond with six different diets.***

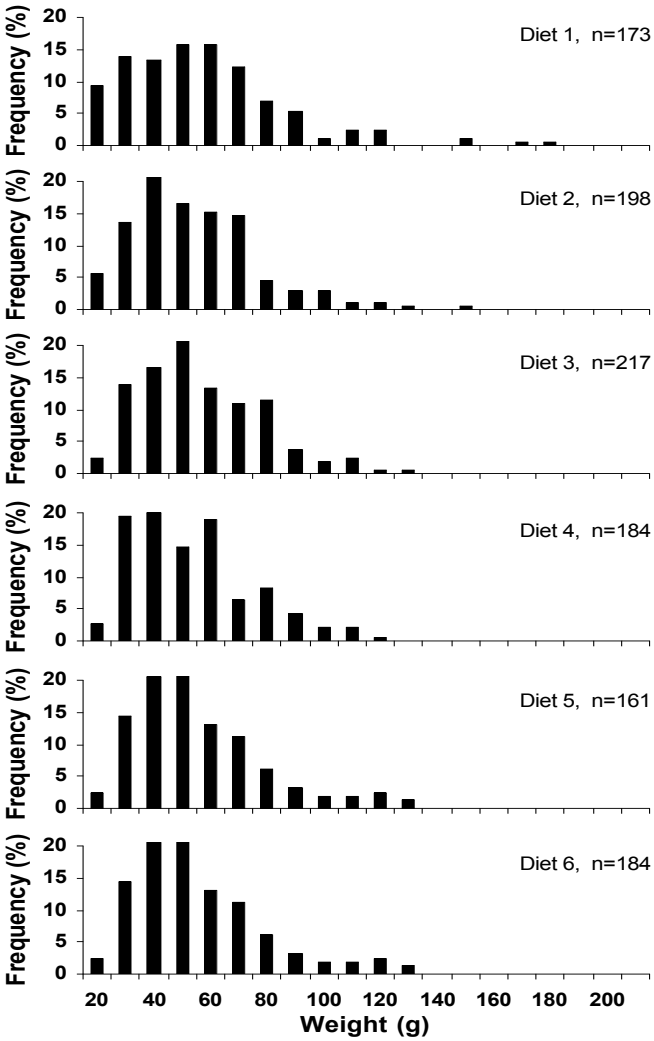


Figure 4.7 ***Size frequency distribution of redclaw at harvest after 5 months growth fed one of six diets.***

4.4 Discussion

The lack of significant differences between the six diets tested for survival and growth suggests the source of carbohydrate is not of particular importance in the nutrition of redclaw. While survival was a little lower than achieved in previous trials, growth was good and compared favourably with that of the trial conducted by Jones (1995) under identical conditions.

The superior growth of crayfish fed diet 1, the commercial Athmaize diet, while statistically not significantly different to the others, suggests that it did provide some additional benefit. Given that this diet was produced commercially in an industrial steam-press mill, it is likely that its physical and biochemical properties were fundamentally different to the experimental diets. In particular, the heat generated in industrial steam pelleting cooks the starch components rendering them more digestible to many organisms, including crayfish. The addition of hot (80°C) water to the mix for the experimental diets was an attempt to mimic the industrial process. It is likely to have had some benefit, although substantially less than that provided by industrial processing. Nevertheless, the differences between diets were small enough to suggest that these factors are of minimal importance only.

The apparent superiority of diet 3 in regard to biomass increase (Figure 4.5) is possibly a little misleading. Relatively good growth and survival for this diet in combination generated the high biomass result compared with the other diets. However statistical analysis indicates the difference was not significant.

Proximate composition of the diets (Table 4.4) suggests they were very similar with the exception of the lupin based diet (#5) which was relatively high in protein. Despite the higher protein, there was no indication of any benefit conferred. As suggested by Jones (1995) the protein level *per se* would appear not to be particularly significant.

Relative cost of the experimental feeds was not determined. On a commercial basis, the five experimental diets are not likely to differ significantly in cost. Given their relatively low protein content and similarity to the Athmaize diet, they are all likely to cost less than $500 per tonne. However, as prices for grains fluctuate widely because of climatic and commodity trade factors, this study suggests substitutions could be made with minimal impact on performance.

Results of this trial provide little guidance as to which nutritional factors would be most beneficially investigated. Previous trials by Jones (1990; 1995; Jones and Ruscoe, 1996) suggested total protein content was not especially important, particularly in view of redclaws propensity for ingesting natural food materials under earthen pond conditions. However, these trials have been based on comparisons of various commercial diets formulated for other species. With acceptable diet formulations for redclaw now identified which sustain good growth and survival, some

manipulation of protein amount, and more importantly protein composition, is justified.

Other non-nutritional factors are also likely to be of some importance. In particular, observations of redclaw in aquaria and a better understanding of the functional morphology of redclaws mouthparts (Loya-Javellana, et al., 1993a; 1993b) strongly suggest that pellet diameter may have a significant influence on the efficacy of a particular diet. Most of the diets trialled for redclaw have been in the form of relatively large (3mm diameter and above) pellets. When seized and manipulated by the mandibles and maxillipeds, a substantial proportion of the pellet is lost as it is broken up in the process of ingestion. A much narrower pellet (<3mm diameter) is likely to be more completely ingested.

Pellet stability must be considered in this context also. If a pellet is to be effectively and completely ingested, it must remain intact through the processes of handling and mouthpart manipulation. Water stability and non-brittleness (pliability) are factors. Recent studies of marron (*Cherax tenuimanus*) in Western Australia (Jussila, 1996) have demonstrated that water stability of pellets plays a significant role in diet effectiveness. Growth rate was 30% greater when fed a pellet which remained intact through 24 hours of submersion than on a nutritionally identical pellet which broke apart in water within one hour (Jussila, pers.comm.).

Attractiveness of the pellet is the third factor likely to be of some significance to the effectiveness of a diet. This may be particularly important for redclaw because of its broad omnivorousness, and its apparent non-discrimination between supplemented food and naturally occurring materials. Provision of a pellet with attractant qualities which ensure its rapid location and complete ingestion may contribute significantly to the success of a diet.

While the development of diets which contribute maximally to the colonisation of micro-organisms has been a justifiable direction for diet development for redclaw, ultimately, a complete diet which provides all the crayfishes nutritional requirements and which makes no reliance on natural food materials, will be superior. Such a diet will have to be nutritionally complete, be sufficiently attractive to ensure its rapid and complete ingestion and must result in crayfish which have maximum consumer appeal in regard to taste, texture and healthy image.

4.5 References:

Avault, J.W. and Brunson, M.W. 1990. Crawfish forage and feeding systems. Reviews in Aquatic Sciences, 3(1):1-10.

Brown, P.B. 1995. A review of nutritional research with crayfish. Journal of Shellfish

Research, 14:561-568.

Chavez, J.R. and Mitchell, B.D. 1995. The role of organic matter in semi-intensive pond production of the yabby *Cherax destructor* Clark, using detrital forage. Freshwater Crayfish, 10:435-446.

Curtis, M.C. and Jones, C.M. 1995. Overview of redclaw crayfish, *Cherax quadricarinatus*, farming practices in northern Australia. Freshwater Crayfish, 10:447-455.

D'Abramo, L.R. and Robinson, E.H. 1989. Nutrition of crayfish. Reviews in Aquatic Sciences, 1:711-728.

Jones, C.M. 1990. The Biology and Aquaculture Potential of the Tropical Freshwater Crayfish, *Cherax quadricarinatus*. Queensland Department of Primary Industries Information Series, QI90028. Queensland Department of Primary Industries, Brisbane:109p.

Jones, C.M. 1995. Evaluation of six diets fed to redclaw, *Cherax quadricarinatus* (von Martens), held in pond enclosures. Freshwater Crayfish, 10:469-479.

Jones, C.M. and Ruscoe, I. 1996. Production Technology for Redclaw Crayfish (*Cherax quadricarinatus*). Final Report FRDC Project 92/119. Fisheries Research and Development Corporation, Canberra

Jussila, J. 1996. Three an a half aspects on pellet stability and marron (*Cherax tenuimanus*) growth. In: Evans, L.H. and Whisson, G. (eds) Proceedings of the Marron Growers Association Open Seminar, May 25 1996, Perth, Australia. Marron Growers Association of Western Australia, Perth:24-28.

Lobegeiger, R. 1995. Queensland Australia, Aquaculture Information Series: Aquaculture Production Survey Queensland 1994/95. Report to Farmers. Queensland Department of Primary Industries,

Loya-Javellana, G.N., Fielder, D.R. and Thorne, M.J. 1993a. Food choice by free-living stages of the tropical freshwater crayfish, *C. quadricarinatus* (Parastacidae: Decapoda). Aquaculture, 118:299-308.

Loya-Javellana, G.N., Fielder, D.R. and Thorne, M.J. 1993b. Ontogeny of foregut in the tropical freshwater crayfish, *Cherax quadricarinatus* von Martens, 1868 (Parastacidae, Decapoda). Invertebrate Reproduction and Development, 25(1):49-58.

McClain, W.R. 1994. Dispelling some misconceptions about crawfish forages. Aquaculture Magazine, 20(6):41-45.

McClain, W.R., Neill, W.H. and Gatlin III, D.M. 1992. Partitioning the contributions of forage-based production system components to weight gain of juvenile crayfish (*Procambarus clarkii*). Aquaculture, 101:267-281.

Mitchell, B.D., Anderson, T., De Silva, S.S., Collins, R.O., Chavez, J.R., Jones, P.L. and Austin, C.M. 1995. A conceptual production model for freshwater crayfish pond culture incorporating detrital forage. Aquacult. Research, 26(2):117-128.

5. Assessment of stocking size and density in the production of redclaw crayfish, *Cherax quadricarinatus,* (von Martens) (Decapoda: Parastacidae) cultured in earthen ponds.

5.1 Introduction

The aquaculture of redclaw, *Cherax quadricarinatus*, is a relatively new industry to north-eastern Australia. Annual production is in the order of 80 tonnes (1994) from approximately 35 farms, most of which have less than two hectares of productive area. The approach taken by individual farmers varies considerably and this is reflected in significant variability in yield (i.e. tonnes per hectare). Production appears to be maximal when the cultivation of redclaw is performed in earthen ponds and the juvenile production and growout phases are managed separately. Juvenile production has been examined by Jones (1995a, b, c). For growout, juveniles of between 20mg (i.e. size at hatching) and 25g are stocked at densities of anywhere between 1 and 50 per square metre of pond surface area. As the size at stocking and density have been shown to have a significant impact on yield for a variety of aquacultured crustaceans (Allan and Maguire, 1992; Daniels and D'Abramo, 1994; Daniels, et al., 1995; Geddes et al., 1993; Lutz and Wolters, 1986; Morrissy et al., 1995), further investigation of these variables for redclaw aquaculture was considered important. To assist in identifying the stocking size and density which results in optimum yield an experiment was designed and performed under conditions typical of those of the developing redclaw aquaculture industry. Pinto and Rouse (1992) previously investigated density effects on redclaw production in ponds, however, their stocking densities were relatively low. This trial was designed to examine a more extensive range, including densities above those commonly applied by commercial aquaculturists.

5.2 Materials and Methods

The trial was conducted in cage enclosures within a 2000m^2 earthen pond at the Freshwater Fisheries and Aquaculture Research Center, Walkamin in Northern Australia (17.1°S, 145.5°E).

Cages were fabricated from a 9mm extruded plastic mesh. Each cage consisted of a box 4m by 4m by 1.8m deep with no top, or bottom. Cages were secured to the pond floor by burying the bottom margin of the mesh 300mm into the pond soil. The four corners of each cage were secured to steel poles, placed inside of the cage and driven deeply into the pond bottom. 90mm PVC pipe was attached to the top margin of each cage to prevent crayfish escape.

Each cage was furnished with an equivalent amount of two artificial shelter types. The first consisted of bundles of plastic oyster mesh (Southcorp Industrial Textiles Pty Ltd) (similar to that used for onion bags) attached to rope, and secured to the pond bottom with a concrete weight. Each mesh bundle was of an equivalent size, and was made from 20 strips (1m x 100mm) of material tied together across their longitudinal centres. Due to the buoyant nature of the mesh, the bundles floated up from their anchor points, such that they simulated large, rooted macrophytes. These habitats therefore provided an abundance of edges, the benefits of which have previously been suggested (Smith and Sandifer, 1979; Jones, 1995b). Four of these mesh bundles were placed in each cage, equivalent to one per $4m^2$. The second shelter type was a fixed structure comprised of twenty-four 250mm lengths of 80mm diameter corrugated polythene agricultural pipe (brand), placed in a 3-high by 8-across stack. Steel fencing clips were applied at both ends of each pipe length where they lay against those adjacent, to hold the structure together. A 240mm x 640mm piece of rigid plastic mesh (6mm, Nylex Pty Ltd) was attached across the open ends of the pipe stack on one side, so that only one end of the pipes was accessible to crayfish. One pipe on the bottom row was filled with concrete to provide weight to ensure the shelter remained upright and on the pond floor. Four pipe stack shelters were provided to each cage.

Each cage was equipped with a single 50mm diameter airlift pump (Jones and Curtis, 1994) to provide aeration and circulation of water. Air was injected at 0.435 kPa through a 12mm polythene pipe at a depth of 1m within the 50mm pump. Airlift pumps were operated continuously throughout the experiment.

Twenty-four cages were used to accommodate 6 treatments with 4 replicates. The treatments consisted of 3 stocking densities (3, 9 and 15 crayfish per m^2) and two stocking sizes (small stocked - 2.5 to 10.0g and large stocked - 12.5 to 20g) allocated randomly to the cages (Table 5.1). Experimental crayfish were harvested with a flowtrap (Jones and Curtis, 1994) from a pond which had been stocked 4 months previously with broodstock (Gilbert River stock). Size frequency distributions for each treatment at stocking are presented in Figure 5.1.

Table 5.1 ***Stocking details of redclaw for stocking size / density trial.***

Density (#/m^2)	Size	# per cage	Mean Wt (g)
3	small	48	4.63 ±0.17
9	small	144	4.68 ±0.12
15	small	240	4.81 ±0.16
3	large	48	16.61 ±0.38
9	large	140	17.06 ±0.42
15	large	248	17.01 ±0.38

A commercial crayfish diet (Athmaize Pty Ltd), previously established as a good redclaw food (Jones, 1995d), was used for the duration of the trial. A feeding schedule

was generated for each treatment (Table 5.2) which accounted for number and size of crayfish stocked, estimated growth and mortality rates, and feeding rate as a proportion of biomass (5 % per day for small and 3.5% per day for large). Actual feeding rate was then adjusted on the basis of observation. Food was introduced on three non-consecutive days each week between 3pm and 5pm. Actual feed amounts were recorded.

The experiment was initiated on June 21, 1994 and ran for a period of 140 days. Crayfish samples from each cage were taken using baited traps at day 56 and day 106. At final harvest on November 8, 1994, all crayfish were removed, and their sex and weight recorded.

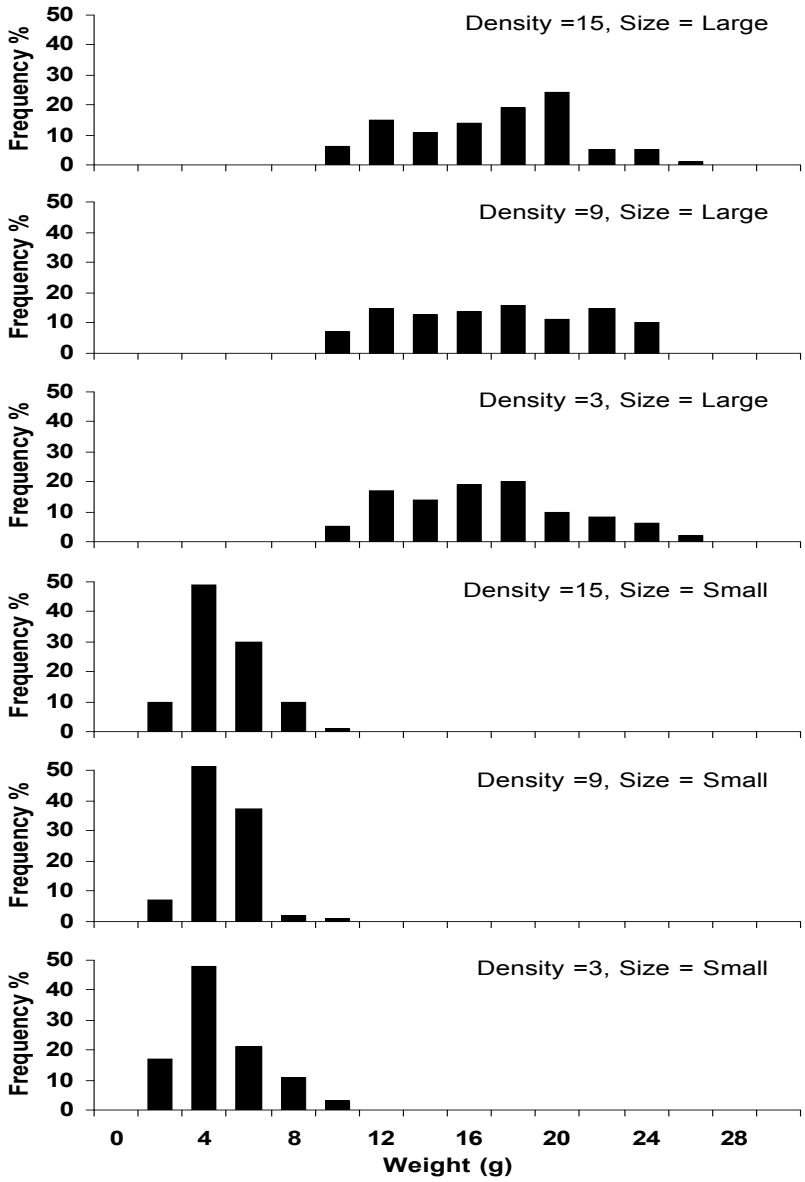


Figure 5.1 ***Size frequency distribution of redclaw at stocking to size/density trial.***

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

Table 5.2 ***Feeding schedule for stocking size/density experiment. Data presented are for density of 3/m^2 and small size. Equivalent schedules were generated for the other density and size treatments.***

Week	Size (g)	#	Biomass (g)	Feed rate (%)	Quantity per day (g)	Quantity/feed (3x /wk)	Total feed per week (g)
1	4.6	48.0	220.8	5.0	11.0	26	77
2	4.9	47.5	235.0	4.8	11.3	26	79
3	5.3	47.0	250.1	4.6	11.5	27	81
4	5.7	46.6	266.2	4.4	11.8	27	82
5	6.1	46.1	283.3	4.2	12.0	28	84
6	6.6	45.6	301.5	4.1	12.3	29	86
7	7.1	45.2	320.8	3.9	12.6	29	88
8	7.6	44.7	341.4	3.8	12.8	30	90
9	8.2	44.3	363.4	3.6	13.1	31	92
10	8.8	43.8	386.7	3.5	13.4	31	94
11	9.5	43.4	411.6	3.3	13.7	32	96
12	10.2	43.0	438.0	3.2	14.0	33	98
13	11.0	42.5	466.1	3.1	14.3	33	100
14	11.8	42.1	496.1	2.9	14.6	34	102
15	12.7	41.7	528.0	2.8	14.9	35	104
16	13.6	41.3	561.9	2.7	15.2	36	107
17	14.6	40.9	598.0	2.6	15.6	36	109
18	15.7	40.5	636.4	2.5	15.9	37	111
19	16.9	40.1	677.3	2.4	16.2	38	114
20	18.2	39.7	720.8	2.3	16.6	39	116

The pond used was initially prepared with applications of dolomite at 1,000 kg/ha, diammonium phosphate at 250 kg/ha and mulching hay at 1,000 kg/ha. Additional applications of fertilisers were applied throughout the experiment to stimulate a plankton bloom. Water was maintained at a constant depth which ranged between 1.3 and 1.8 m for all cages. New water was added only to replace evaporation and seepage. Dissolved oxygen content, pH, secchi depth and maximum and minimum temperature at the pond bottom were measured weekly.

A food quotient (FQ) was calculated to measure the efficiency of food conversion (Maguire and Leedow, 1983). Although a substantial proportion of the food consumed by redclaw may be naturally occurring microbial organisms in the benthos (Jones, 1995d, Mitchell, et al., 1995), the quantity of artificial feed provided is likely to be proportional to natural food abundance, as it provides a substrate for microbial colonisation.

FQ = Weight of supplementary feed provided / Increase in crayfish biomass

An index of economic return (after Maguire and Leedow, 1983) was also calculated to provide a suitable parameter for determining the optimal stocking size and density combination.

Economic return = Value of crop (Y_C) - Cost of original juveniles (Y_J) - Cost of feed provided (Y_F)

Cost of original juveniles Y_J was estimated to be \$0.05 for the small size (2.5 to 10.0g) and \$0.10 for the large size (12.5 to 20.0g). Cost of feed Y_F = \$0.40/kg. Because the market recognises several size grades of redclaw for which different prices are paid, the value of crop Y_C was calculated by summing the individual value of each crayfish harvested. Individual crayfish value was determined using the size dependant Price (Y_P).

Y_P (\$/kg) = 0.0983 W_F + 4.35

where W_F is the wet weight in grams of redclaw at harvest.

Data analysis was carried out using Statistix 4.0 and Excel 5.0 (Microsoft) analysis software. Homogeneity of variance was established amongst the four replicate cages allocated to each size/density treatment. It was evident that cage 22 sustained an abnormally low survival, with only 18.8% (45 from 240) of crayfish harvested. This poor survival was attributed to significant predation by water rats (*Hydromys* spp.) whose entry to the cage was facilitated by insufficient freeboard. Data for this replicate were eliminated from all analyses.

Because stocking size was one of the experimental treatments, individual harvest weight or increase in weight were not suitable variables for measuring the treatment effect. Percentage increase in mean crayfish weight and total biomass were therefore used. Before accepting analysis of variance results for percentage data (survival and weight increase), residuals were examined and found to be randomly distributed (Sokal and Rohlf, 1981).

5.3 Results

Conditions in the pond during the period of the experiment remained reasonably stable and conducive to redclaw production. Water quality data are summarised in Figure 5.2. Statistics for samples taken during the conduct of the trial are presented in Table 5.3. Mean harvest weight for each treatment is depicted in Figure 5.3.

Means (±SE) for survival, percentage increase in mean weight, percentage increase in biomass, FQ, economic return and yield are presented in Figures 5.4 to 5.9.

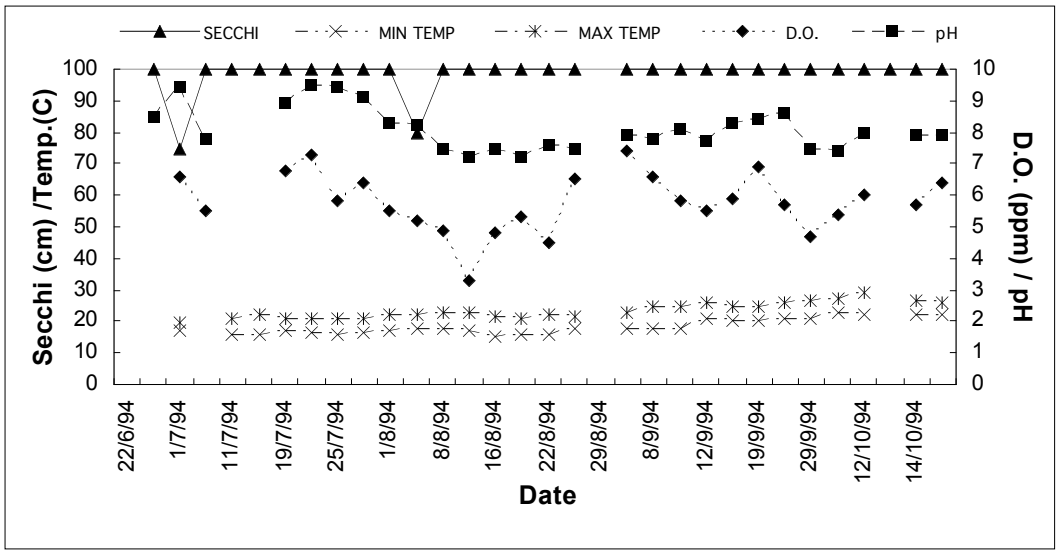


Figure 5.2 ***Summary of water quality during stocking size and density trial for redclaw.***

Table 5.3 ***Mean weight (g) (± SE) of redclaw at stocking, interim samples and harvest from stocking size / density trial.***

Stocking Density #/m^2	Stocking Size	Start Day 0		Sample Day 56		Sample Day 106		Harvest Day 140	
		Weight	n	Weight	n	Weight	n	Weight	n
3	small	4.63 ±0.17	104	8.6	1	41.9 ±3.79	6	45.15 ±1.45	147
9	small	4.68 ±0.12	102	13.78 ±1.04	20	31.66 ±1.11	51	31.44 ±0.60	453
15	small	4.81 ±0.16	100	14.49 ±0.73	35	30.28 ±0.91	86	28.19 ±0.51	649
3	large	16.61 ±0.38	101	31.18 ±1.63	21	56.48 ±4.37	17	60.55 ±1.75	168
9	large	17.06 ±0.42	101	31.1 ±1.03	31	50.13 ±1.95	52	46.28 ±0.78	479
15	large	17.01 ±0.38	100	31.07 ±0.83	67	53.47 ±1.58	41	43.89 ±0.56	805

With the exception of one cage, survival rates were high for all treatments (range 76.6 to 87.5%). There was no significant ($p > 0.05$) effect of density or stocking size on survival (Fig. 5.4).

Because survival was consistent amongst all treatments, percentage increase in mean weight and percentage increase in biomass display a similar trend. As stocking density increased, significant ($p < 0.001$) decreases in both percentage increase in mean weight and biomass occurred for both stocking sizes of crayfish (Figures 5.5 and 5.6). Both variables were significantly ($p < 0.05$) higher for large stocked crayfish than small stocked crayfish at each stocking density. There was no significant ($p > 0.05$)

interaction between stocking size and stocking density in relation to either mean weight or biomass increase.

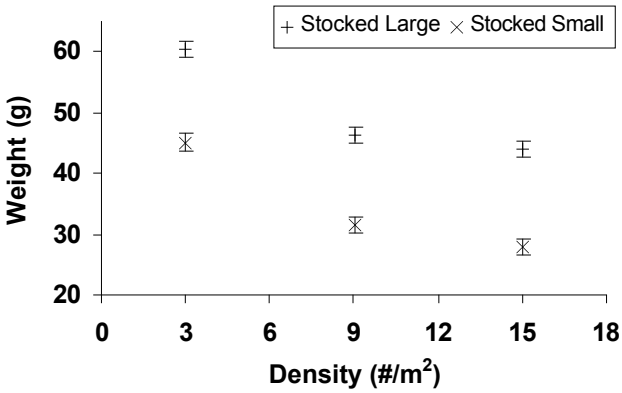


Figure 5.3 ***Mean weight (g)(±SE) at harvest of redclaw cultured over 140 days at two stocking sizes and three densities.***

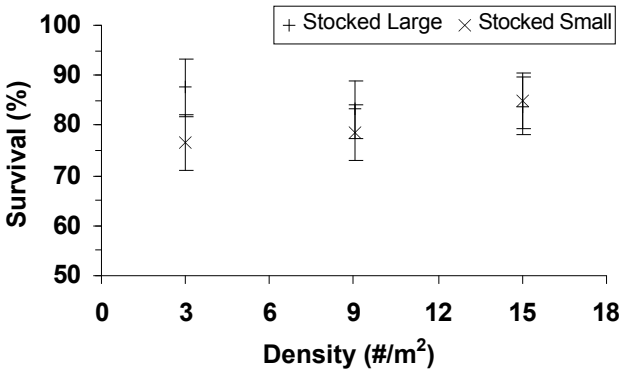


Figure 5.4 ***Survival (%)(±SE) of redclaw cultured over 140 days at two stocking sizes and three densities.***

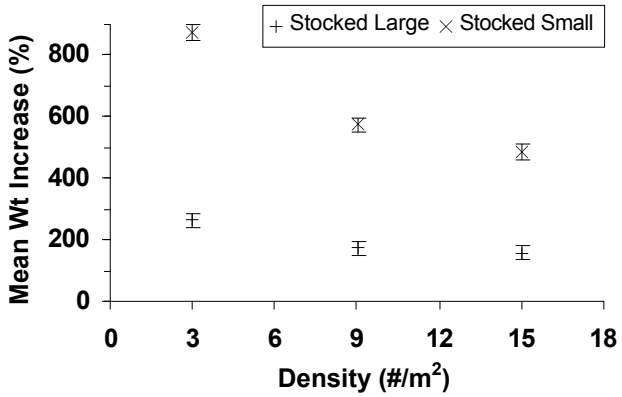


Figure 5.5 ***Mean weight increase (%)(±SE) of redclaw over 140 days at two stocking sizes and three densities.***

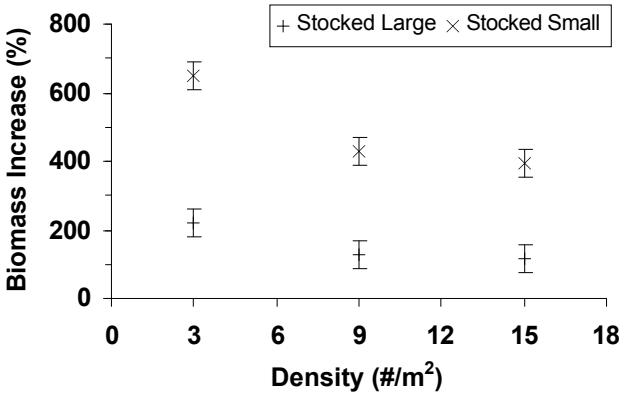


Figure 5.6 ***Mean increase in biomass (%) of redclaw over 140 days at two stocking sizes and three densities.***

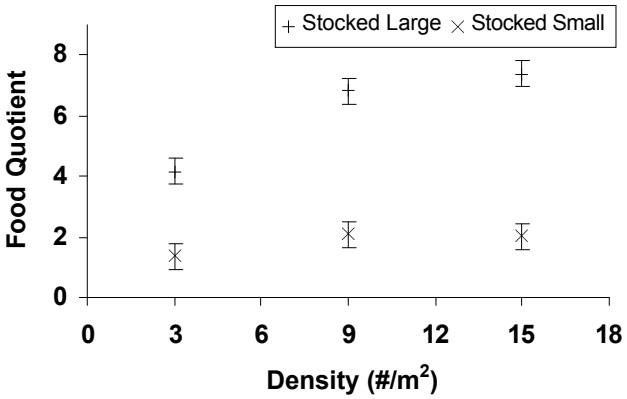


Figure 5.7 ***Mean food quotient for redclaw over 140 days at two stocking sizes and three densities.***

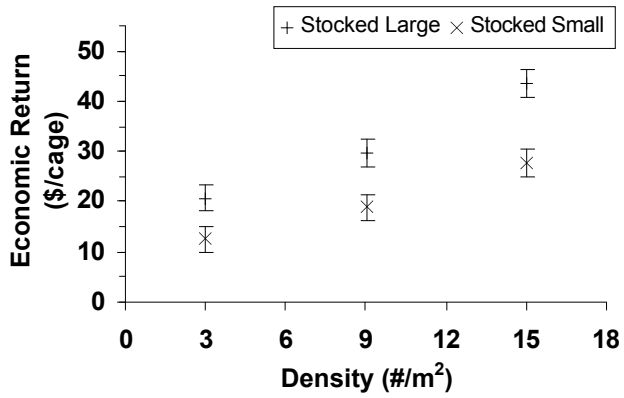


Figure 5.8 ***Mean economic return ($/cage) for redclaw cultured for 140 days at two stocking sizes and three densities.***

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

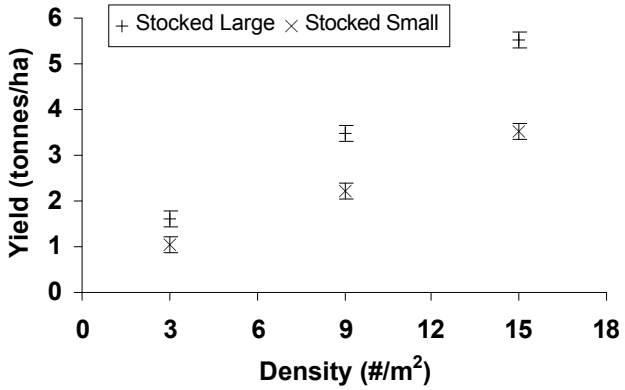


Figure 5.9 ***Mean estimated yield (t/ha)(±SE) of redclaw at two stocking sizes and three densities.***

Food Quotient (FQ) was significantly ($p < 0.001$) influenced by both stocking size and density. For each density, FQ was more than 3 times greater for large stocked crayfish than for small. For both stocking sizes, FQ increased significantly with density from 3 to 9 per m^2, but insignificantly from 9 to 15/m^2. A significant ($p = 0.002$) interaction between density and stocking size on FQ was also determined.

Similarly, economic return was significantly ($P < 0.001$) influenced by both stocking size and density, although there was no significant interactive effect. Economic return increased with increasing density and was higher for large stocked crayfish than for small (Fig. 5.8). Of the treatments applied, the large stocking size and density of 15/m^2 produced the greatest economic return of \$45.53 ± 2.56 for the 16m^2 cage. This return is equivalent to \$27,200 per hectare. The level of economic return is reflected in the yield (tonnes per hectare). Yield ranged from 1.04 to 5.52 tonnes per hectare (over 140days), increasing with increased stocking size and density (Fig. 5.9).

Size frequency distributions for each treatment are presented in Figure 5.10. They clearly demonstrate the influence of both stocking size and density on population characteristics. The decreased spread of each distribution with increasing density suggests uniformity of growth is positively correlated with density.

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

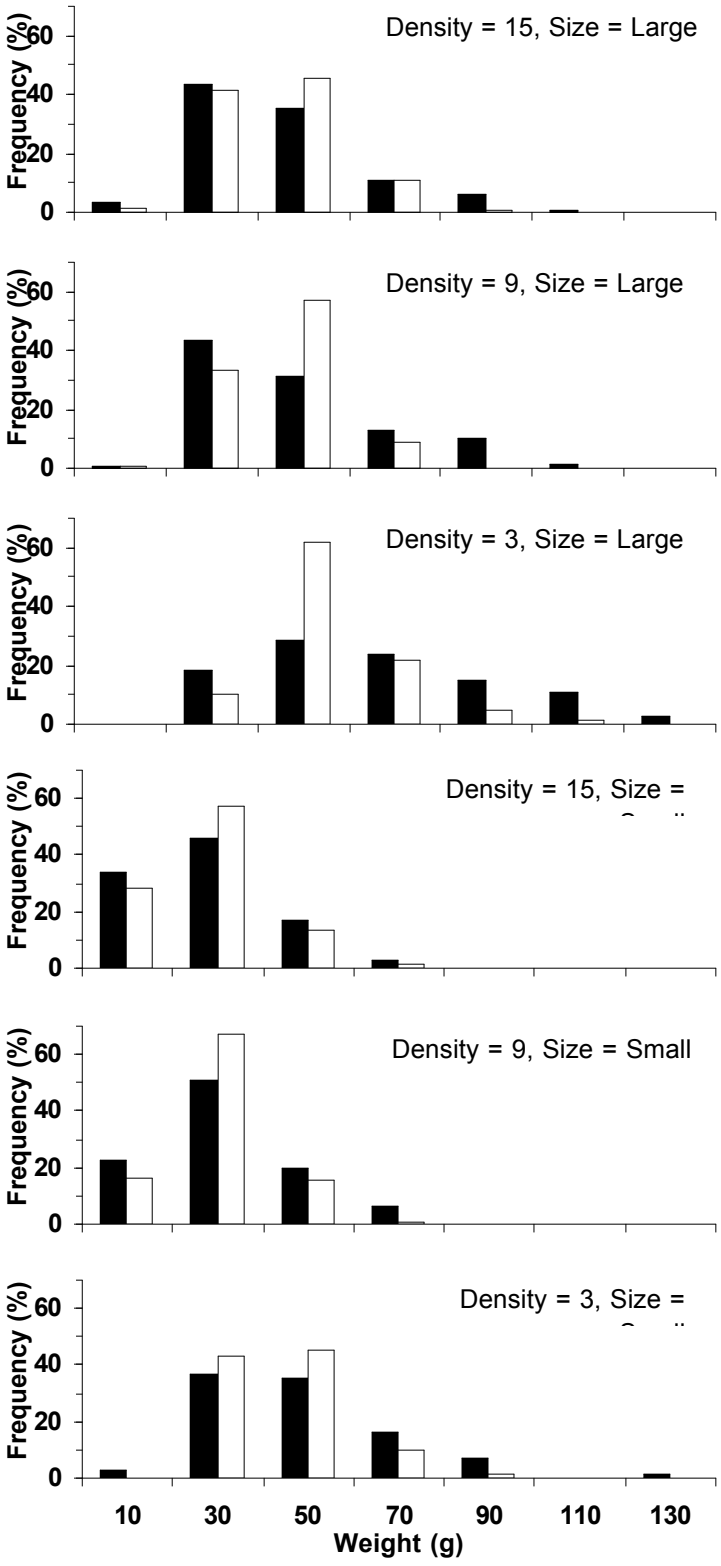


Figure 5.10 ***Size frequency distribution of redclaw at harvest after 140 days culture at two stocking sizes and three densities.***

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

5.4 Discussion

This trial demonstrated that by increasing stocking density, from 3 to 15 crayfish per square metre, and increasing stocking size from a mean of approximately 5g to 17g, individual growth declined, survival rate was unaffected and food quotient, economic return and yield increased. These results are similar to those documented for other aquacultured crayfish (Brown et al., 1995; Geddes et al., 1993; Lutz and Wolters, 1986; McClain, 1995; Mills and McCloud, 1983; Morrissy et al., 1995; Whisson, 1995).

Results of this trial were also similar to those of Pinto and Rouse (1992) who examined redclaw production characteristics at stocking densities of 1, 3 and 5 /m^2. As in this study, survival was uniformly high (73%) and mean growth rate was inversely correlated with density. Although size at stocking was a little smaller than the small (5g) size of this trial, culture periods were equivalent, and at 3/m^2, this study and that of Pinto and Rouse generated yields of 1,039 and 1,029 kg/ha respectively.

In comparison with similar studies of redclaw and other *Cherax* species, the survivals achieved in this study were exceptionally high. The most influential factor in this regard is likely to be the advanced nature (i.e. > 4g) of the juveniles stocked. Survival generally does not exceed 50% in studies where size at stocking was less than 1g (Geddes, et al., 1993; Jones, 1995c; Mills and McCloud, 1983). This is not surprising given the cannibalistic tendencies of freshwater crayfish and the increased vulnerability of very small crayfish which moult frequently. With successful methodologies now developed for the production of advanced juveniles (Jones, 1995c; Jones et al., 1996), stocking of juveniles less than 1 to 2g is inadvisable.

The decline in growth with increasing stocking density and size (Fig. 5.5) is likely to be attributable to behavioural factors and food availability. As supplementary food input in the experiment was maintained at a rate proportional to the estimated biomass, which closely approximated actual biomass, the availability of the food was reasonably constant across all treatments. However, the significant positive correlation of food quotient and density suggests that at higher densities food consumption decreased. Previous studies (Jones, 1995d) have suggested the importance of natural food in the pond production of redclaw. If the reduction in growth (mean weight increase) at the higher densities were attributable to decreased availability of natural food materials as suggested by Allan and Maguire (1992) for a penaeid, it might be expected that the relative importance of the supplementary food would have increased. The increased food quotient at higher densities does not support this contention.

Lower growth at high densities may therefore be more attributable to behavioural factors, increased interaction and antagonism, and possibly deteriorated sediment

conditions due to increased nitrogenous wastes (Chien and Lai, 1988). Although water quality conditions were clearly uniform for all treatments, localised sediment deterioration within an experimental cage was possible. Given that the experimental cages represented a small proportion of the total pond area, such factors may be of greater significance if conditions applied across the entire pond.
On this basis the efficacy of the highest stocking size and density under the experimental conditions may not be replicated under normal commercial conditions and care must be taken in extrapolating the results. While economic return at the highest density (15/m^2) was significantly greater than the lower densities, the lack of a significant difference in biomass increase between densities of 15 and 9 /m^2 suggests the higher density may be limiting. In view of the likelihood of deteriorated sediment conditions at higher densities applied across an entire pond, a maximum density for commercial aquaculture of between 9 and 15 /m^2 is recommended. With further development of formulated feeds, which more precisely satisfy the crayfishes nutritional requirements, and which generate less waste, higher densities may be sustainable.

Food quotient values for the small stocking size at all densities were economically attractive at around 2, and growth indices indicated good growth was achieved. However, the much higher values (> 4) for food quotient for the large stocking size treatments suggest over-feeding. As the feeding regime was based upon a preconceived proportion of biomass, it suggests that the rate may have been too high for the larger crayfish. These factors had little impact on economic return because the feed cost at $0.40/kg is proportionally insignificant relative to the crayfish value. Nevertheless, good economic management necessitates that costs be minimised. Furthermore, over-feeding is likely to contribute to excessive nitrogen loading and sediment deterioration. On a commercial basis, with conditions applied across the entire pond, over-feeding is also likely to contribute to deterioration of water quality.

Behavioural factors which may explain reduced growth of crayfish at higher densities can only be speculated. Redclaw has been described as a reasonably non-aggressive species for which minimum interactions occur at high densities (Jones, 1990). However, no specific investigation of behavioural interaction for redclaw has been made, and while aggression may be minimal for this species, non-aggressive interactions may still involve significant expenditure of energy and interruption to feeding. The physical environment may be of some significance to the degree and type of interactions which occur and the importance of shelter for redclaw has been clearly demonstrated (Fielder and Thorne, 1990; Thorne and Fielder, 1992; Jones and Ruscoe, 1996). Jones and Ruscoe (1996) demonstrated the significant effect that insufficient or unsuitable shelter has on survival of redclaw. Given the uniform and high survival for this trial across all treatments, shelter type and abundance is not likely to have been limiting. Mitigation of behavioural interactions which impact on growth in relation to density may be beyond the scope of environmental or food/feeding conditions and manipulations. Such interactive behaviour is intrinsically programmed and not easily

modified. An avenue which may provide scope for modification would be genetic selection, although such an approach would seem unjustified at present when economically acceptable yields are achievable.

Impacts of density on the size distribution and population structure have been described for *Macrobrachium rosenbergii* (Karplus et al., 1986). Similarly, this study revealed clear density effects (Fig.5.10). Variability of growth appeared to decrease with increasing density, suggesting that the establishment of size dominance heirachies may be facilitated at lower densities. From a commercial perspective, uniformity of growth is desirable to maximise the consistency of product for markets. Higher densities may not only provide greater yields, but more marketable product. The size distribution also revealed the relatively greater proportion of males in the larger size classes, although there was no indication of a density effect on this characteristic.

Results of this trial provide instructive information in regard to stocking practices for redclaw, to maximise economic return for a given pond area. However, further examination and elucidation of best practice is required. In particular, factors including uniformity of stocking size, feeding rates and availability of shelter should be considered.

This trial has clearly demonstrated that relatively high yields in excess of 3 tonnes per hectare are achievable for redclaw. A key to generating such yields would appear to be the practice of stocking advanced juveniles of a uniform size above 5g, and at densities of between 9 and 15 per square metre.

5.5 References

Allan, G.L. and Maguire, G.B. 1992. Effects of stocking density on production of *Penaeus monodon* Fabricius in model farming ponds. Aquaculture, 107(1):49-66.

Brown, P.B., Wilson, K.A., Wetzel II, J.E. and Hoene, B. 1995. Increased densities result in reduced weight gain in *Orconectes virilis*. Journal of the World Aquaculture Society, 26:165-171.

Chien, Y.H. and Lai, H.T. 1988. The effects of aged sediment and stocking densities on freshwater prawn *Macrobrachium rosenbergii* culture. Journal of the World Aquaculture Society, 19(1):22A-23A.

Daniels, W.H. and D'Abramo, L.R. 1994. Pond production and characteristics of freshwater prawns *Macrobrachium rosenbergii* as influenced by the stocking of size-graded populations of juveniles. Aquaculture, 122(1):33-45.

Daniels, W.H., D'Abramo, L.R., Fondren, M.W. and Durant, M.D. 1995. Effects of

stocking density and feed on pond production characteristics and revenue of harvested freshwater prawns *Macrobrachium rosenbergii* stocked as size-graded juveniles. Journal of the World Aquaculture Society, 26(1):38-47.

Fielder, D.R. and Thorne, M.J. 1990. Are shelters really necessary? In: Macreadie, M. (ed) Australian Fisheries: Aquaculture Special: Redclaw. Australian Government Publishing Service, Canberra, Vol.49(11):26-28.

Geddes, M.C., Smallridge, M. and Clark, S. 1993. The effect of stocking density, food type and shelters on survival and growth of the Australian freshwater crayfish, *Cherax destructor*, in experimental ponds. Freshwater Crayfish, 9:57-69.

Jones, C.M. 1990. The Biology and Aquaculture Potential of the Tropical Freshwater Crayfish, *Cherax quadricarinatus*. Information Series, QI90028. Queensland Department of Primary Industries, Brisbane. 109pp.

Jones, C.M. 1995a. Evaluation of six diets fed to redclaw, *Cherax quadricarinatus* (von Martens), held in pond enclosures. Freshwater Crayfish, 10:469-479.

Jones, C.M. 1995b. Production of juvenile redclaw crayfish, *Cherax quadricarinatus* (von Martens)(Decapoda, Parastacidae) I. Development of hatchery and nursery procedures. Aquaculture, 138(1995):221-238.

Jones, C.M. 1995c. Production of juvenile redclaw crayfish, *Cherax quadricarinatus* (von Martens)(Decapoda, Parastacidae) II. Juvenile nutrition and habitat. Aquaculture, 138(1995):239-245.

Jones, C.M. 1995d. Production of juvenile redclaw crayfish, *Cherax quadricarinatus* (von Martens)(Decapoda, Parastacidae) III. Managed pond production trials. Aquaculture, 138(1995):247-255.

Jones, C.M. and Curtis, M.C. eds 1994. Redclaw Farming. Proceedings of the Redclaw Farming Workshops, Feb.12-17, 1994, Walkamin, Rockhampton, Nambour. Queensland Department of Primary Industries.

Jones, C.M. and Ruscoe, I. 1996. Production Technology for Redclaw Crayfish (*Cherax quadricarinatus*). Final Report FRDC Project 92/119. Fisheries Research and Development Corporation, Canberra

Jones, C.M., Ruscoe, I. and Grady, J. 1996. Production of juvenile redclaw (*Cherax quadricarinatus*) at two demonstration sites in north Queensland. Freshwater Farmer (Australia), 4(1):12-13.

Karplus, I., Hulata, G., Wohlfarth, G.W. and Halevy, A. 1986. The effect of density

of *Macrobrachium rosenbergii* raised in earthern ponds on their population structure and weight distribution. Aquaculture, 52:307-320.

Lutz, C.G. and Wolters, W.R. 1986. The effect of five stocking densities on growth and yield of red swamp crawfish *Procambarus clarkii*. Journal of the World Aquaculture Society, 17(1-4):33-36.

Maguire, G.B. and Leedow, M.I. 1983. A study of optimum stocking density and feed rate for school prawns *Metapenaeus macleayi* (Haswell) in some Australian brackish water farming ponds. Aquaculture, 30:285-297.

McClain, W.R. 1995. Investigations of crayfish density and supplemental feeding as factors influencing growth and production of *Procambarus clarkii*. Freshwater Crayfish, 10:512-520.

Mills, B.J. and McCloud, P.I. 1983. Effects of stocking and feeding rates on experimental pond production of the crayfish *Cherax destructor* Clark (Decapoda:Parastacidae). Aquaculture, 34:51-72.

Mitchell, B.D., Anderson, T., De Silva, S.S., Collins, R.O., Chavez, J.R., Jones, P.L. and Austin, C.M. 1995. A conceptual production model for freshwater crayfish pond culture incorporating detrital forage. Aquaculture Research, 26(2):117-128.

Morrissy, N.M., Bird, C. and Cassells, G. 1995. Density-dependent growth of cultured marron, *Cherax tenuimaus* (Smith 1912). Freshwater Crayfish, 10:560-568.

Pinto, G.F. and Rouse, D.B. 1992. Growth and survival of Australian red claw crayfish in earthern ponds at three densities. In: Abstracts, Aquaculture '92 - World Aquaculture Society Annual Conference, Orlando, FL, USA, May 21-25, 1992. World Aquaculture Society.

Smith, T.I.J. and Sandifer, P.A. 1979. Observations on the behavior of the Malaysian prawn, *Macrobrachium rosenbergii* (de Man), to artificial habitats. Marine Behaviour and Physiology, 6:131-146.

Sokal, R.R. and Rohlf, F.J. 1981. Biometry. The Principles and Practice of Statistics in Biological Research. Second Edition. W.H. Freeman and Co., San Francisco.

Thorne, M. and Fielder, D. 1992. Benefits from the provision of pond shelters in production of redclaw crayfish *Cherax quadricarinatus*. In: Abstracts of papers presented at the 9th IAA Symposium, Reading University, England, April 5-10, 1992. International Association of Astacology, Reading, England.

Whisson, G.J. 1995. Growth and survival as a function of density for marron *(Cherax tenuimanus* (Smith)) stocked in a recirculating system. Freshwater Crayfish, 10:630-637

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

6. Assessment of five shelter types in the production of redclaw crayfish *Cherax quadricarinatus,* (von Martens) (Decapoda: Parastacidae) cultured in earthen ponds.

6.1 Introduction

Aquaculture of redclaw crayfish, *Cherax quadricarinatus*, is a relatively new industry to north-eastern Australia poised for substantial expansion. Government survey results indicate an increase in redclaw production in the State of Queensland from 32 tonnes in 1993/94 to 60 tonnes in 1994/95. Average farm yield increased from 680kg/ha to 1,046kg/ha over the same period (Lobegeiger, 1995). Production for the year 2000 is projected to be in excess of 200 tonnes. The approach taken by farmers varies considerably, ranging from simple harvesting of unmanaged farm dam populations of crayfish to semi-intensively managed aquaculture ponds. Well managed redclaw farms are now achieving yields in excess of 2,000kg/ha/yr and are characterised by consistencies in the approach taken and the pond environment provided. One factor in particular which appears to be of fundamental importance in maximising yields of redclaw is the provision of shelter.

The natural habitat of redclaw generally consists of permanent water-holes in the upper reaches of rivers, with static or slow water flow. Where crayfish abundance is relatively high, there is usually an abundance of fallen timber in the water, which has been washed downstream during flood, or which has fallen directly from the heavily vegetated banks. In addition or alternatively, dense beds of macrophytes may occur where redclaw abundance is high. The correlation of redclaw abundance and the physically complex environment afforded by the fallen timber or macrophytes suggests that redclaw require shelter.

It is clear that the bulk of freshwater crayfish species do require some form of shelter (Hogger, 1988). Many species satisfy this demand by burrowing into the soil substrate where they live, sometimes forming very intricate burrows (Horwitz and Richardson, 1986; Hogger, 1988) from which they rarely, or only seasonally emerge, eg. *Procambarus clarkii* (Huner and Barr, 1984). Other non-burrowing species will utilise rocks, gravel or vegetation to obtain shelter (Mason, 1978; Hogger, 1988; Foster, 1993). It has been suggested that these habitat preferences provide shelter for the crayfish during periods of vulnerability when moulting, protect against predation and minimise aggressive interactions.

Previous studies of redclaw have indicated the importance of shelter for early stage juveniles (Du Boulay, 1993; Jones, 1995a; 1995b; Karplus et al., 1995). These studies demonstrated that redclaw are able to discriminate between different shelter types and display clear preferences.

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

Most redclaw farmers provide some form of shelter in their ponds, however there is no consensus as to the amount or type of shelter which is most effective. Greatest consideration is given to the cost, and this explains the widespread popularity of discarded car tyres as a redclaw shelter. In most instances, used tyres will be delivered to a farm at no cost. Increasingly strict government guidelines for the disposal of tyres have favoured their use on crayfish farms which are seen as a substantial and legitimate consumer of this resource. However, if environmental authorities choose to disallow this usage or to demand their removal, redclaw farmers may be faced with a significant financial burden. Moreover, the adequacy of tyres as a redclaw shelter has not been formally assessed.

It is also common for redclaw farmers to use bundles of onion bags or similar mesh material as crayfish shelters, particularly for juveniles (Fielder, and Thorne, 1990; Jones, 1990). Material is bunched together and weighted to the bottom. Less common, are off-cuts of pipe, corrugated fibre-board sheet, plastic sheeting, discarded fishing nets, bamboo pieces, or mounds of fallen timber.

As the redclaw aquaculture industry progresses, it will be important to have a better definition of suitable shelter specifications. Ultimately, it should be possible to design an artificial shelter with characteristics which maximise its use by redclaw.

To assist in defining the ideal shelter, with a view to providing specifications that a manufacturer could use to mass-produce it at a cost-effective price, an experiment was designed to assess the relative performance of several shelter types under conditions typically used for the pond production of redclaw.

6.2 Materials and Methods

The trial was conducted in cage enclosures within a 2000m^2 earthen pond at the Freshwater Fisheries and Aquaculture Research Center, Walkamin in Northern Australia (17.1°S, 145.5°E) over a 162 day period June 22 to December 1, 1995.

Cages were fabricated from a 9mm extruded plastic mesh. Each cage consisted of a box 4m x 4m x 1.8m high with no top or bottom. Cages were secured to the pond floor by burying the bottom margin of the cage approximately 300mm into the pond soil. The four corners of the cages were secured to steel poles, placed inside the corners and driven deeply into the pond bottom. Ninety millimetre PVC pipe was attached to the top margin of each cage to prevent crayfish escape.

The pond was prepared with applications of dolomite at the rate of 1,000kg/ha, di-ammonium phosphate at 250kg/ha and mulching hay at 1,000kg/ha. Additional applications of fertilisers were used throughout the experiment to maintain a plankton

bloom. Water was maintained at a constant depth of between1.3m and 1.8m for all cages. New water was added only to match losses due to evaporation and seepage. Dissolved oxygen, pH, secchi depth and maximum and minimum temperatures at the pond bottom were measured twice per week.

Each cage was furnished with a single 100mm diameter PVC airlift pump (Jones and Curtis, 1994) to provide aeration and water circulation. Air was injected at 0.435kPa through a perforated 12mm polythene pipe at a depth of 1 metre within the 100mm pipe. Airlift pumps were operated continuously throughout the experiment.

Twenty-four cages were used to accommodate 6 treatments with 4 replicates, arranged in a randomised block design. The treatments consisted of a control for which no shelter was provided and 5 artificial shelter types (Table 6.1). Juvenile redclaw stock for this trial were harvested with a flow trap (Jones and Curtis, 1994) from ponds which had been stocked 4 months previously with Flinders River broodstock. Each cage was stocked with 200 juvenile redclaw (12.5 crayfish/m^2) with a mean weight of approximately 15 grams. A sample of 50 crayfish allocated to each cage were individually weighed. Size frequency distributions at stocking for each treatment are presented in Figure 6.1.

Shelters used for this trial were chosen on the basis of those commonly used by redclaw farmers, and to maximise the variability in specifications and characteristics of the habitat. Having chosen five shelter types, consideration was given to their volume, surface area and how they may be used by redclaw, in determining the appropriate number of each habitat per cage. The quantity used was considered surplus to the minimum requirements of the stocking density applied. Shelter types are described in Table 6.1. Photographs of each shelter type are presented in Appendix 10.5.2.

A commercial crayfish diet (Athmaize crayfish pellet), previously established as a good redclaw food was provided 3 times per week at dusk. Feeding was based on a schedule accounting for stocking size and number of crayfish, estimated growth and mortality and percentage of biomass, initially calculated at 5% per day. Feeding was then adjusted according to observations for under or excess feeding.

Because individual crayfish were not identifiable, growth was expressed as individual weight at harvest minus the mean weight of each cage when stocked. Survival was expressed as the proportion of crayfish alive at harvest. Biomass represented the total weight of crayfish harvested for each cage.

Mean harvest weight, mean growth, survival and biomass for the 6 treatments were compared with analysis of variance. The proportion of berried females in each cage was also examined. Residuals were examined to determine any requirement for data transformations. Growth data were log transformed prior to analysis. Pairwise comparisons of means were made with the Least Significant Difference test. Analyses were performed using Statistix 4.0 and Microsoft Excel 7.0.

Table 6.1 ***Description of shelter types as assessed for redclaw. Photographs of each are presented in Appendix 10.5.2.***

	Shelter Type	Description	Quantity
1	Control	no shelter	
2	Tyres	14 inch diameter car tyres, arranged in rows of three. The first tyre lay flat on the substrate with the remaining two propped up on an angle of about 30°. A hole (minimum diameter 50mm) was cut in both walls of each tyre, diametrically opposed, to facilitate drainage of water when draining the pond, and to prevent the capture of air when the pond was filled	Four rows of three tyres were provided per cage equivalent to 3 tyres per four square metres
3	Mesh Bundles	Made from strips of oyster shade material (Southcorp Industrial Textiles Pty Ltd.), a light-weight open weave mesh similar to that used for onion bags. Each bundle was attached to a rope which was weighted at one end, with a float at the other. All bundles were of an equivalent size and were made from 12 strips of material (1m x 10cm lengths) tied on their longitudinal centres to the main rope. Because of the buoyant nature of the material used, this shelter simulated a large rooted macrophyte and provided an abundance of edges, the benefits of which have previously been suggested (Smith and Sandifer, 1979; Jones, 1995a).	Eight mesh bundles were provided per cage, equivalent to one shelter per two square metres
4	Elevated Sheets	Each consisted of two flat sheets of synthetic fibre board, 300mm x 300mm x 5mm attached together to two pairs of 300mm length, 50mm polythene pipe. Similar structures have been shown to provide shelter for the spiny lobster Panulirus argus (Eggleston et al., 1990).	Sixteen of these shelters were placed equidistant from each other on the pond floor (per cage), equivalent to one per square metre.
5	Flat Sheets	A single sheet of synthetic fibre board, 300mm x 300mm x 5mm, was placed directly on the substrate.	Sixteen of these shelters were placed equidistant from each other on the pond floor (per cage), equivalent to one per square metre.
6	Pipe Stack	A fixed structure consisting of twenty-four 250mm lengths of 80mm diameter corrugated polythene pipe, placed in a stack 3 high by 8 wide. Steel fencing clips were used to secure each pipe to adjacent pipes. A 240mm x 640mm piece of rigid plastic mesh was attached to one side of the structure so that crayfish access was from one end only. One pipe on the bottom row was filled with concrete to facilitate sinking and to ensure that the habitat remained upright throughout the experiment.	Eight of these shelters were provided per cage, equivalent to one unit per two square metres.

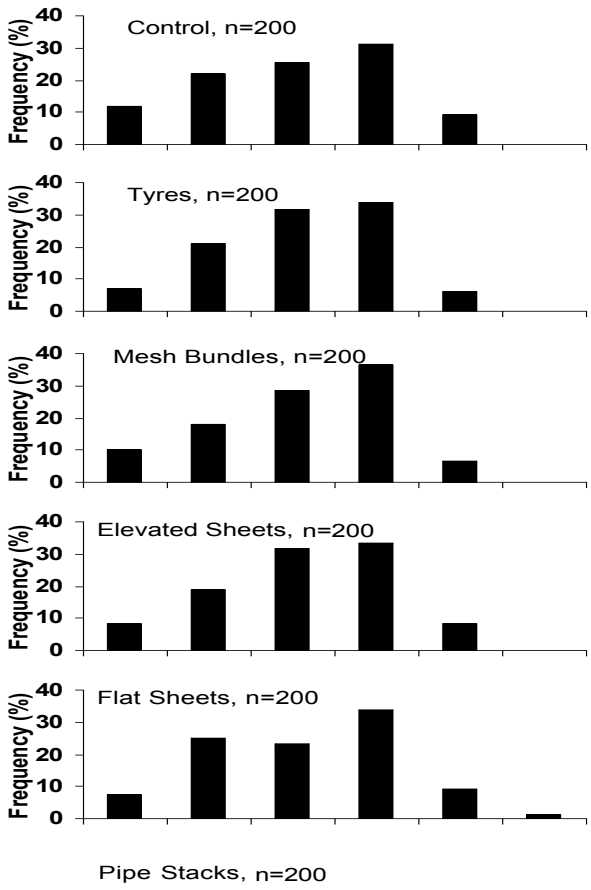


Figure 6.1 ***Size frequency distribution of redclaw at stocking to shelter experiment.***

6.3 Results

Conditions in the pond remained relatively stable and suitable to the cultivation of redclaw throughout the experimental period. Water quality data are summarised in Figure 6.2.

Reasonable numbers of crayfish were harvested from each cage. A summary of harvest statistics including mean weight and survival for each treatment is presented in Table 6.2. Harvest statistics for each cage are presented in Appendix 10.5.1.

While growth of crayfish was not significantly different ($p > 0.05$) among the shelter types, survival was ($p < 0.01$). As a consequence, biomass was also significantly different between shelter types ($p < 0.01$). Mean growth for each shelter type is

illustrated in Figure 6.3. Data are also presented for crayfish which escaped from cages during the experimental period and were collected from the pond at harvest.

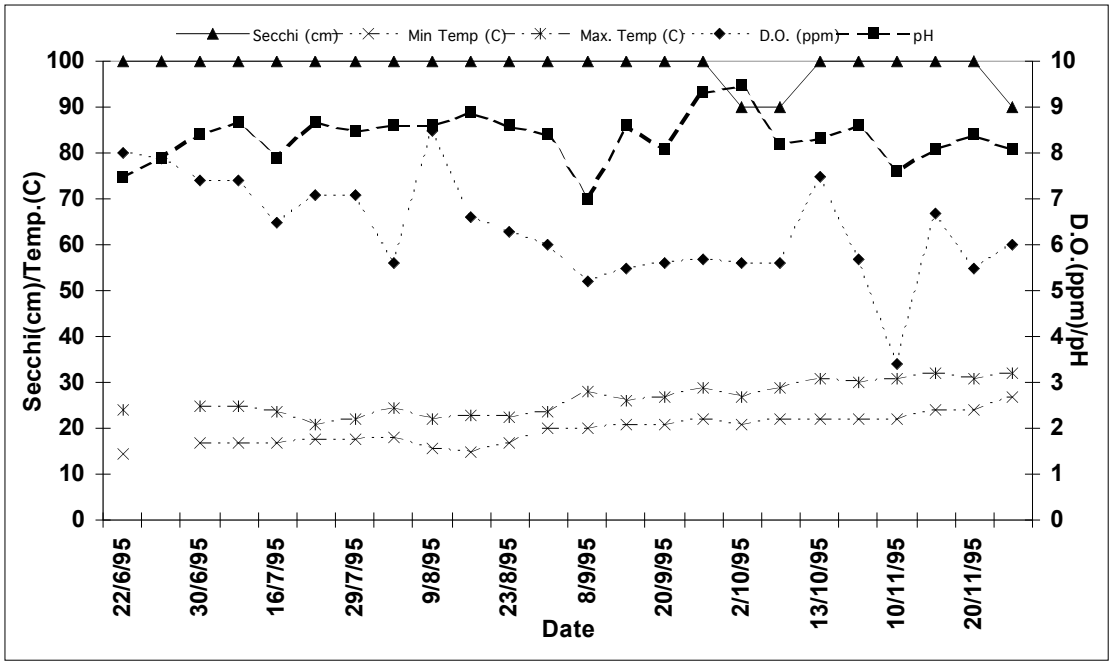


Figure 6.2 ***Summary of water quality data for the experimental period.***

Means for survival and biomass for each shelter type are depicted in Figure 6.4 and Figure 6.5. They show the clear variability between treatments, and the significant advantage conferred by the mesh bundle shelter. Tyres and pipe stacks were moderately successful as shelters, but elevated sheets and flat sheets were clearly deficient. Means comparisons for survival and biomass as derived from analysis of variance are presented in Tables 6.3 and 6.4.

A comparison of the population structure at harvest, for each shelter type is illustrated in Figure 6.6. Frequency of each 10g size class is shown as a percentage of the total (4 replicates pooled) number harvested. Note that the total number for each shelter type varied significantly as indicated by the n value appended to each size frequency distribution.

Analysis of variance of harvest weight for each gender indicated that males were significantly ($p < 0.01$) heavier than females at harvest. Mean harvest weight for each sex is shown in Figure 6.7.

Many of the females harvested were berried. To examine the influence of shelter on the proportion of females bearing eggs, an analysis of variance was performed. While

no significant variability ($p > 0.05$) was detected, Figure 6.8 indicates differences were apparent.

Table 6.2 ***Summary statistics at harvest for redclaw cultured with five different shelter types. Escape represents crayfish found outside the experimental cages at harvest.***

	Control (none)	Tyres	Mesh Bundles	Elevated Sheets	Flat Sheets	Pipe Stacks	Escape
Mean weight males (g)	35.5	40.3	30.9	40.0	34.9	38.6	32.0
Mean weight females (g)	28.6	29.4	29.2	29.8	29.2	28.8	25.5
Mean survival (%)	21.8	51.4	75.1	20.8	17.5	43.3	-
Berried females (%)	18.3	33.5	29.5	34.5	38.3	36.8	-

Table 6.3 ***Mean survival (%) of redclaw at harvest after 162 days cultivation with one of five shelter types. Means underscored by the same line are not significantly different ($p > 0.05$).***

	Shelter Type					
	Mesh Bundle	Tyres	Pipe Stacks	Elevated Sheets	Flat Sheets	Control
Mean	75.1	51.4	43.3	20.8	17.5	15.1

Table 6.4 ***Mean biomass (kg per cage) of redclaw at harvest after 162 days cultivation with one of five shelter types. Means underscored by the same line are not significantly different ($p > 0.05$).***

	Shelter Type					
	Mesh Bundle	Tyres	Pipe Stacks	Elevated Sheets	Flat Sheets	Control
Mean	4.51	3.54	2.90	1.44	1.10	0.96

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

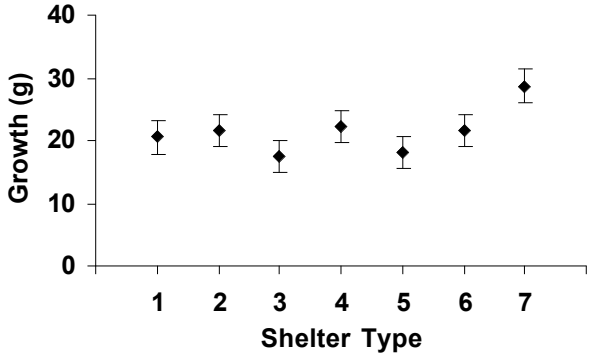


Figure 6.3 ***Mean growth (±SE) of redclaw cultured in an earthen pond and provided with one of five shelter types. 1, control (no shelter); 2, tyres; 3, mesh bundles; 4, elevated sheets; 5, flat sheets; 6, pipe stacks. 7 represents data for escaped crayfish found outside the experimental cages at harvest.***

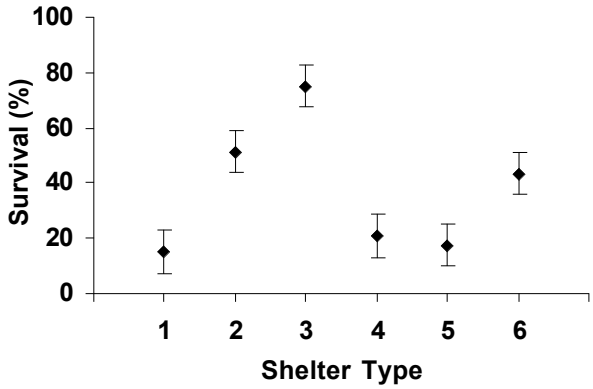


Figure 6.4 ***Mean survival (±SE) of redclaw cultured in an earthen pond and provided with one of five shelter types. 1, control (no shelter); 2, tyres; 3, mesh bundles; 4, elevated sheets; 5, flat sheets; 6, pipe stacks.***

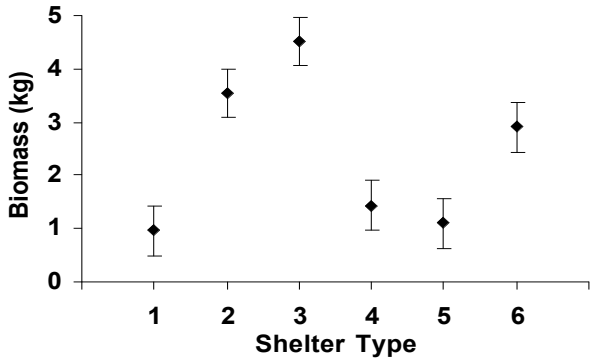


Figure 6.5 ***Mean biomass (±SE) of redclaw per 16m^2 experimental cage at harvest after 162 days cultured in an earthen pond and provided with one of five shelter types. 1, control (no shelter); 2, tyres; 3, mesh bundles; 4, elevated sheets; 5, flat sheets; 6, pipe stacks.***

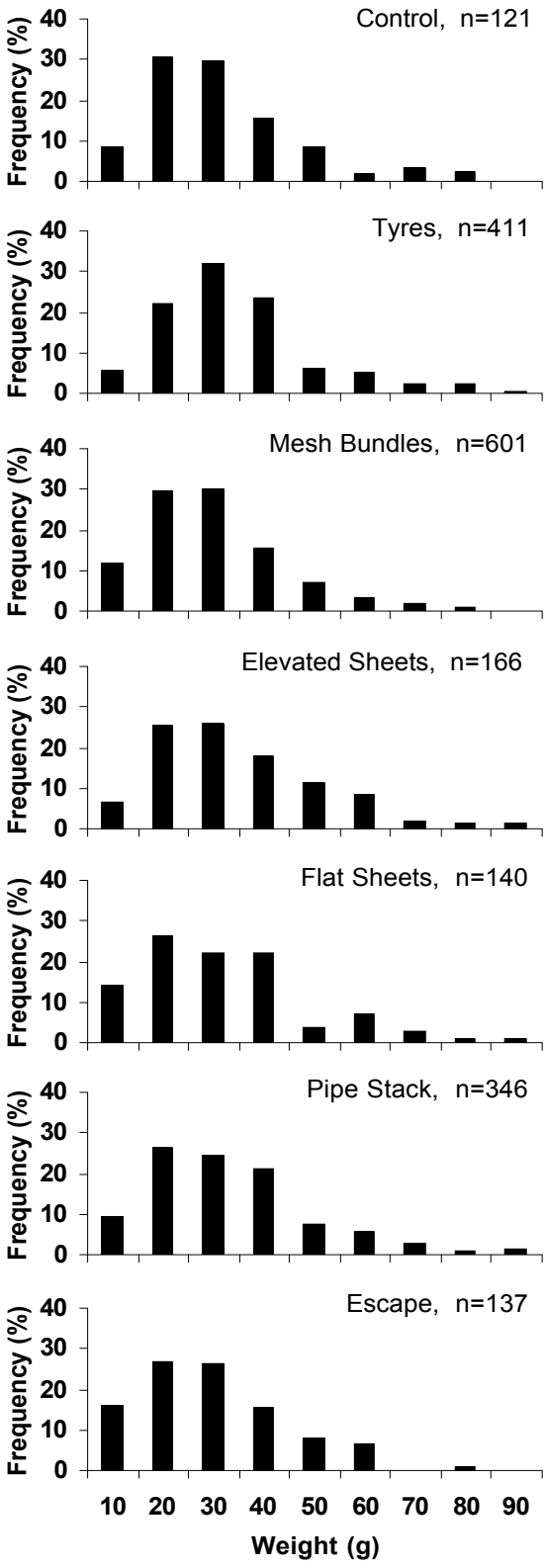


Figure 6.6 ***Size frequency distribution of redclaw at harvest after 162 days culture in an earthen pond and provided with one of five shelter types. Escape represents crayfish found outside the experimental cages at harvest.***

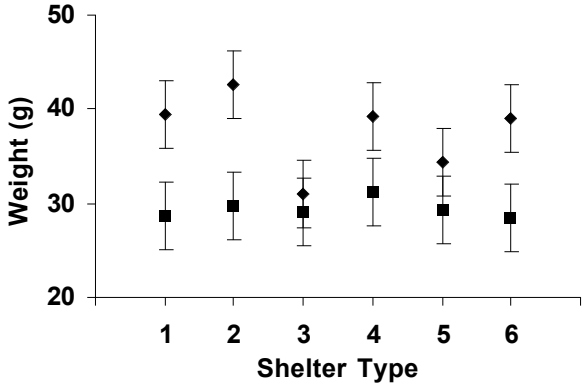


Figure 6.7 ***Mean weight (g) (±SE) of redclaw at harvest after 162 days and provided with one of five shelter types. Male (diamond) and female (square) data shown separately. 1, control (no shelter); 2, tyres; 3, mesh bundles; 4, elevated sheets; 5, flat sheets; 6, pipe stacks.***

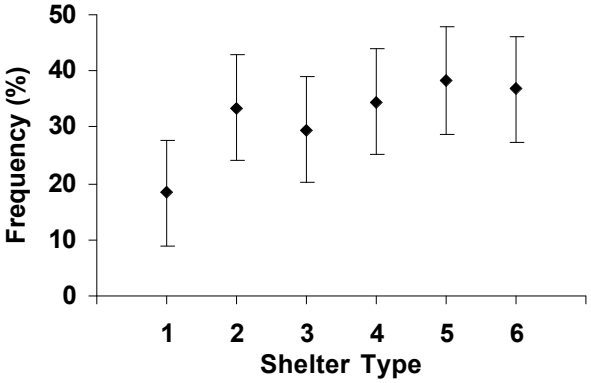


Figure 6.8 ***Mean frequency (%) (±SE) of berried female redclaw at harvest after 162 days and provided with one of five shelter types. 1, control (no shelter); 2, tyres; 3, mesh bundles; 4, elevated sheets; 5, flat sheets; 6, pipe stacks.***

6.4 Discussion

Provision of shelter and type of shelter have a significant influence on the production of redclaw in earthen ponds. Results showed very clearly that when no shelter was provided, production was severely curtailed, primarily because of decreased survival (Figure 6.4). Differences between shelter types were also significant with regard to survival. Mean individual growth for each treatment did not vary significantly. However, when multiplied by the number of crayfish to generate biomass estimates, clear differences were apparent.

The dependence of survival and independence of growth in relation to shelter availability and specification appears to be common to many benthic crustaceans (Van Olst, 1975; Mason, 1978; Eggleston and Lipcius, 1992; Geddes et al., 1993; Ingerson, 1995). However, exceptions have been noted also. Karplus et al. (1995) found shelter impacted heavily on growth but not survival for juvenile redclaw.

The reasons why crayfish require shelter have not been well investigated. Some investigators (Lowery, 1988; Fielder and Thorne, 1990 and Smallridge, 1994) have suggested that shelters may play an important role in providing refuge during ecdysis when vulnerability to predation is very high. While this is a logical argument, casual observation (Jones, unpublished) of redclaw over many years suggests the opposite. Exuviae are commonly found in the shallows of ponds, well removed from shelters available. Furthermore, during periods when redclaw have been held in tanks furnished with shelters, exuviae are often found on the tops of shelters provided, suggesting pre-moult crayfish will seek out areas away from normal shelter. Given the propensity of intermoult crayfish to cannibalise their post-moult conspecifics, there is adaptive advantage in moulting in areas remote from those where abundance of intermoult animals is greatest, i.e. in and near shelter. Presumably, the predation risk from other species is lower than that from their own kind. Observations of crayfish actively leaving shelters to moult have been documented for *Astacus astacus* (Westin and Gydemo, 1988) and for *Pacifastacus leniusculus* (Westman, 1973).

Van Olst (1975) suggested survival of the marine lobster *Homarus americanus* in captivity was primarily reduced by cannibalism (presumably during moulting) and this may be independent of food availability. A similar mechanism may be at play for redclaw, and shelter design and placement should consider mitigation of moult-related cannibalism by providing suitable habitat for both moulting and intermoult crayfish.

Redclaw would appear to seek out and occupy shelter as general protection against predation, although not during moulting episodes. Sheltering behaviour may provide a mechanism for concentrating individuals which facilitates reproduction. This hypothesis was supported by the increased incidence of berried females from the shelter treatments in contrast to the control (Figure 6.8).

While this trial did not specifically investigate why redclaw use shelter, it clearly demonstrated that shelter is important. Of the shelter types assessed, mesh bundles were significantly more effective than the others. Mean survival with mesh bundles (75%) was 46% higher than the next best shelter, tyres. Tyres and pipe stacks were effectively equivalent in their suitability. The two shelter types based on flat fibre-board sheets were singularly ineffective. Survival for them was only marginally better than no shelter at all. Despite the perceived suitability of the elevated sheet type shelter for enhancing the physical environment for the rock lobster *Panulirus argus* (Eggleston et al., 1990), they appear not to be suitable at all for redclaw.

Uniform growth amongst the treatments including the no shelter control suggests all crayfish were able to achieve maximum intrinsic growth within this trial. That is, given the uniform and suitable environmental conditions, abundance of food and initially uniform density, growth was not limited by the shelter available. Widely disparate survival however indicates that the shelter types were different in their capacity to accommodate the behavioural preferences of redclaw. From a commercial production perspective, this is clearly as significant as an influence on growth would have been, in that the biomass generated was significantly influenced by shelter type. Mean biomass for the mesh bundle treatment (4.5kg per cage) was 28% higher than the next most effective shelter (tyres) and over 370% higher than no shelter at all. Clearly, from an economic perspective, these differences are extremely significant. Figure 6.9 illustrates the equivalent yields per hectare as derived from the biomass estimates.

The uniformity of growth was mirrored in uniformity of population structure as illustrated in Figure 6.6. This figure, based on percentage frequency, does not reflect the disparate abundance between shelters, but shows that the distribution of sizes for each shelter treatment was very similar.

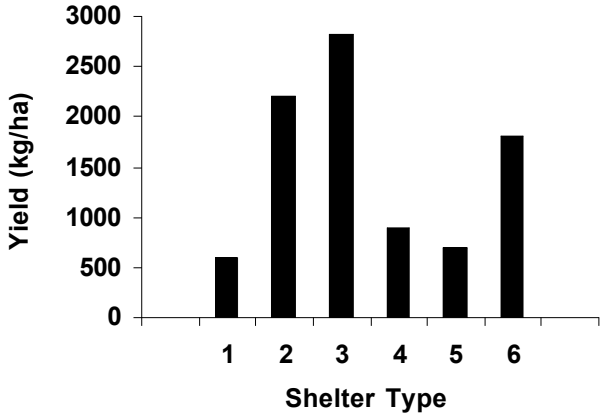


Figure 6.9 ***Estimated yield (kg/ha) for redclaw with different shelter types based on experimental biomass data, generated over a 6 month culture period.***

Physically, the different shelter types provide significantly different environments to the crayfish. The superiority of the mesh bundle, despite its lack of firm structure, may be attributable to its capacity to separate many individuals. It has been demonstrated that many shelter-seeking crustaceans are sensitive to spaces and edges, quite independent of shelter volume (Sheehy, 1976; Smith and Sandifer, 1979). In addition, some researchers have found a strong relationship between refuge size and animal size in relation to the suitability of a particular shelter for occupation (Eggleston et al., 1990; Wahle, 1992; Foster, 1993). The mesh bundle shelters superiority may be attributable to its plasticity in regard to the size of spaces it can provide. While the pipe stack also provided the capacity to separate individuals, its

rigid structure limits the number of crayfish it can hold to a fixed and lower maximum. The edge effect as described by Smith and Sandifer (1979) may also explain the advantage of the mesh bundle. The mesh bundle provides many edges while the pipe stack provides significantly less.

However, the efficacy of the tyres negates these arguments to some extent in that the tyre provides little physical separation of individuals and possesses few edges. The advantage of the tyre may be minimisation of light penetration, which is likely to be another influential factor. Alberstadt et al. (1995) and Fielder and Thorne (1990) have both demonstrated that opaque structures were preferred to translucent ones for crayfish. Both the pipe stack and tyre shelter were opaque and provided an abundance of dark space. The mesh bundle however would provide an even greater abundance of dark spaces well hidden from incident light. It was not possible to maintain a very dense plankton bloom in the experimental pond during the shelter assessment trial. Light penetration may have been more influential on the performance of the shelters than it otherwise would be in a pond with secchi readings below 70cm.

Mitchell et al. (1994) found multi-level shelters, similar to the pipe-stack of this study, to be superior for *Cherax destructor*. However, they did not indicate what other shelter types were compared.

Attributing reasons for the extremely poor performance of the fibre-board sheet shelters is uncertain, particularly given Eggleston et al.'s (1990) demonstration of the effectiveness of the elevated sheet shelter ('casita') for marine rock lobsters. It should be noted however that their work was conducted in a natural environment, and the effects of shelter manipulations were primarily related to reduction of predation risk and its positive impact on survival. Although shelter manipulations for redclaw also impacted heavily on survival, this was due to factors other than predation risk, as the environment was a controlled one with no predators (other than cannibalistic conspecifics) present.

Casual observation of both sheet type shelters during harvesting of the trial indicated that some excavation of the soil beneath the shelters took place, but that the resultant 'burrow' was only ever occupied by one or two crayfish. Further, the soil beneath these shelters was often anoxic, a characteristic not seen under any of the other shelter types. Following the incident light hypothesis (Alberstadt et al., 1995), the elevated sheet shelters would permit a high degree of light penetration through the open sides, diminishing their suitability for crayfish occupation. While the flat sheets would not permit light entry, their inferiority as a redclaw shelter may be attributed simply to their lack of structure and the poor environmental conditions they confer. Poor performance of the fibre-board sheet shelters may also be related to their lack of edges. Smith and Sandifer (1979) demonstrated that shelters with high edge to surface area ratios supported higher densities of animals.

In assessing these shelters from a commercial perspective, consideration must be given to the cost of manufacture. From a purely economic standpoint, second-hand car tyres are likely to be the most cost-effective, given their zero material cost. Government regulations now stipulate that a small disposal levy must be paid for each tyre. Use of tyres in aquaculture ponds is considered a legitimate disposal and throughout Queensland used tyres can be delivered to a farm at no cost. However, considering the labour necessary to cut holes in each tyre and to place them in the pond, the difficulty of moving or removing them from the pond at harvest and the possibility of a financial liability for disposal if environmental authorities deem the practice unacceptable, their economic superiority is not likely to be sustainable. Material costs for mesh bundles were not particularly high, however, they require considerable labour to fabricate and the nature of their design does not lend itself to automated production. On the basis of manual construction, the pipe stack shelter had the highest material cost and a substantial labour component. The costs of the fibre-board shelters were quite low, however, since they performed so poorly their further consideration is not warranted.

As the optimal specifications for a redclaw shelter are further defined, consideration of size specific requirements may also be necessary. This trial covered the mean size range of around 15g to 30-40g. Redclaw are generally marketed at a minimum size of 30g up to 150g and above. It is possible that the superiority of the mesh bundle in this trial reflected juvenile shelter requirements (Jones, 1995a; 1995b), and that larger crayfish above 30g may prefer different shelter characteristics and specifications.

Another factor which was not specifically investigated in this trial, but that has important economic implications, is the quantity of shelter necessary for a given pond area or density of crayfish. While every attempt was made to provide equivalent quantities of the various shelter types in this trial, their widely variable design characteristics made this difficult.

Having established the effectiveness of the mesh bundle shelter relative to the other four shelters assessed, improvements on its design should now be sought. Pursuing the theme of multiple spaces with separation and minimal light penetration, modifications of the mesh bundle can be conceptualised which would be worthy of further assessment. A disadvantage of the mesh bundle design as used in this trial is that it does not lend itself to mass production. A more rigid structure which could be moulded or extruded in plastic, would provide greater opportunity for automated manufacture and lower unit cost.

6.5 References

Alberstadt, P.J., Steele, C.W. and Skinner, C. 1995. Cover-seeking behavior in juvenile and adult crayfish, *Orconectes rusticus*: effects of darkness and thigmotactic cues. Journal of Crustacean Biology, 15(3):537-541.

Du Boulay, A.J.H., Sayer, M.D.J. and Holdich, D.M. 1993. Investigations into intensive culture of the Australian red claw crayfish *Cherax quadricarinatus*. Freshwater Crayfish, 9:70-78.

Eggleston, D.B. and Lipcius, R.N. 1992. Shelter selection by spiny lobster under variable predation risk, social conditions, and shelter size. Ecology, 73(3):992-1011.

Eggleston, D.B., Lipcius, R.N., Miller, D.L. and Coba-Cetina, L. 1990. Shelter scaling regulates survival of juvenile Caribbean spiny lobster *Panulirus argus*. Marine Ecology Progress Series, 62(1-2):79-88.

Eversole, A.G. and Foltz, J.W. 1993. Habitat relationships of two crayfish species in a mountain stream. Freshwater Crayfish, 9:300-310.

Fielder, D.R. and Thorne, M.J. 1990. Are shelters really necessary? In: Macreadie, M. (ed) Australian Fisheries: Aquaculture Special: Redclaw. Australian Government Publishing Service, Canberra, Vol.49(11):26-28.

Foster, J. 1993. The relationship between refuge size and body size in the crayfish *Austropotamobius pallipes* (Lereboullet). Freshwater Crayfish, 9:345-349.

Geddes, M.C., Smallridge, M. and Clarke, S. 1993. The effect of stocking density, food type and shelters on survival and growth of the Australian freshwater crayfish, *Cherax destructor*, in experimental ponds. Freshwater Crayfish, 9:57-69.

Hogger, J.B. 1988. Ecology, Population Biology and Behaviour. In: Holdich, D.M. and Lowery, R.S. (eds) Freshwater Crayfish. Biology, Management and Exploitation. Croom Helm, London:114-144.

Horwitz, P.H.J. and Richardson, A.M.M. 1986. An ecological classification of the burrows of Australian freshwater crayfish. Australian Journal of Marine and Freshwater Research, 37:237-242.

Huner, J.V. and Barr, J.E. 1984. Sea Grant Publication No. LSU-T-80-001: Red swamp Crawfish: Biology and exploitation. Louisiana Sea Grant College Program, Louisiana State University, USA.

Ingerson, T. 1995. The effect of shelters on the growth and mortality of juvenile marron held under low and high stocking conditions. Freshwater Farmer (Australia), 3(1):23-24.

Jones, C.M. 1990. The Biology and Aquaculture Potential of the Tropical Freshwater

Crayfish, *Cherax quadricarinatus*. In: Queensland Department of Primary Industries Information Series, QI90028: . Queensland Department of Primary Industries, Brisbane:109p.

Jones, C.M. 1995. Production of juvenile redclaw crayfish, *Cherax quadricarinatus* (von Martens)(Decapoda, Parastacidae) II. Juvenile nutrition and habitat. Aquaculture, 138(1995):239-245.

Jones, C.M. 1995. Production of juvenile redclaw crayfish, *Cherax quadricarinatus* (von Martens)(Decapoda, Parastacidae) III. Managed pond production trials. Aquaculture, 138(1995):247-255.

Jones, C.M. and Curtis, M.C. eds 1994. Redclaw Farming. Proceedings of the Redclaw Farming Workshops, Feb.12-17, 1994, Walkamin, Rockhampton, Nambour. Queensland Department of Primary Industries,

Karplus, I., Barki, A., Levi, T., Hulata, G. and Harpaz, S. 1995. Effect of kinship and shelters on growth and survival of juvenile Australian redclaw crayfish (*Cherax quadricarinatus*). Freshwater Crayfish, 10:494-505.

Lobegeiger, R. 1995. Queensland Australia, Aquaculture Information Series: Aquaculture Production Survey Queensland 1994/95. Report to Farmers. Queensland Department of Primary Industries,

Lowery, R.S. 1988. Growth, Moulting and Reproduction. In: Holdich, D.M. and Lowery, R.S. (eds) Freshwater Crayfish. Biology, Management and Exploitation. Croom Helm, London:83-113.

Mason, J.C. 1978. Effects of temperature, photoperiod, substrate, and shelter on survival, growth, and biomass accumulation of juvenile *Pacifastacus leniusculus* in culture. Freshwater Crayfish, 4:73-82.

Mitchell, B.D., Collins, R.O. and Austin, C.M. 1994. Multi-level refuge utilization by the freshwater crayfish *Cherax destructor* Clark (Decapoda: Parastacidae): a potential harvest and sampling technique. Aquaculture and Fisheries Management, 25:557-562.

Sheehy, D.J. 1976. Utilization of artificial shelters by the American lobster, *Homarus americanus*. Journal of the Fisheries Research Board of Canada, 33:1615-1622.

Smallridge, M. 1994. Use of shelters in freshwater crayfish farming. Freshwater Farmer (Australia), 2(2):10-11.

Smith, T.I.J. and Sandifer, P.A. 1979. Observations on the behavior of the Malaysian

prawn, *Macrobrachium rosenbergii* (de Man), to artificial habitats. Marine Behaviour and Physiology, 6:131-146.

Van Olst, J.C., Carlberg, J.M. and Ford, R.F. 1975. Effects of substrate type and other factors on the growth, survival, and cannibalism of juvenile *Homarus americanus* in mass rearing systems. Proceedings of the World Mariculture Society, 6:261-274.

Wahle, R.A. 1992. Substratum constraints on body size and the behavioural scope of shelter use in the American lobster. Journal of Experimental Marine Biology and Ecology, 159:59-75.

Westin, L. and Gydemo, R. 1988. The locomotor activity patterns of juvenile noble crayfish (Astacus astacus) and the effect of shelter availability. Aquaculture, 68:361-367.

Westman, K. 1973. Cultivation of the American crayfish *Pacifastacus leniusculus*. Freshwater Crayfish 1: 252.

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

7. An assessment of the biological and aquaculture characteristics of five stocks of redclaw, *Cherax quadricarinatus* (von Martens) (Decapoda: Parastacidae) representing discrete river catchments in north Queensland, Australia.

7.1 Introduction:

Cherax quadricarinatus, commonly referred to as redclaw, is a freshwater crayfish broadly distributed across north-eastern Australia, and for which an aquaculture industry is now developing. The species natural distribution (Figure 7.1) includes the major drainages flowing to the Gulf of Carpentaria, some easterly flowing rivers on northern Cape York, northerly flowing rivers across the Northern Territory and southern parts of New Guinea. Within this distribution, redclaw inhabits the upper reaches of the river systems where permanent water is available. Despite regular flooding of these rivers during monsoonal rains each summer, the upper catchments where redclaw reside remain reasonably discrete and there is limited opportunity for crayfish of one catchment to mix with another. Consequently, populations of redclaw representing these catchments have been considered discrete strains which may be genetically isolated.

Several sources (Hutchings, 1988, Fielder, 1990; Herbert,1987; Jones and McPhee, 1993) have claimed or suggested that the various strains display different characteristics and may be of varying superiority and suitability for cultivation. As has been the case with other intensive animal production candidates, it is of great importance that the differences are investigated so the emerging aquaculture industry can proceed with confidence that the best stock or stocks are being developed (Macaranas et al., 1995). Such investigations may also suggest which strains may best be crossed to maximise superior traits in selective breeding programs (Tave, 1992; Bosworth et al., 1994). The lack of genetic variability displayed by other freshwater crayfish species, in many cases attributed to widespread translocations, has been recognised as a major disadvantage to the development of aquaculture (Busack, 1988; Fevolden et al., 1994). Because of the remote and isolated distribution of redclaw, it is unlikely that any translocations have occurred within the species natural distribution.

However, within the existing redclaw aquaculture industry the exploitation of the significant genetic resource available has been largely ignored. In fact, it is likely that the bulk of existing stocks held in commercial aquaculture ponds is genetically highly homogeneous to the extent that inbreeding depression is likely to have suppressed the production potential of the stock severely. As a further consequence of the species remote and isolated distribution, and the relative difficulty of obtaining ‘wild’ stock, the majority of aquaculturists have obtained their initial farm stock from each other. A relatively small (but unknown) number of wild stock collected when the aquaculture of the species was first initiated represents the base from which probably 95% of farm

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

stock have been generated. Selective breeding can provide significant improvement in economically important traits, however, it can only be successful if it is built from a base of reasonable genetic heterogeneity. This base should be generated from genetically disparate stocks which display advantageous characteristics.

A preliminary investigation was undertaken to evaluate a variety of biological and production related characteristics of five recognised strains of redclaw representing the Mitchell, Gilbert, Flinders, Leichhardt and Gregory River catchments. Stock from these particular river systems were chosen on the basis that they represent those being commercially cultivated, those with the perceived best attributes, and a broad geographic range.

Specific objectives were to determine the relative growth rates, the reproductive characteristics (size at maturity, fecundity, breeding seasonality), the production characteristics (total yield, size/sex distribution), and the morphological characteristics of the five strains, and on the basis of these investigations assess the relative suitability of the Gregory, Leichhardt, Flinders, Gilbert and Mitchell River strains of redclaw for aquaculture.

The genetic integrity of the five strains was investigated by Macaranas et al. (1995) using both allozyme electrophoresis and RAPD analyses.

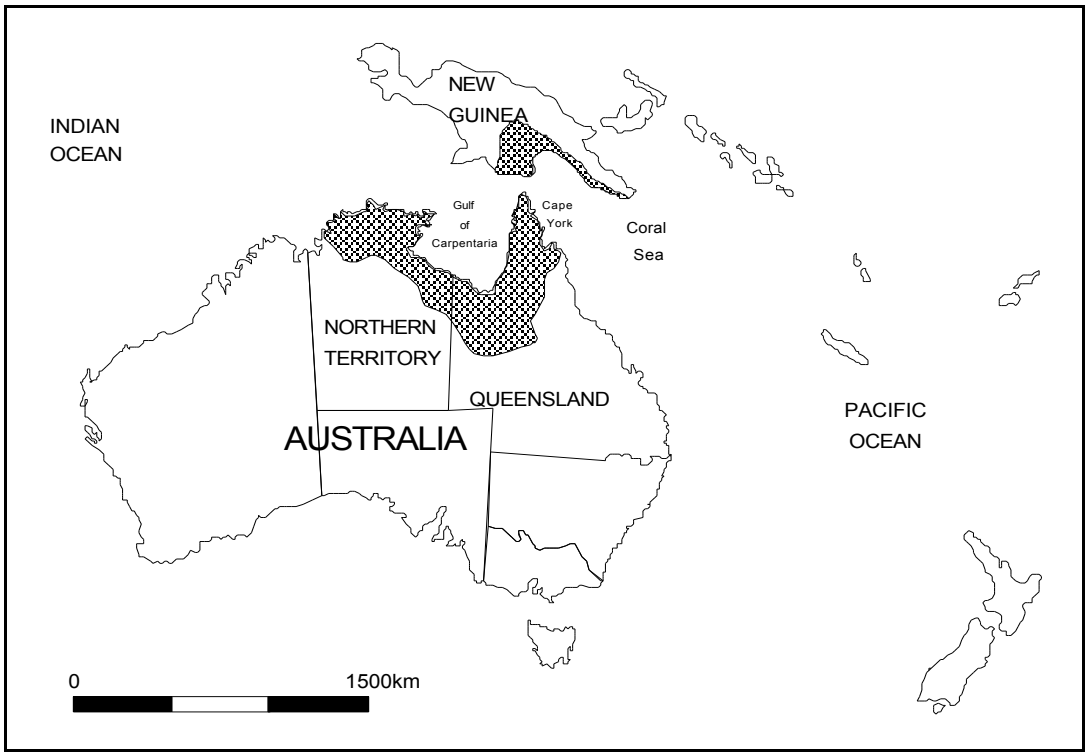


Figure 7.1 ***Natural distribution of redclaw,*** **Cherax quadricarinatus.**

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

7.2 Methods and Materials:

This study was conducted at Freshwater Fisheries and Aquaculture Research Center, Walkamin in Northern Australia (17.1°S, 145.5°E) over the period April 1992 to October 1994. Initially, wild stock were collected, returned to Walkamin and stocked to ponds. Populations of each stock developed, from which a standardised sample was taken to initiate the comparative production trials.

7.2.1 Stock Collection

Initial stocks of redclaw from the Mitchell, Gilbert, Flinders, Leichhardt and Gregory River catchments were collected on a series of field trips to specific sites identified by industry contacts and local landholders over the period November 1992 to November 1993. Collection site details are presented in Table 7.1 and the localities marked in Figure 7.2.

Table 7.1 ***Details of collection of wild stock of redclaw from five river catchments in north Queensland as used for strain comparison study.***

River System	Position	Locality	Date	Quantity
Mitchell	16°55'S	Biboorah storage dam west of	15/10/93	74
	145°25'E	Mareeba	25/10/93	136
Gilbert	18°15'S	Little Gilbert River near Inorunie	3/4/92	377
	142°50'E	Station		
Flinders	20°10'S	Saxby River near Millungera	7/1/93	222
	142°30'E	Station		
Leichhardt	19°55'S	Leichhardt River near Kajabi	22/3/93	24
	140°10'E		21/10/93	26
Gregory	18°40'S	Gregory River near Lawn Hill	5/1/93	67
	138°35'E	Station		

As stock were returned to the Freshwater Fisheries and Aquaculture Centre they were placed into designated ponds. Ponds used to hold the stock were equivalent in specification, approximately 1,000m^2 in surface area, and individually fenced to prevent any escape or mixing of stocks. Ponds were prepared with applications of lime, inorganic and organic fertiliser and crayfish shelters as specified in Table 7.2. Crayfish were maintained in these ponds until September 1994 under a regime of regular water quality monitoring, feeding of a formulated diet five times per week.

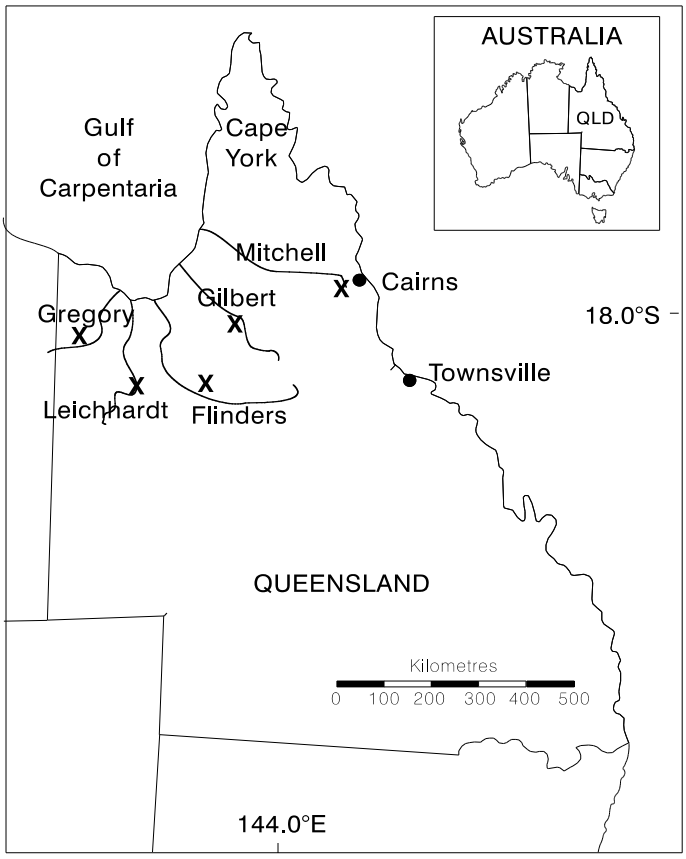


Figure 7.2 ***Map indicating position of collection sites for redclaw used for strain comparison. Approximate collection point is marked by X. The primary river course only has been shown, with tributaries omitted for clarity.***

Table 7.2 ***Pond preparation details for ponds stocked with five strains of redclaw. All ponds received identical treatment. Each pond was approximately 1,000m^2 in surface area.***

Material	Quantity
Agricultural Lime	100kg
Diammonium phosphate fertiliser	20kg
Urea	20kg
Mulching Hay	100kg
Crayfish shelters - pipe stacks	50
Crayfish shelters - mesh bundles	60

7.2.2 Trial Protocol

Each of the ponds was drained and harvested with the application of a flow trap over the period 1/9/94 to 7/9/94. For each pond, stock were removed to tanks and a selection was made for restocking. For Gilbert, Flinders and Gregory strains, 150 mature individuals of each sex for each strain were used, however, for Mitchell and Leichhardt stocks insufficient numbers of mature stock were available, and a lesser number were stocked. A summary of the stocking details is presented in Table 7.3.

Approximately 40 crayfish (20 males and 20 females) of each strain were individually tagged and examined for 15 morphological variables as described in Table 7.4 and illustrated in Figure 7.3. The tag used was a Visible Implant tag (Northwest Marine Technology Inc.), an individually numbered metal plate, 2.5mm x 1.0mm x 0.1mm placed under the integument of the ventral surface of the first abdominal segment with an applicator syringe. The integument in this area is transparent permitting the tag to be easily read. Previous trials and advice from the manufacturer indicated that this placement would enable the tag to be retained through moult.

Table 7.3 ***Statistics for redclaw stocked to separate ponds for comparison of biological and production characteristics.***

Strain	Date	Females		Males		Total
		#	mean wt (g)	#	mean wt (g)	#
Mitchell	25/10/93	75	31.0	135	42.1	210
Gilbert	14/10/93	150	42.8	150	49.7	300
Flinders	12/10/93	150	47.8	150	46.5	300
Leichhardt	21/10/93	43	46.2	38	93.8	81
Gregory	11/10/93	150	38.7	150	49.9	300

The original ponds were dried briefly (2 to 4 days) and prepared with applications of lime and fertiliser as previously (Table 7.2). Each pond was equipped with an equivalent number and specification of artificial shelters. These consisted of 50 pipe stacks and 60 mesh bundles. The pipe stack was a fixed structure consisting of twenty-four 250mm lengths of 80mm diameter corrugated polyethylene pipe, placed in a stack 3 high by 8 wide. Steel fencing clips were used to secure each pipe to adjacent pipes. A 240mm x 640mm piece of rigid plastic mesh was attached to one side of the structure so that crayfish access was from one end only. One pipe on the bottom row was filled with concrete to facilitate sinking and to ensure that the habitat remained upright. The mesh bundle shelter was made from strips of a synthetic mesh (Oyster Mesh, Southcorp Industrial Textiles Pty Ltd.) attached to a rope which was weighted at one end, and suspended from the pond surface at the other. Each bundle was of an equivalent size and was made from 12 strips of material (1m x 10cm lengths) tied on their longitudinal centres to the main rope.

Table 7.4 ***Definition of morphological parameter measurements as used for strain comparison of redclaw. All linear measurements made with vernier callipers to nearest mm (Fig.7.5). Weight measured on electronic balance to nearest gram.***

Morphological Parameter	Measurement
Ocular Carapace Length	From posterior margin of orbit to posterior margin of carapace
Chela Length	From anterior margin of chela propodus to posterior margin measured on exterior lateral surface
Propodal Membrane Length	Maximum length of chela red patch
Dactyl Length	From anterior to posterior margin of chela dactyl measured on exterior lateral surface
Chela Width	Maximum width of chela between lateral surfaces
Cephalon Width	Maximum width of cephalon measured dorsally between lateral surfaces
Thorax Width	Maximum width of thorax measured dorsally between lateral surfaces
Carapace Depth	Maximum depth of carapace measured between dorsal and ventral extremities at approximately mid-thorax
Total Carapace Length	Measured from tip of rostrum to posterior margin of carapace
Abdominal Length	Measured dorsally from anterior margin of first abdominal segment to posterior margin of last abdominal segment above articulation point of telson
Telson Length	Measured dorsally from articulation point of telson to posterior margin of telson including marginal setae
Telson Width	Maximum width of telson measured dorsally between lateral margins
Abdominal Width	Maximum width of abdomen measured dorsally on second abdominal segment between pleura
Weight	Total wet weight of crayfish
Rostral Spine Count	Number of lateral spines on each side of the rostrum

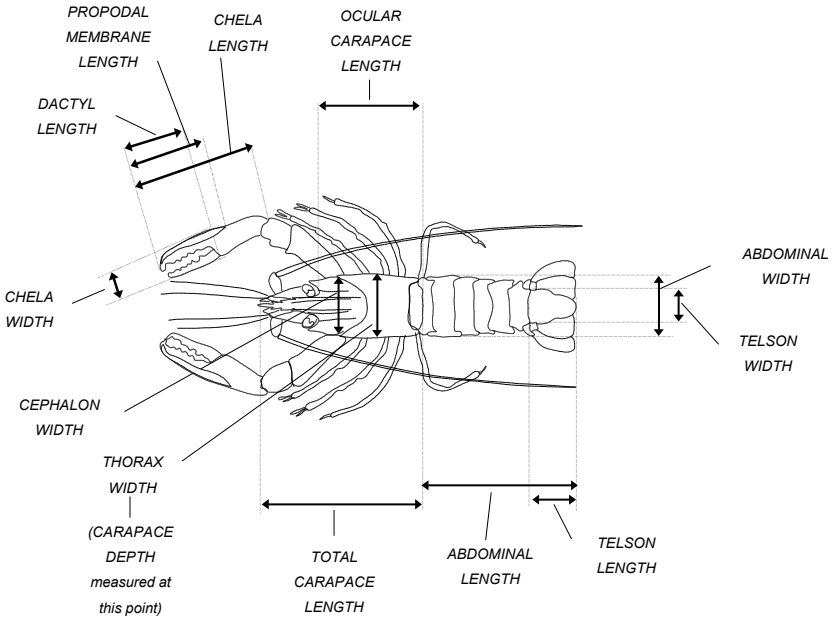


Figure 7.3 ***Diagrammatic representation of redclaw defining 13 morphometric measurements as used for strain comparison. Further definition of each measurement is provided in Table 7.3.***

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

Aeration was provided in the form of 6 airlift pumps per pond. Each airlift consisted of a 1.5m length of 90mm diameter PVC pipe, secured to a concrete weight, and supplied with approximately 80 l/min of air at 0.4kPa through a 12mm diameter polyethylene pipe at a depth of approximately 1.0m. Airlifts were operated continuously.

Ponds were maintained according to established practices (Jones and Curtis, 1994) with regular measurements of water quality parameters and provision of a formulated crayfish pellet (Athmaize Pty Ltd). Feed application rates were based previous experience and observations for under or over feeding. Care was taken to provide an equivalent amount of food to each pond.

Stock were cultured in the ponds for a period of 12 months, from mid-October 1993 to late October 1994.

7.2.3 Sampling

Standardised samples of crayfish were obtained every two months by extracting all the crayfish from 10 pipe stack shelters and 15 mesh bundle shelters. Approximate sampling dates are presented in Table 7.5. For each sample, randomly chosen shelters were quickly lifted off the pond floor into a fine mesh net slung from a floating frame. Sampled crayfish were taken to a laboratory area where sex, weight, presence of eggs, presence of red patch (males only) and tag number (where present) were measured and recorded. Additional morphological assessments of some crayfish were made from time to time to add to the data previously collected. The same 15 measurements as described in Table 7.4 were made. All sampled crayfish were returned to their original pond.

Table 7.5 ***Approximate sampling dates for strain comparison study.***

Sample Number	Week Beginning
1	20/12/93
2	21/2/94
3	18/4/94
4	27/6/94
5	22/8/94
6 Total harvest	24/10/94

7.2.4 Harvest

At the completion of the trial, each pond was drained and harvested over successive days using a flowtrap (Jones and Curtis, 1994). Total yield (i.e. total weight) was determined and a representative sample of approximately 500 crayfish was examined for individual

assessment. This involved determination of sex, weight, presence of eggs, presence of red patch (males only) and tag number (where present). In addition to other measurements, ocular carapace length was measured for all tagged crayfish. Additional morphological assessments involving the same 15 measurements as described in Table 7.4 were made of some crayfish to add to the data previously collected. A sample of berried females (approximately 25 of each strain) was set aside for fecundity estimation. A sample of 50 females (20 to 100g) was set aside for ovary staging.

7.2.5 Production Statistics

A variety of economically important statistics were measured or calculated to assist in the assessment of the strains in regard to their relative suitability for commercial aquaculture. Expressions of yield, market size, proportion saleable, crop value as per size structure are presented.

7.2.6 Morphological Assessment

Initially, simple bivariate analysis was performed using linear regression. Data were examined for homogeneity of variance, and where necessary, appropriate log transformations were applied prior to scatter-plotting. All linear measurements and weight measurements were plotted on ocular carapace length as the independent variable. Analyses were performed separately for each strain and gender. Slopes were compared using t-tests, and where significantly different, the respective linear functions were described. Where slopes were homogeneous, further t-tests were applied to test for differences in intercept. Different intercepts resulted in independent functions being described, otherwise, a common linear function was derived. Where various comparisons resulted in significant differences, plots and/or regression statistics are presented.

To provide a more comprehensive examination of the morphological database, canonical variate analysis and cluster analysis (average link, cityblock) were used to examine the degree of variation within and between the five strains using 1 morphological characters. These analyses use each measurement individually to maximise the variation between the designated groups (strains and sex) relative to within group variation. Given the nature of the 15 measurements used (Figure 7.4, Table 7.4), the shape of the crayfish was used as a means of comparison, standardised for overall size. The canonical variate analysis provides useful measures of the variables which contribute most to any differences found, while the cluster analysis provides a classification of the groups (five strains) on the basis of their overall similarity. Both analyses were performed using Genstat 5 (Payne et al., 1993).

Several redclaw aquaculturists with experience in collecting wild stocks have suggested that body coloration is distinctive for the different strains. While it was not possible to quantitatively describe or analyse body coloration, casual observations were made and noted.

7.2.7 Reproductive Characteristics

A number of biological and morphological characteristics associated with reproduction were examined including sex ratio, differences in body characteristics between male and female (sexual dimorphism), size at which sexual maturity occurs, the number of eggs carried in each brood (fecundity) and the seasonality of reproduction. Sex ratio was examined for each strain for each sample to gauge any deviation from the expected 1:1.

Sexual dimorphism was investigated on the basis of the linear regression analyses, with male and female data plotted together for direct comparison. Differences in slopes and intercepts were interpreted for their biological and functional significance.

A number of techniques have been applied in studies of crustaceans to estimate the size at which sexual maturity is achieved. All have some error and consequently a combination of methods is often applied to improve the estimates. For female redclaw, two techniques were used. From a sample of approximately 50 crayfish from each strain representing a wide size range, ovaries were inspected and staged as either immature or maturing/mature as described by Jones (1995a). The percentage of immature crayfish within 10g size classes was then plotted and a logistic curve fitted to the data with the formula,

$$Y = M / [1 + \exp(-k(X-m))]$$

where, Y is percentage immature
X is size (g)
and M, k and m are parameters

By convention (Grey, 1979; Somerton, 1980; Jewett et al., 1985; Wenner et al., 1985), the size for which the logistic function returns a value of 50% is used as an estimate of size at maturity.

Changes in the relative growth of various body parts was used as a second method for estimating size at maturity. Scatterplots of the 14 morphometric measurements plotted against ocular carapace length were examined for clear discontinuities. Such discontinuities may reflect significant physiological changes associated with sexual maturation. Where discontinuities were evident, a bent stick analysis (Clayton, 1990; Payne et al., 1993) was applied and estimates of the model parameters were made. For those morphometric relationships where the bent stick model was fitted adequately, the transition point between the two straight lines was used as an estimate of size at maturity. For those instances where several such estimates were available, their mean was taken as an overall estimate. These were transformed from OCL measurements to total weight measurements for direct comparison with other estimates.

For male redclaw, examination of scatterplots for discontinuities was also used to estimate size at maturity. In addition, estimates were derived from examination of the development of the propodal membrane of the large chelae, i.e. the red patch, in relation to size. The

percentage of crayfish within 10g size classes which had no red patch development, as opposed to those with a developing or fully developed red patch, were plotted and a logistic curve as described above was fitted. The size at which the logistic function returned a value of 50% was used as an estimate of size at maturity.

Estimation of fecundity involved the staging and counting of eggs from a sample of approximately 50 crayfish for each strain. Eggs were staged according to the developmental stages recognised by Jones (1995a) and counted directly with the aid of a dissecting microscope, after removing them from the pleopods with forceps. Egg counts were grouped according to development stage as early (stages 1 and 2), mid (stages 3,4 and 5) or late (stages 6 and 7) development, and plotted against ocular carapace length. Regression analyses were applied and slopes and intercepts compared using t-tests.

Percentage frequency of egg-bearing females was examined for each sample to explore patterns of reproductive seasonality. As the bulk of each sample consisted of small juveniles, frequencies were calculated on the portion above 10g individual weight to provide more useful distributions.

7.2.8 Population Structure

Data gathered from each sample taken at 2 month intervals were examined to describe population structure and dynamics. Size frequency distributions based on 10g size class intervals were plotted. Because of the preponderance of juveniles in each sample, separate axes were used for crayfish less than 20g and those over 20g to aid in data interpretation. Percentage frequencies are displayed separately for each gender.

7.2.9 Growth

Growth data were generated from tagged crayfish recaptured after varying periods of liberty within the culture ponds. Data were in the form of size at release (weight and carapace length), size at recapture, and time at liberty. To generate a growth curve, a progressive sequence of linear regressions were performed for each recapture data set from the smallest crayfish (at release) through to the largest. The age of the smallest crayfish at tagging was estimated using the function $\text{Weight} = 0.0221e^{(0.05561 \times \text{Age (d)})}$ (Jones, 1995a). The linear function describing the growth of this crayfish from size at release to size at recapture was determined, and this function was applied to the size of the second smallest crayfish to provide an estimate of its age at release. A regression was then performed on the data set for this second smallest crayfish. Age at release was estimated and regressions performed successively for all tagged and recaptured crayfish. Thus, for each crayfish tagged and recaptured, the size and age at both release and recapture were estimated. This series of data was then plotted and a best-fit line was calculated using a power function.

7.3 Results

Pond conditions remained stable and conducive to redclaw (Jones and Curtis, 1994) throughout the culture period. A summary of water quality statistics is presented in Figure 7.4. Water quality dynamics were reasonably uniform amongst the five ponds, and there were no major anomalies which would have contributed to significantly different environmental conditions for the five strains. Approximately 830kg of a formulated pellet diet (20% protein) was provided to each pond over the 12 month culture period. To maintain reasonable plankton abundance, several fertilisers were used over the culture period. Table 7.6 documents the relative amounts of nitrogen, phosphorus and potassium applied to each pond.

Table 7.6 ***Quantities of feed and nutrients (kg) applied to each pond for strain comparison study over 12 months. Nutrient quantities are derived from NPK ratios of several commercial fertilisers used.***

Strain	Feed	Nitrogen	Phosphorus	Potassium
Mitchell	833.5	11.2	7.7	0.9
Gilbert	832.5	4.5	5.1	0.2
Flinders	832.5	11.0	9.6	0
Leichhardt	837.5	11.7	10.6	0.2
Gregory	831.5	11.9	6.6	0.7

While every effort was made to provide equivalent conditions in each pond for this trial, and water quality data suggest this was achieved, the absence of replication must be given due consideration. The individuality of aquaculture ponds in relation to their production record is well documented (Maguire and Leedow, 1983; Boyd, 1990), and identical ponds prepared and managed consistently may generate widely variable results. Notwithstanding these comments, the similarity of water quality between ponds for this trial suggests confidence in the fidelity of the results.

Due consideration must also be given to the unequal numbers of original breeding stock. Although broodstock numbers for Gilbert, Flinders and Gregory were equal (300), and Mitchell were equivalent (210), the number of Leichhardt was considerably less (81). However, the magnitude of impact of this inconsistency would appear to have been slight. Leichhardt was the second highest yielding stock in terms of both total kilograms produced and total numbers of crayfish. Despite the unequal numbers of broodstock, it is likely that for each strain, there was sufficient reproductive capacity to generate equivalent steady-state populations in each pond.

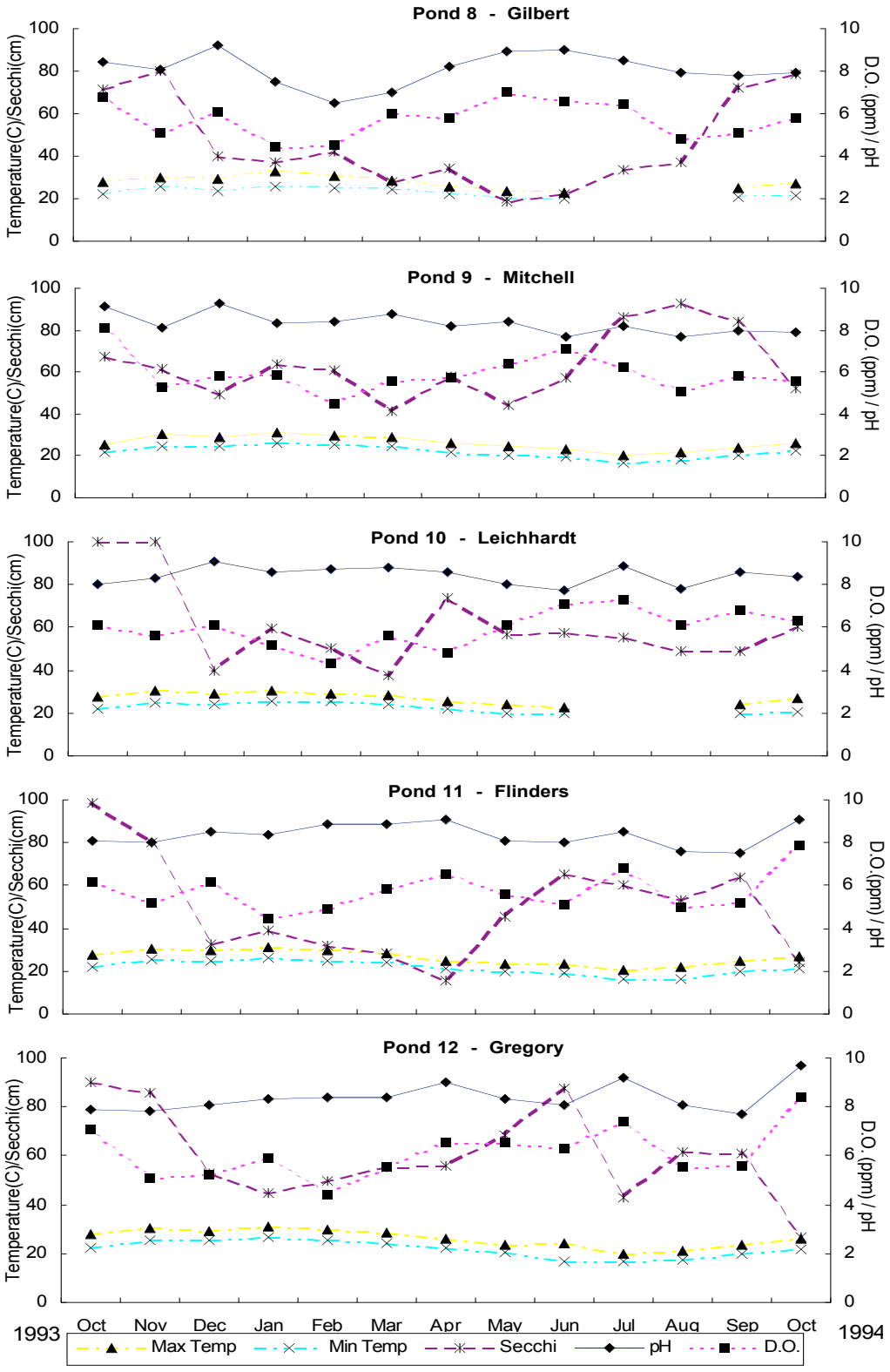


Figure 7.4 ***Summary of water quality for each pond of the strain comparison study based on monthly means for each parameter over 12 months.***

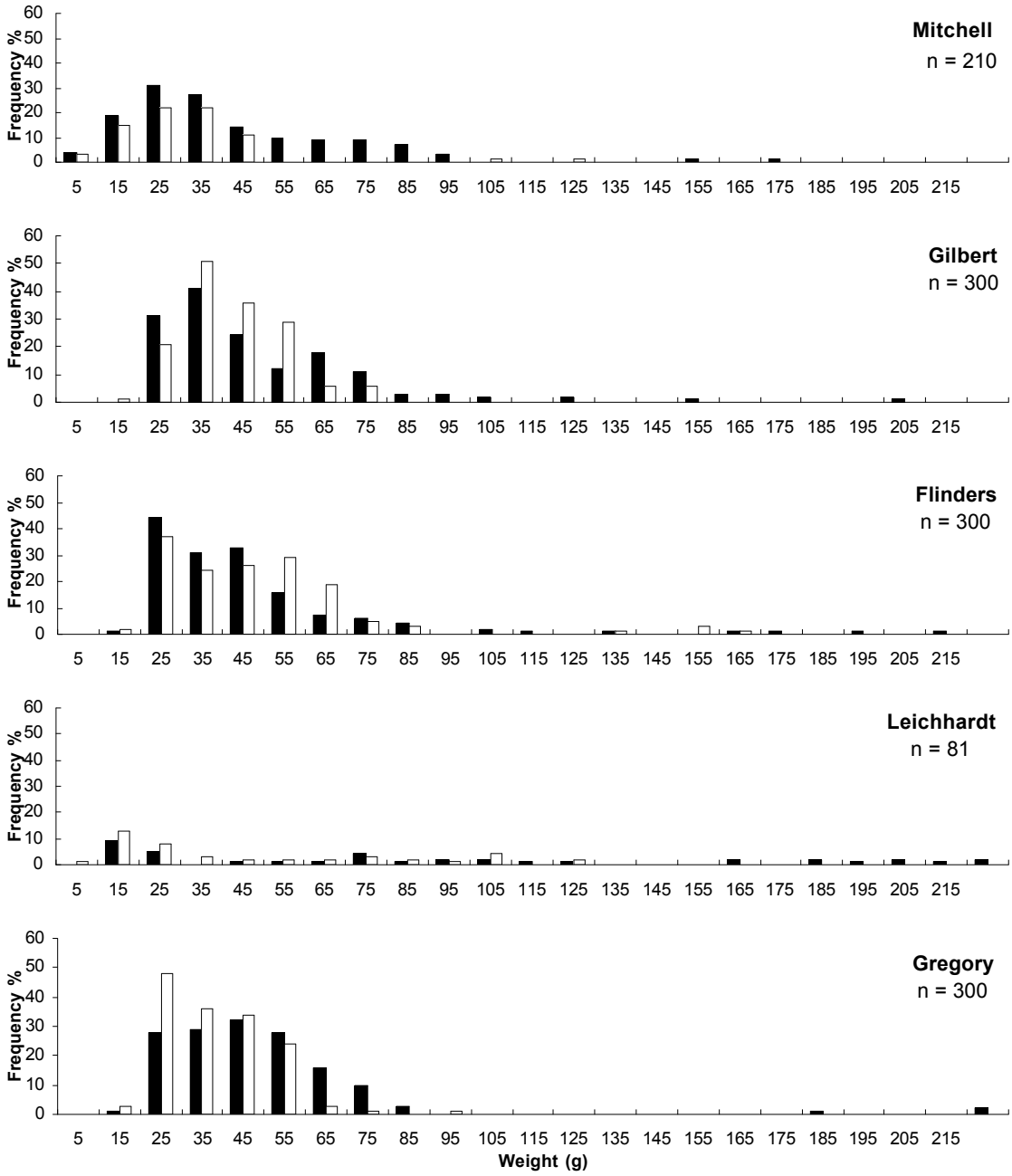


Figure 7.5 ***Size frequency distributions for each strain at stocking. Data for male (solid) and female (open) shown separately.***

Consequently, the biological and production characteristics displayed are likely to be equally representative and directly comparable for each strain. Size frequency distributions for the original stock are presented in Figure 7.5.

Sampling of crayfish every two months provided reasonable samples numerically, with the exception of the first sample in December 1993. The small sample at this time can be attributed to the low density of crayfish, so soon after stocking. Subsequent samples were substantial, although dominated by small juveniles. Size

frequency distributions generated from these data below, have been modified to account for the preponderance of juveniles, and to facilitate interpretation of size classes above 10g.

7.3.1 Production Statistics

A summary of production and population statistics for each strain are presented in Table 7.7. Yields for all strains were of a level above industry averages (Lobegeiger, 1995), although there was considerable variability, with total yield ranging from 135kg to over 350kg per pond. As the ponds were approximately 1,000m^2 in surface area, this range of yield represents a per hectare range of 1.35 to 3.51 tonnes per hectare.

Table 7.7 ***Population statistics for five redclaw strains cultured in separate earthen ponds over 12 months. The first four statistics were derived from the whole population. Subsequent statistics were based on a sub-sample.***

Statistic	Mitchell	Gilbert	Flinders	Leichhardt	Gregory
Total Yield (kg)	135.1	214.3	350.7	254.0	192.5
Yield > 30g (kg)	87.0	151.3	262.3	197.4	138.2
Yield > 30g (%)	64.4	70.6	74.8	77.7	71.8
Total Number	4,218	4,554	8,465	6,571	4,521
Sample Number	506	507	508	515	506
Number > 30g (%)	41	48	56	51	53
Males (%)	48	49	46	46	51
Females (%)	50	51	52	53	48
Intersex (%)	2	0	1	1	1
Berried females	21	16	23	13	9
Mean weight (g)	32	47	41	39	43
Mean weight of males (g)	32	58	40	37	49
Mean weight of females (g)	32	36	43	40	35

Figures are also presented for yield of >30g crayfish. Thirty grams is the minimum acceptable market size, and the proportion of the crop above 30g therefore represents the commercial or saleable yield. For this statistic, yields ranged from 0.87 to 2.6 tonnes/ha. While yield varied significantly between strains, the percentage of yield representing >30g crayfish was reasonably similar, ranging from 64 to 78% (Figure 7.6). Giving due consideration to the absence of replication, the magnitude of difference in yield between the five strains suggests real differences in their relative production capacity. Flinders stock yielded the highest production at 350.7kg, which was 38% higher than the next highest yielding stock, Leichhardt (254.0kg). Gilbert, Gregory and Mitchell stocks were progressively lower yielding.

Relative reproductive capacity can also be gauged from the statistics presented in Table 7.7. Total number of crayfish produced varied significantly, ranging from 4,218

to 8,465. Flinders stock generated the highest number, some 29% greater than Leichhardt. The ranking of the strains in regard to this statistic was the same as for yield.

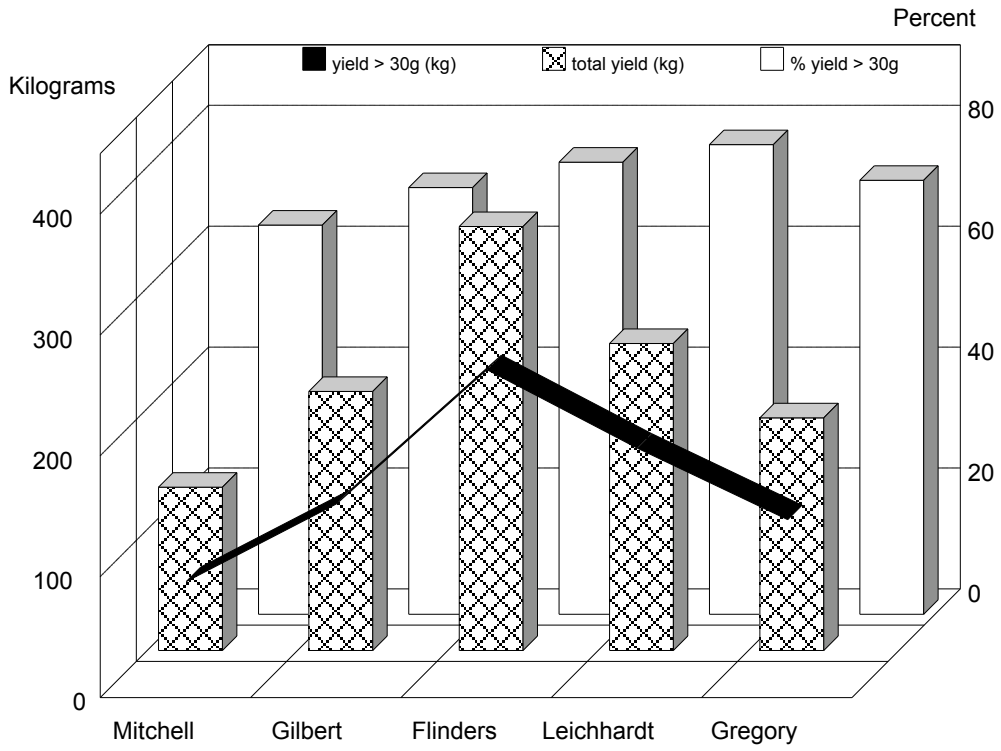


Figure 7.6 ***Production statistics for five redclaw strains cultured in separate earthen ponds over 12 months.***

The percentage of crayfish by number over 30g in each strain suggests that Flinders displays a further advantageous characteristic. Despite the high total population number for this strain and therefore the relatively high density (>8/m^2), 56% of all individuals were over 30g. Gregory, Leichhardt and Gilbert were a little lower in this regard, however, Mitchell was considerably lower at 41%.

7.3.2 Population Structure

Size frequency distributions for each strain at two monthly intervals throughout the culture period and at harvest, are presented in Figures 7.7 to 7.11. Size frequency distributions for the original broodstock are presented in Figure 7.5.

The most noticeable characteristic of the distributions is the preponderance of juvenile crayfish less than 20g over the first 6 months. This was to be expected given that

original stock were sexually mature, stocking occurred early in summer, and redclaw has the capacity to produce successive broods during summer conditions. Small numbers of larger stock in the December (1993) sample for some of the strains represent the original broodstock (eg. Figure 7.8), however, they disappear in the February (1994) sample as their proportional significance was greatly reduced relative to the many new recruits.

By the April sample the oldest and fastest growing of the new recruits had progressed so that reasonable numbers appear in the 20 to 50g size ranges. The largest numbers for these sizes occurred for Flinders stock and the least for Gregory. At this time Gilbert appeared to have the greatest proportion of larger crayfish above 50g.

Recruitment of juveniles appeared to diminish by June, when the overall proportion of <20g crayfish fell below 90% for the first time. At this time a distinct mode at around 25g was evident for all strains, although it was largest for Mitchell, Gilbert and Flinders. The June sample also indicated a broad distribution of sizes for all strains , suggesting that all strains have some fast growing individuals. Flinders displayed the largest proportion of larger animals.

The August samples showed little difference to those of June, reflecting low growth during the winter months. By October when harvesting occurred, the population structure for all strains had progressed substantially. Although the primary mode of each strains distribution was centred around 15 to 25g, greater proportions were distributed in the larger size classes. By this time there was substantial variation between strains evident. Mitchell was characterised by having the smallest proportion of larger crayfish with less than 25% of the population greater than 50g. The distribution was a bell-shaped curve with a positive skew to the right.

For Gilbert strain at this time, a broad juvenile mode was evident centred at 20g, with an even spread of crayfish above 40g representing approximately 50% of the population. As indicated in Table 7.7, Gilbert had the highest mean size (47g), although this was heavily influenced by relatively large numbers of large males over 100g. Mean size of male Gilbert was 58g in contrast to the female mean of 36g.

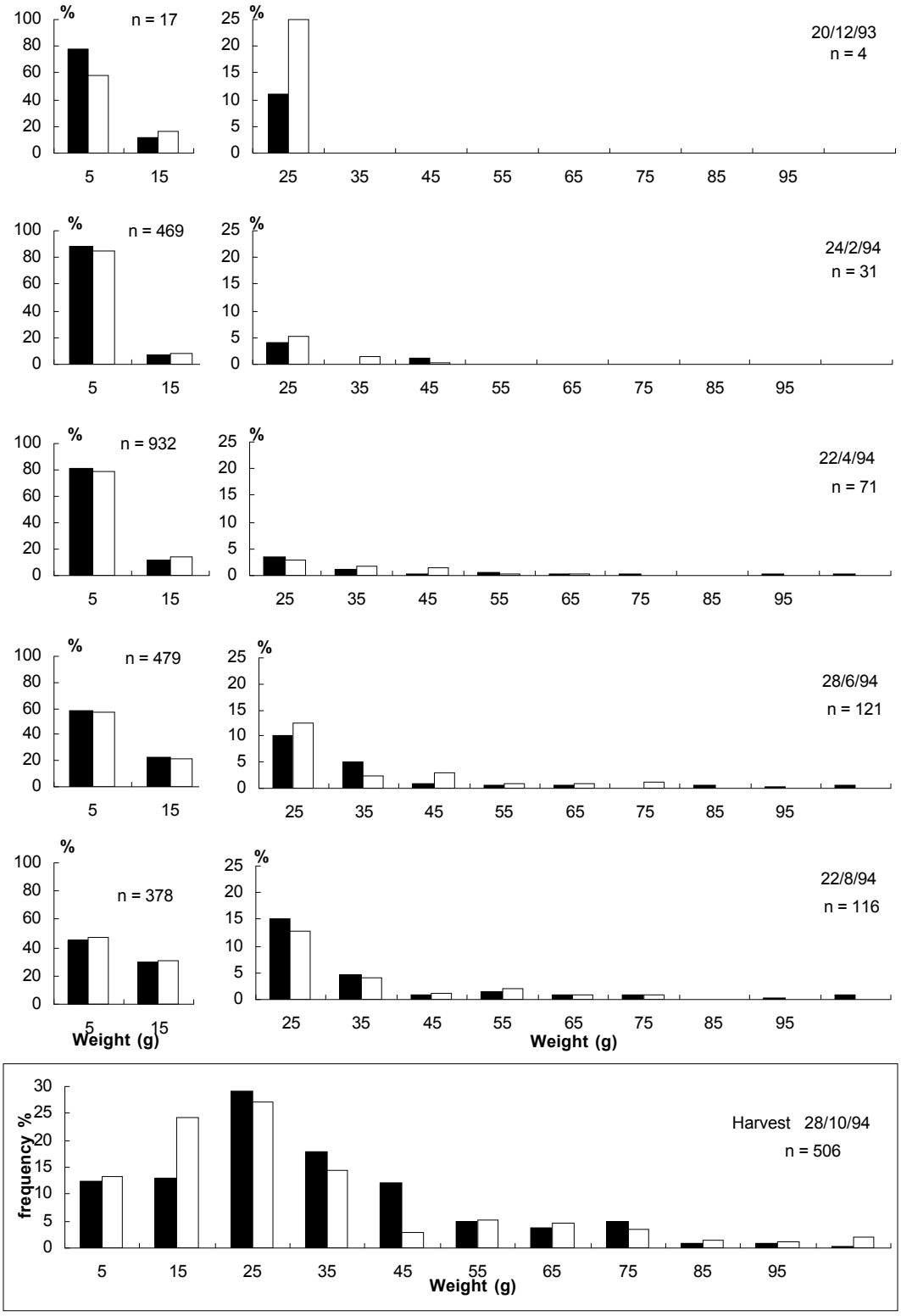


Figure 7.7 ***Size frequency distributions for Mitchell strain at two month intervals over 12 months. Date indicates sample date. n indicates sample size. Data for male (solid) and female (open) are shown separately.***

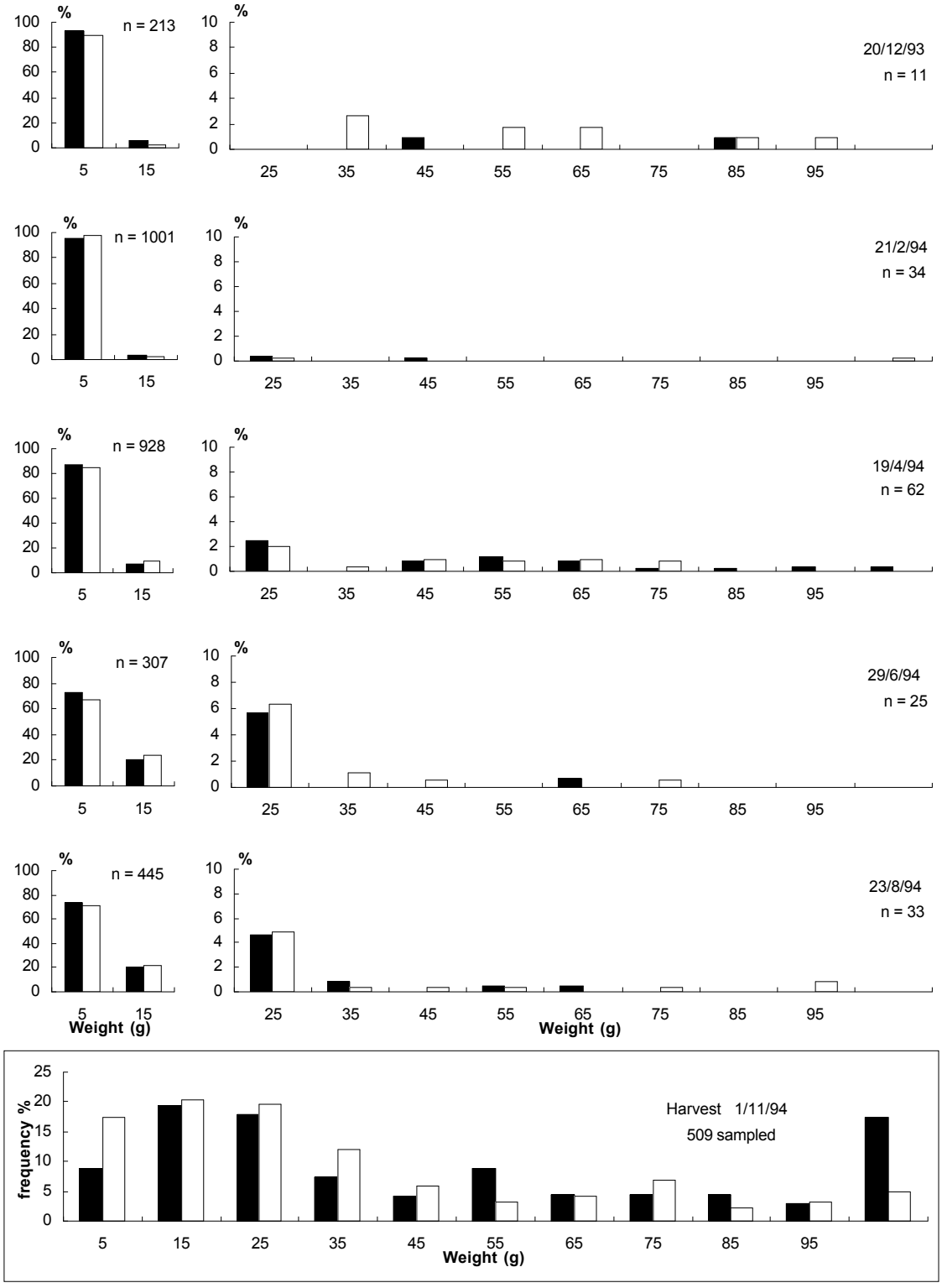


Figure 7.8 ***Size frequency distributions for Gilbert strain at two month intervals over 12 months. Date indicates sample date. n indicates sample size. Data for male (solid) and female (open) are shown separately.***

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

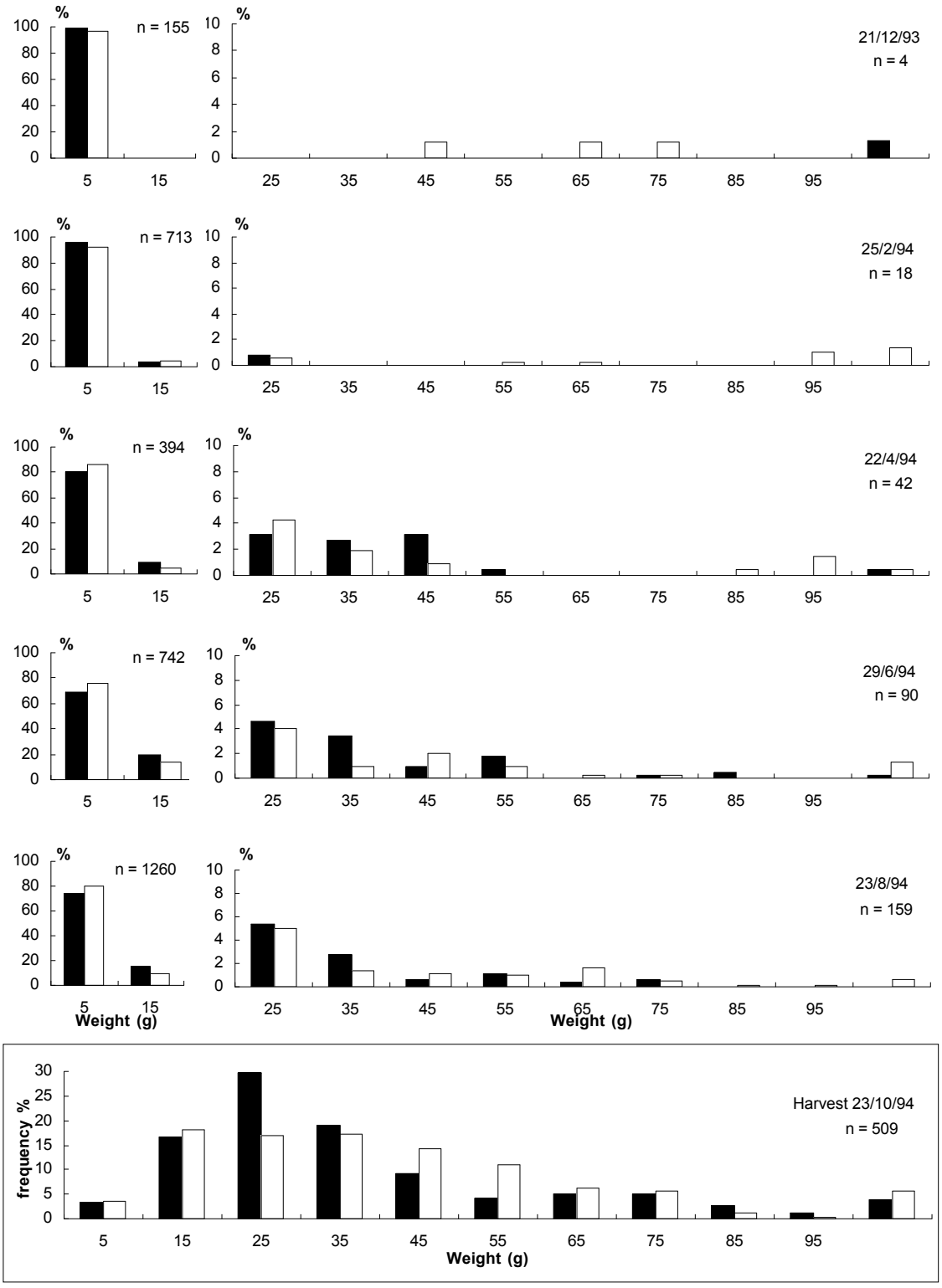


Figure 7.9 ***Size frequency distributions for Flinders strain at two month intervals over 12 months. Date indicates sample date. n indicates sample size. Data for male (solid) and female (open) are shown separately.***

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

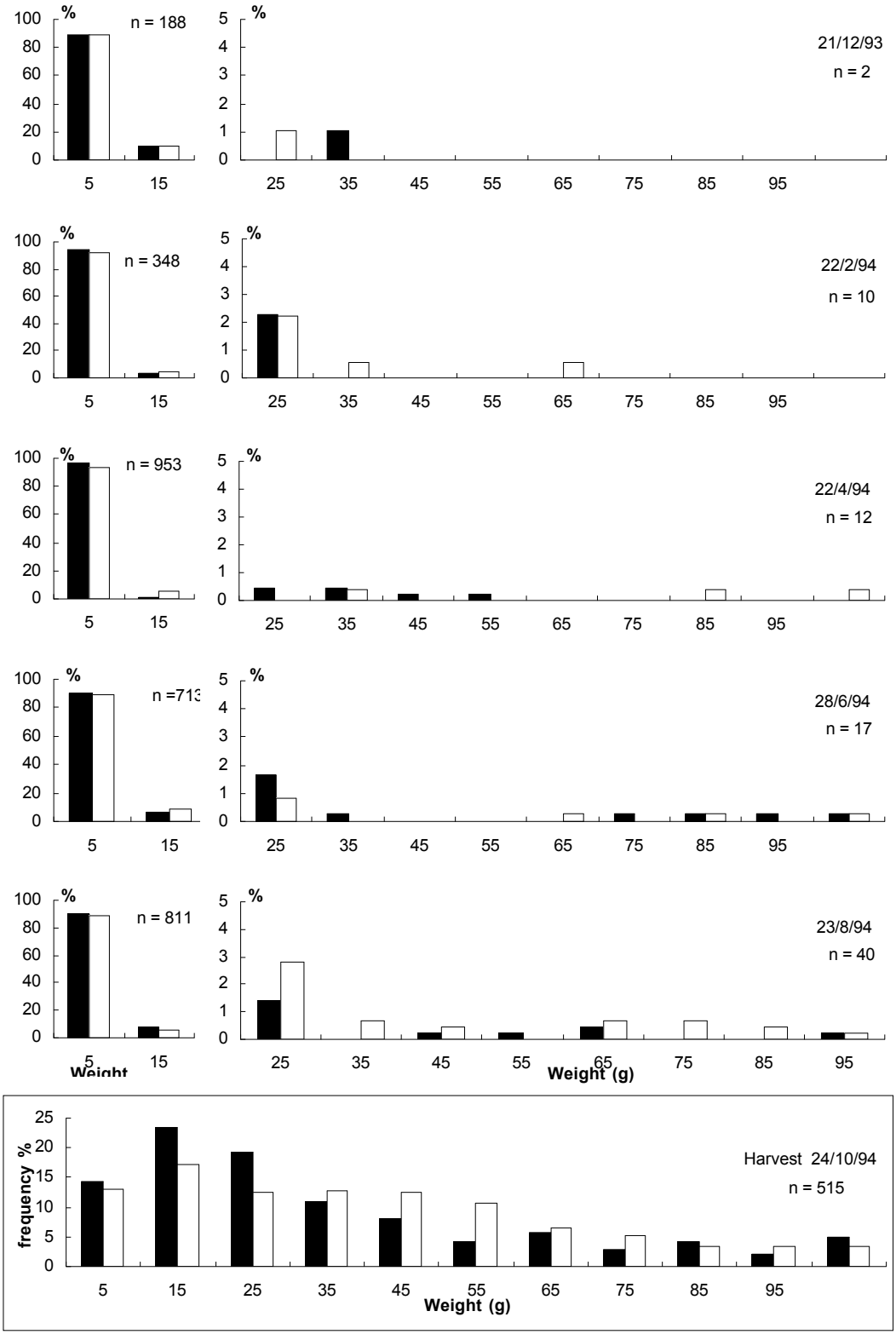


Figure 7.10 ***Size frequency distributions for Leichhardt strain at two month intervals over 12 months. Date indicates sample date. n indicates sample size. Data for male (solid) and female (open) are shown separately.***

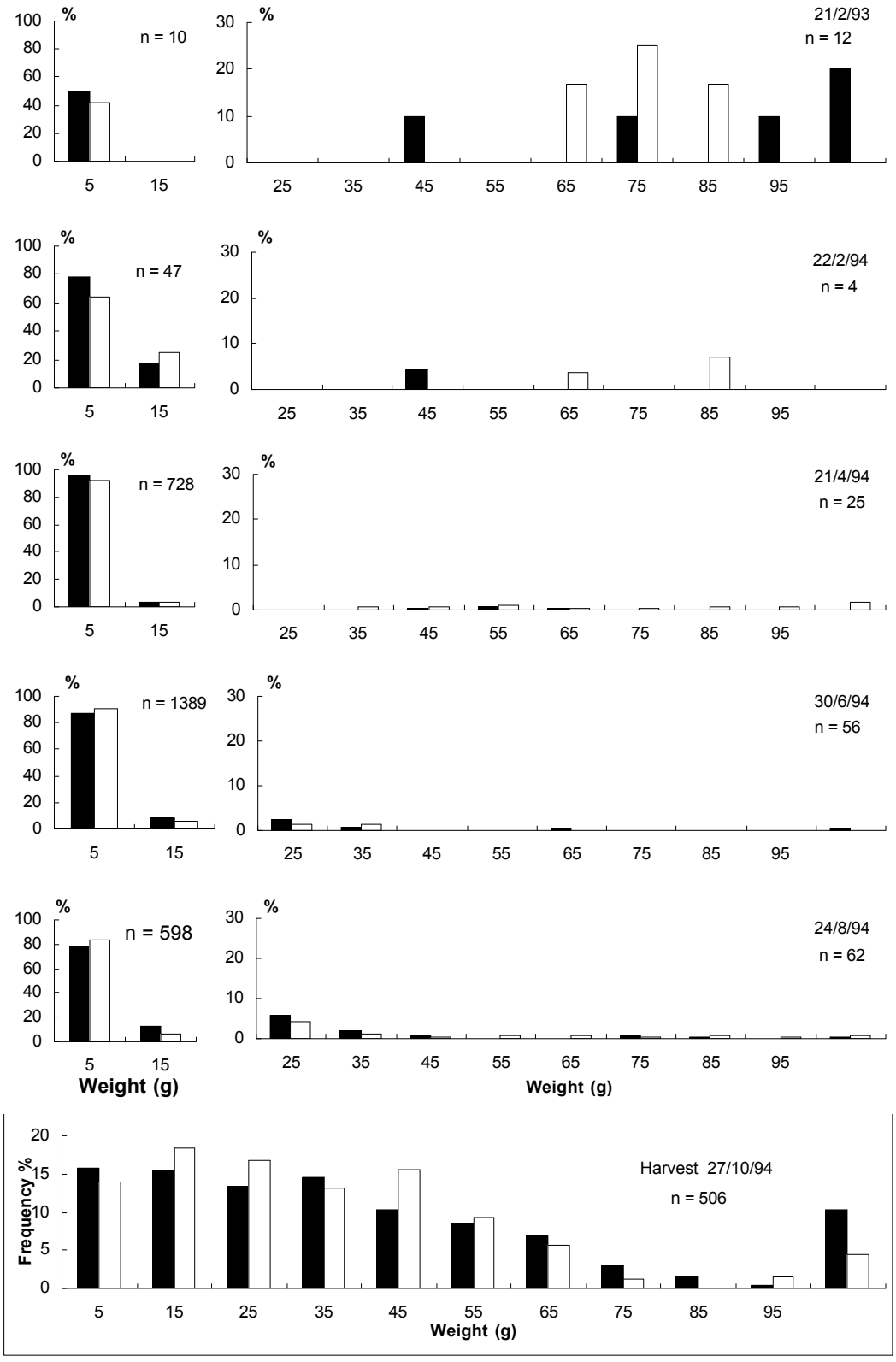


Figure 7.11 ***Size frequency distributions for Gregory strain at two month intervals over 12 months. Date indicates sample date. n indicates sample size. Data for male (solid) and female (open) are shown separately.***

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

The Flinders strain at harvest was characterised by a distinct bell-shaped distribution, skewed to the right as it was for Mitchell, but with a considerably larger proportion of animals to the right side of the mode. This is reflected further by the percentage of >30g individuals at 56% (Table 7.7) in contrast to 41% for Mitchell. Leichhardt was characterised by a reasonably flat distribution with large numbers of small crayfish (<10g) balanced by large numbers of larger crayfish greater than 30g. The distribution of Gregory was the most exceptional in its flatness, with relatively equal proportions of crayfish in all size classes up to 50g.

7.3.3 Morphological Assessment

A summary of morphometric statistics for each strain is presented in Appendix 10.6.

Bivariate analysis indicated several morphological characteristics which may be useful in distinguishing between male and female crayfish, or which may reflect attainment of maturity (both are discussed below under Reproductive Characteristics), however, there were no indications of major or consistent differences between strains.

Similarly, multivariate analyses (canonical variate analysis and cluster analysis) indicated that on the basis of the morphological characteristics measured, there was no significant difference between strains. Canonical variate analysis suggested that of the 16 morphological variables, combinations of unrelated measurements (eg. thorax width and telson length) contributed most to the insignificant differences found. Clearly, such combinations have no biological meaning and can be dismissed as statistical anomalies. The cluster analysis provides a more useful output for interpretation in the dendrogram (Figure 7.12). However, the magnitude of differences are so small as to be biologically meaningless. Furthermore, the different classification for each sex confirms the insignificance of the analysis.

Herbert (1987) suggested that differences in the number of lateral spines on the rostrum between populations of redclaw may be diagnostic. Rostral spine counts were made for each strain and are presented graphically in Figure 7.13. While it is clear that on the basis of this characteristic crayfish of each strain cannot be conclusively distinguished, there are clear differences in the distribution of counts for the 5 strains. The majority of all crayfish possess 3 rostral spines on the left and right, with the exception of Gregory for which equal proportions of animals have 2 or 3 spines on either side. A small proportion of Leichhardt and a substantial proportion of Flinders (≈30%) have 4 spines on at least one side. In regard to this characteristic, Flinders is the most exceptional.

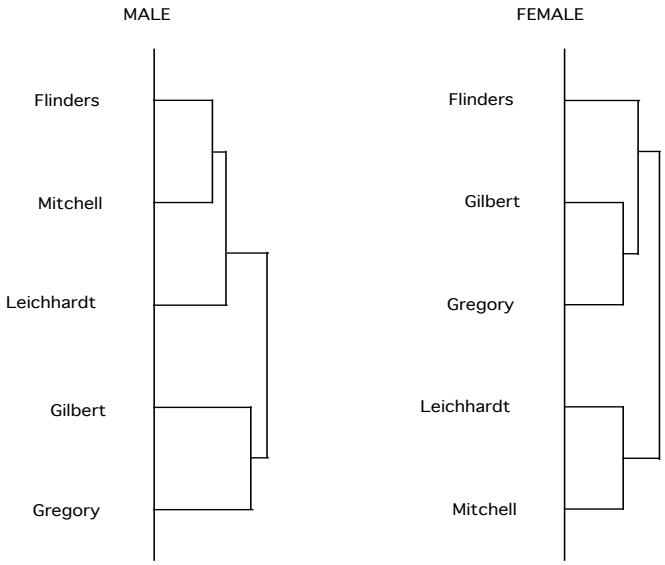


Figure 7.12 ***Dendrograms for five strains of redclaw classified on the basis of 16 morphological characters. Male, left; female, right.***

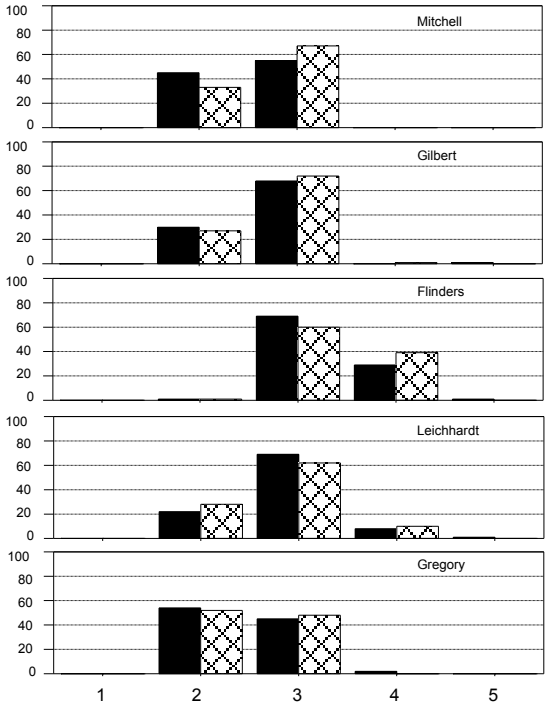


Figure 7.13 ***Percentage frequency of lateral rostral spine counts (left [solid] and right [hatched]) for five strains of redclaw.***

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

Despite the contention of several experienced redclaw fishers, general body coloration of redclaw cannot be used to distinguish between any of the five strains. Variability of body colour between and within each strain population in this study was significant. While some general trends were noticeable, they were not sufficiently consistent to discriminate between strains.

7.3.4 Reproductive Characteristics

Sex ratio. With the exception of Gregory, females were slightly more prevalent than males for each strain (Table 7.7). However, the difference in proportion was generally made up of inter-sex crayfish displaying external characteristics of both male and female. Internal examination of such animals previously (unpublished) has indicated that the majority are functionally male with partial or full testis development and no ovarian development at all. This observation is supported by the detailed examinations of Sagi et al. (1996).

Sexual Dimorphism.For each of the morphological characters, linear regression and subsequent comparison of regression statistics between males and females generated one of three outcomes as illustrated in Figure 7.13. Significantly different slopes were interpreted as different relative growth of the character for male and female, homogeneous slopes, but different intercepts indicated a fixed difference in the character between male and female over all sizes, and no differences in regression statistics for male and female indicated that the character was the same for each gender.

All regressions statistics are presented in Table 7.8. While numerous slope and intercept differences were found, they were not all consistent between strains. Those morphological characters for which very clear dimorphism was evident between male and female included abdominal width, telson length and width, and chela length and width. Significant differences between the sexes for other characteristics were evident for some strains only, were often statistically marginal and were likely to be less biologically significant.

Significant slope differences ($p < 0.01$) between male and female for abdominal width indicate that abdominal width increases at a greater rate in females than in males. Averaged over the five strains, the difference represents a 22% higher growth rate of abdominal width for females than males. There was a less significant indication that abdominal length was also proportionally greater for females than males.

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

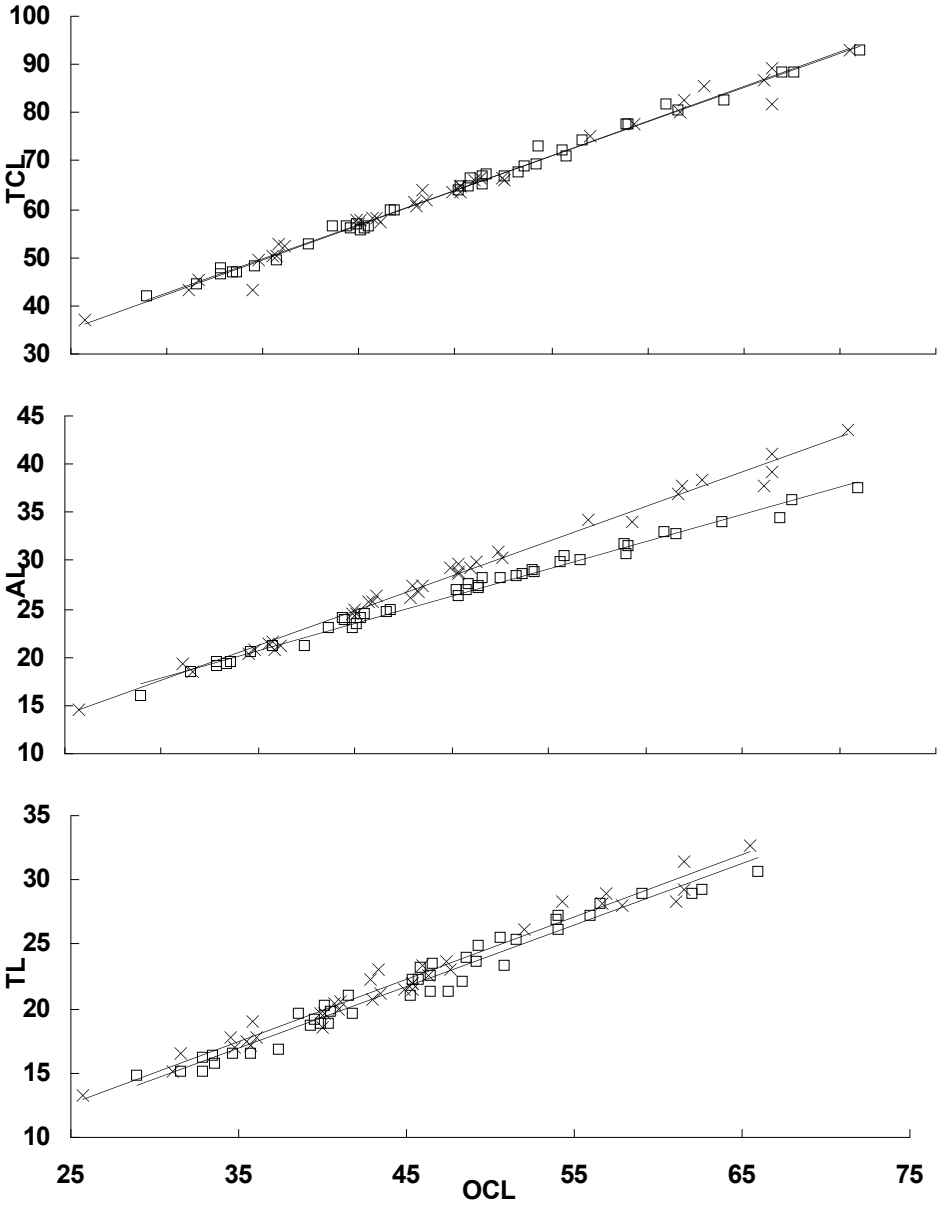


Figure 7.14 ***Regressions of total carapace length (TCL), abdominal length (AL) and telson length (TL) on ocular carapace length (OCL) for Flinders strain redclaw males (□) and females (X). The total carapace length plot illustrates male and female relationships for which slopes and intercepts were not significantly different, abdominal length illustrates significantly different slopes, and telson length illustrates slopes not significantly different, but intercepts significantly different.***

Telson dimension differences between male and female were of a fixed nature as indicated by significantly different intercepts ($p < 0.01$) for each strain except Leichhardt, for which a significantly different slope for both telson length and width indicated different relative growth for these characters. For Mitchell, Gilbert, Flinders and Gregory strains, the female telson was approximately 0.8mm longer and 0.5mm

wider than that of males over the entire size range. For Leichhardt, the female telson increased in length and width at a 10% higher rate than males.

The most significantly sexually dimorphic character relates to the growth of the chelae. For males of each strain, growth of chela length was over 50% greater, and growth of chela width over 100% greater than for females.

Size at Maturity. Bent stick analyses were able to identify discontinuous growth in several body parameters for each strain, although inconsistently. The inconsistency suggests that despite statistical significance, the biological significance may be minimal. This was confirmed by visual inspection of scatterplots which showed few clearly visible discontinuities as exemplified by chela length for Flinders males (Figure 7.15). Figure 7.15 also illustrates the chela width relationship for Flinders males for which the bent stick model was successfully fitted, but the discontinuity is difficult to visualise.

Where the bent stick model was successfully fitted, the point of transition was calculated and recorded as an estimate of size at maturity. For each strain and gender all estimates were pooled and a mean calculated (Table 7.9) for comparison with estimates generated elsewhere.

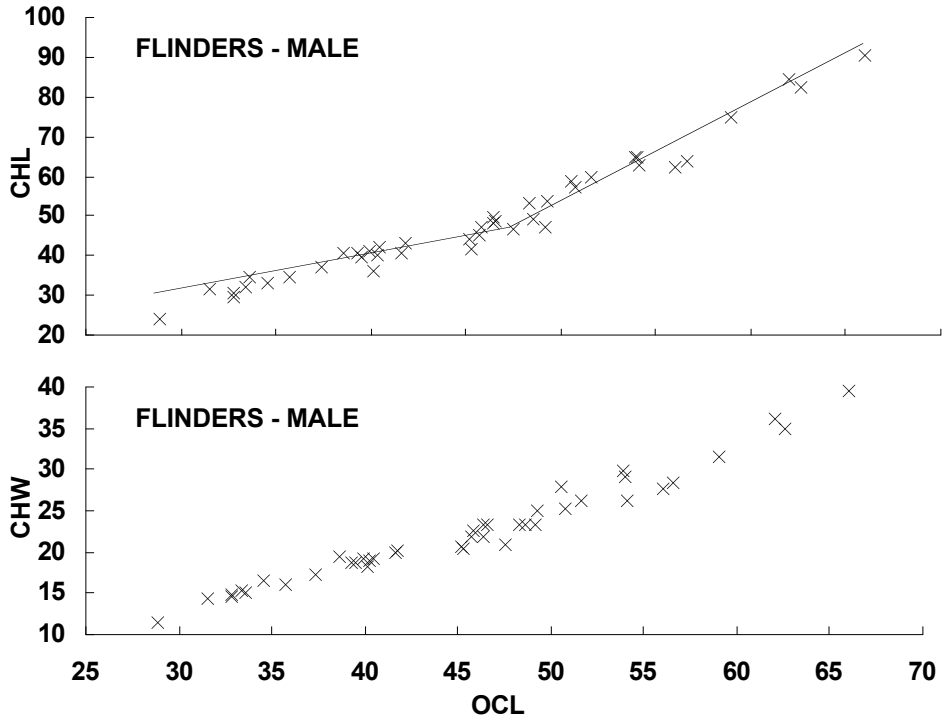


Figure 7.15 ***Scatterplots of chela length and chela width on ocular carapace length for male Flinders strain redclaw. For both relationships, a bent stick model was successfully fitted as illustrated by the regression lines plotted for chela length.***

Table 7.8 ***Regression statistics for relationships of 16 morphological characters on ocular carapace length for five strains of redclaw. Comparison of male and female regression statistics was based on t-tests. SD = significant difference (p < 0.01).***

Morphological Character	Strain	Slope		Intercept		Slope	Intercept
		male	female	male	female	SD	SD
Weight	Mitchell	0.0804	0.0804	0.4099	0.4099	N	N
	Gilbert	0.0689	0.0689	0.8694	0.8694	N	N
	Flinders	0.0682	0.0682	0.9187	0.8733	N	Y
	Leichhardt	0.0716	0.0716	0.7474	0.7474	N	N
	Gregory	0.0686	0.0686	0.9009	0.9009	N	N
TCL	Mitchell	1.4442	1.4442	-0.001	-0.158	N	Y
	Gilbert	1.4709	1.4709	-1.663	-0.757	N	Y
	Flinders	1.428	1.428	-0.246	-0.246	N	N
	Leichhardt	1.4427	1.4427	-1.866	-1.138	N	Y
	Gregory	1.4808	1.4808	-3.02	-1.931	N	Y
AL	Mitchell	1.0486	1.0486	4.39	5.47	N	Y
	Gilbert	1.038	1.038	5.178	6.963	N	Y
	Flinders	0.9725	1.092	6.04	2.57	Y	
	Leichhardt	1.1229	1.2322	0.521	-1.425	Y	
	Gregory	1.0484	1.0484	2.61	4.24	N	Y
AW	Mitchell	0.5985	0.7095	-0.612	-3.117	Y	
	Gilbert	0.5762	0.6816	0.403	-1.793	Y	
	Flinders	0.5636	0.7195	1.05	-3.955	Y	
	Leichhardt	0.6029	0.7313	-1.495	-4.314	Y	
	Gregory	0.5541	0.6929	1.15	-2.495	Y	
TL	Mitchell	0.5253	0.5253	-1.28	-0.647	N	Y
	Gilbert	0.4609	0.4609	0.014	0.713	N	Y
	Flinders	0.4803	0.4803	0.101	0.657	N	Y
	Leichhardt	0.4934	0.5433	-1.279	-2.55	Y	
	Gregory	0.483	0.483	-1.002	0.452	N	Y
TW	Mitchell	0.3519	0.3519	-0.189	0.254	N	Y
	Gilbert	0.3865	0.3865	-1.505	-0.908	N	Y
	Flinders	0.3619	0.3619	-0.589	-0.189	N	Y
	Leichhardt	0.357	0.3957	0.051	-0.893	Y	
	Gregory	0.3775	0.3775	-1.338	-0.591	N	Y
CD	Mitchell	0.6437	0.6437	0.093	0.093	N	N
	Gilbert	0.6801	0.6316	0.377	-1.231	Y	
	Flinders	0.6263	0.6263	0.522	0.522	N	N
	Leichhardt	0.6705	0.6705	-1.65	-1.65	N	N
	Gregory	0.6435	0.6435	0.461	0.273	N	Y
CW	Mitchell	0.5408	0.5408	0.338	0.338	N	N
	Gilbert	0.5993	0.5993	-2.531	-2.531	N	N
	Flinders	0.5435	0.5191	-1.048	0.092	Y	
	Leichhardt	0.512	0.512	1.051	1.67	N	Y
	Gregory	0.5839	0.5839	-2.824	-2.426	N	Y
TXW	Mitchell	0.6505	0.6505	-1.142	-1.142	N	N
	Gilbert	0.6743	0.6743	-2.759	-2.334	N	Y
	Flinders	0.6354	0.6354	-0.699	-0.699	N	N
	Leichhardt	0.6613	0.6613	-2.538	-2.538	N	N
	Gregory	0.6878	0.6878	-3.742	-3.257	N	Y
CHL	Mitchell	1.7105	1.119	-23.87	-6.42	Y	
	Gilbert	1.5736	1.2103	-20.28	-7.38	Y	
	Flinders	1.643	1.007	-25.65	-2.06	Y	
	Leichhardt	1.5808	1.0705	-16.08	-2.3	Y	
	Gregory	2.0394	1.291	-39.22	-9.95	Y	
CHW	Mitchell	0.5995	0.2658	-10	-0.63	Y	
	Gilbert	0.5076	0.2565	-7.19	1.03	Y	
	Flinders	0.5037	0.2709	-8.75	-0.68	Y	
	Leichhardt	0.5057	0.277	-5.188	-0.15	Y	
	Gregory	0.6348	0.253	-12.77	0.95	Y	
DL	Mitchell	0.6455	0.6455	-6.4	-6.4	N	N
	Gilbert	0.6187	0.6187	-4.903	-5.949	N	Y
	Flinders	0.6671	0.4917	-7.866	-0.86	Y	
	Leichhardt	0.6489	0.5049	-6.311	-1.716	Y	
	Gregory	0.7587	0.7587	-10.23	-11.39	N	Y

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

Table 7.9 ***Estimates of size at maturity for five strains of redclaw based on discontinuities in regressions of various morphological characters.***

	Mitchell		Gilbert		Flinders		Leichhardt		Gregory	
Parameter	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**
AL	46.44			55.11	51.58	44.58	64.09	48.62		
AW			44.15	41.40	43.28	48.84		57.44	46.03	
TL			45.70	52.10			39.98	54.61	47.02	49.91
TW					56.72				46.15	45.90
CD	37.04		61.71	61.71	39.89	48.30	39.47	52.94	47.07	47.35
TXW	48.91				43.28	43.33	36.14	38.47		
CHL	48.92		53.52		47.50	49.95	54.08			
CHW			39.02	46.73	47.77	47.73	52.78		41.90	
DL						54.28	48.95			
Mean OCL	45.33		48.82	51.41	47.15	48.14	47.93	50.42	45.63	47.72
Mean Wt	57.60		68.90	82.40	63.80	63.90	65.10	77.80	56.40	65.00

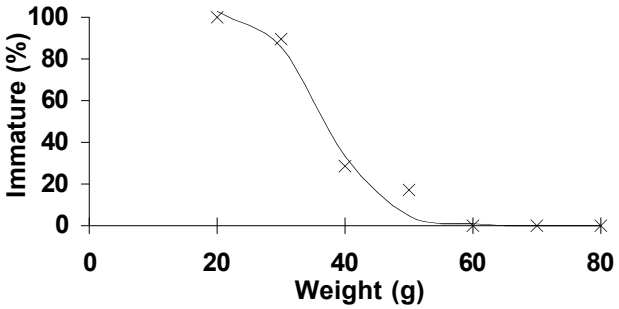


Figure 7.16 ***Relationship of maturity (% of size class immature) and size (g) for Gilbert River strain of redclaw.***

Table 7.10 ***Estimates of size (g) of five strains of redclaw at which 50% of females do not yet have fully developed ovaries, as derived from logistic functions. Parameter estimates are from the logistic function*** **$Y = M / [1 + \exp(-k(X-m))]$.**

Strain	Size (g)	Parameter estimates			R^2
	50% of crayfish with ovaries undeveloped	M	k	m	
Mitchell	37.7	84.439	-0.15828	40.058	0.9867
Gilbert	37.1	104.90	-0.22441	36.671	0.9834
Flinders	39.7	271.64	-0.046059	7.3766	0.8715
Leichhardt	58.1	106.62	-0.075972	56.44	0.9738
Gregory	56.5	100.12	-0.32023	56.532	0.9999

The relationship of percentage ovary maturity in relation to size for Gilbert strain is presented in Figure 7.16. Logistic curves of this type were fitted to data for each strain, and size at 50 % maturity was estimated. Estimates and the logistic equation statistics are presented in Table 7.10.

Logistic functions derived from the development of the male red patch in relation to total weight (Table 7.11) were used to provide estimates of size at maturity. For all strains, a logistic curve was successfully fitted, although that of Gilbert was weakest due to a number of very small crayfish with red patch development. In comparison to the size at maturity estimates derived from morphometric discontinuities, these estimates are smaller in all instances, and particularly for Mitchell and Gilbert strains. While the red patch is a distinct male characteristic, its relationship with sexual maturity has not been closely investigated. On the basis of these analyses, it would appear that its development does not directly correspond to the attainment of sexual maturity, and that it may develop prior to sexual maturity. Nevertheless, the estimates provide a relative measure of the size at which the five strains mature, and support the contention based on the morphometric data (for male and female) and the ovarian development data, that size at maturity is largest for Flinders, and progressively smaller for Gregory, Leichhardt, Mitchell and Gilbert. Estimates of size at maturity are summarised in Figure 7.17.

Table 7.11 ***Estimates of size (g) of five strains of redclaw at which 50% of males do not yet have a fully developed red patch on their chelae, as derived from logistic functions. Parameter estimates are from the logistic function*** **$Y = M / [1 + \exp(-k(X-m))]$.**

Strain	Size (g)	Parameter estimates			R^2
	50% of crayfish with red patch not fully developed	M	k	m	
Mitchell	14.1	142.42	-0.16042	10.315	0.9991
Gilbert	12.5	152.68	-0.039162	-5.8891	0.8743
Flinders	38.7	102.18	-0.16602	38.428	0.9985
Leichhardt	30.3	106.09	-0.10396	29.172	0.9882
Gregory	35.2	102.5	-0.12439	34.832	0.9992

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

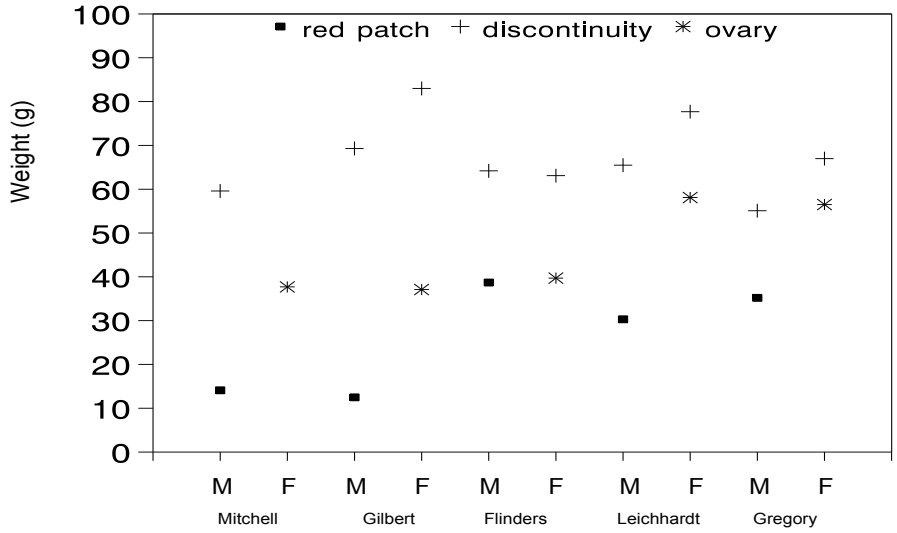


Figure 7.17 ***Comparison of estimates of size at maturity for five strains of male and female redclaw as derived from assessment of red patch development (male only), ovary development (female only) and discontinuities in growth of various morphological characters.***

Fecundity. Regression analyses indicated no significant difference in the fecundity / size relationship between strains. Figure 7.18 shows the relationship of fecundity and ocular carapace length for each strain. This relationship can be expressed by a common linear function where,

Egg number = 15.26 x ocular carapace length (mm) - 447

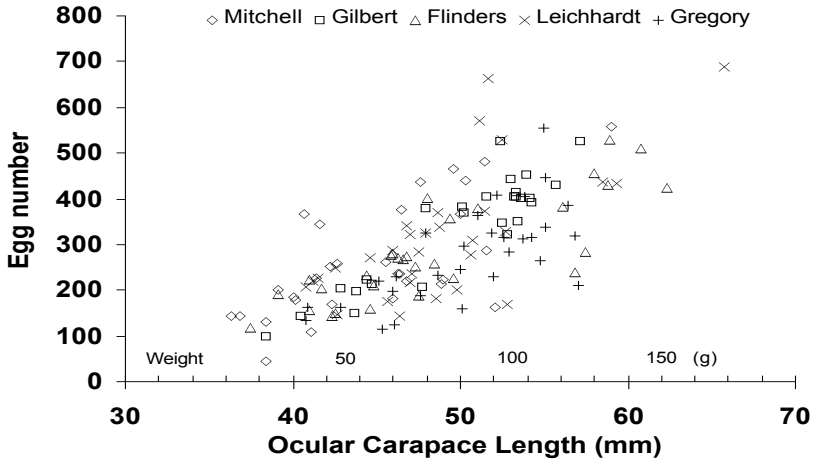


Figure 7.18 ***Egg number (pleopodal egg count) / carapace length relationship for five redclaw strains. Weights at 50g increments are presented at equivalent carapace lengths to clarify size.***

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

7.3.5 Growth

Tag and recpature data are detailed in Appendix 10.6.6.

Sufficient numbers of recaptured tagged crayfish were avaialble to generate growth curves for Mitchell, Flinders, Leichhardt and Gregory strains (Figure 7.19). However, in view of the small sample size and lack of replication, no attempt was made to describe the mathematical function of each curve, or to compare the curves statistically. The trends indicated, support the contention that Mitchell displays relatively low growth rate. Growth rate of Flinders, Leichhardt and Gregory, as interpreted from slope, was similar. The apparent superiority of the Gregory curve was heavily influenced by a few data for smaller younger animals.

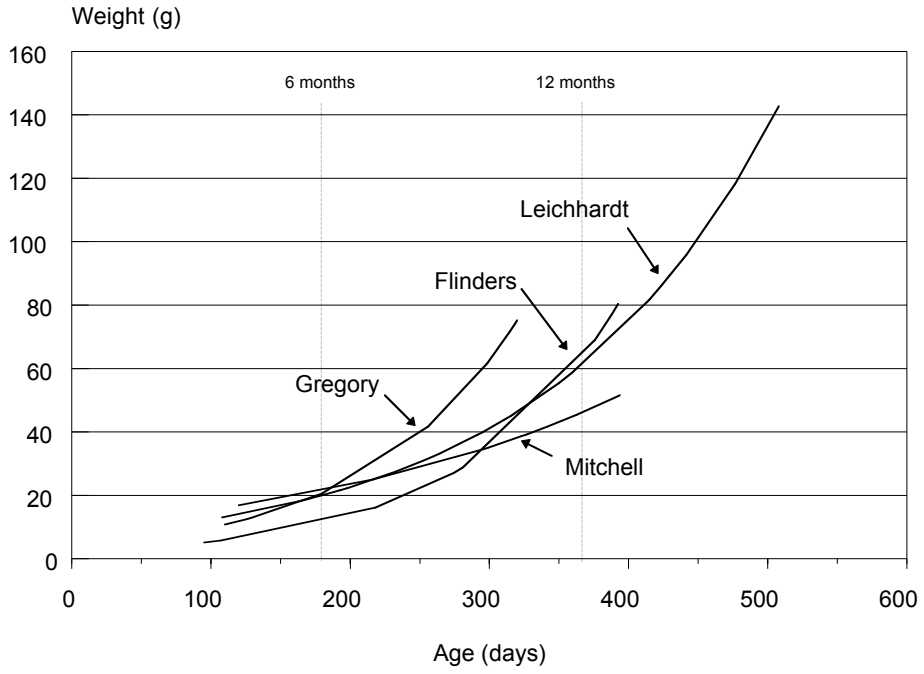


Figure 7.19 ***Growth curves for four redclaw strains cultured under equivalent conditions in earthen ponds. Data generated from tagged individuals using a progressive plotting technique as described above.***

7.4 Discussion

Interpretation of results from this comparison of five strains of redclaw is inconclusive given the absence of any replication in the experimental design. Despite some clear and significant differences in some parameters between strains, without replication it is not

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

possible to conclude that such differences are fixed and genetically based. While every effort was made to provide uniform environmental conditions to the culture ponds, and they appeared to behave uniformly throughout the culture period, subtle differences may have influenced the biological / production performance of the different strains. Furthermore, there were subtle differences in the stocking characteristics for each strain. Such differences may have been amplified over the culture period. Notwithstanding these comments, some of the differences demonstrated were clear, and given their economic significance should be considered.

Similar studies have employed a variety of methods to assess the separateness of geographically discrete groupings of various crustacean species. These have generally been of a morphological nature involving linear, meristic or multistate measurements or descriptive characters, or biochemical involving allozyme electrophoresis, isoelectric focusing, mitochondrial DNA analyses, RAPD or PCR analyses. Several of these methods have now been applied to the assessment of redclaw from different river catchments, both in this study and those of Austin (1986) and Macaranas et al. (1994). On the basis of these methods and the characteristics they relate to, it is clear that degree of variability within each strain is substantial, but the differences between strains are minimal. From a general morphological perspective, differences between strains were insignificant, and therefore there was no relative aquacultural advantage of one strain over another in terms of body shape or characteristics. While the homogeneity of allozymes amongst the strains is typical of many crustaceans (Redfield et al., 1980; Busack, 1988; Benzie et al., 1992; Macaranas et al., 1994), morphological differences between populations are not uncommon (Cohen et al., 1981; Malecha, 1983; Jones, 1990; Campbell et al., 1994). Fetzner (1996) has provided strong argument against the use of allozyme analysis for distinguishing groups below a sub-generic level.

Despite the contention of experienced redclaw aquaculturists that different strains of redclaw may be distinguished on the basis of colour, the variability of colour observed in this study was contradictory. Although colour differences between sub-populations of crayfish have been noted, the dependence of colour on environmental conditions suggests there is little gentic basis to recognised colour morphs (Thacker et al., 1993).

Differences in regard to production characteristics between strains however were significant. The genetic basis of these differences and their relative heritability could have important implications for the development of the redclaw aquaculture industry. Craig and Wolters (1988) demonstrated that differences in several economically important traits measured for *Procambarus clarkii* from different populations were genetically based and significantly heritable. This is despite the homeogeneous nature of *P. clarkii* based on allozyme analysis (Busack, 1988) and attributed to wide translocation of stock. Given that the redclaw strains have not been subjected to such translocations, and despite the relative homogeneity based on morphology and allozymes, there is cause for some optimism that the perceived differences in production characteristics have considerable genetic basis and may respond positviely to selection.

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

The nature of the differences clearly demonstrated the superiority of Flinders strain. Total yield was 38% higher than the yield for the next best strain, Leichhardt. However, the method employed to compare the production of the five strains is not directly representative of industry 'best practice'. Highest yields are achieved when fixed densities of advanced juveniles are stocked and grown to market size quickly, and within a management regime which minimises reproduction amongst the growout stock. As a production strategy, stocking a pond with breeding stock and allowing multiple cohorts of juveniles to recruit and progress through to market size is likely to be substantially less productive than the growout of a single cohort. Consequently, the results of this trial are likely to underestimate the production capacity of each strain under a best practice management regime. On this basis, the production characteristics of the Flinders strain are particularly attractive.

Population structure characteristics were generally similar for the five strains. Interpretation of the size frequency distributions suggested that some Gilbert strain individuals displayed the fastest growth rate. The April sample in particular showed relatively higher proportions of Gilbert crayfish in the largest size classes. However, discriminating between original broodstock and fast growing juveniles was not possible, and specific experimentation would be required to determine relative growth rate. Slow growth was evident for all strains from June to August reflecting low temperature. As maximum temperature was generally below 20°C over this period, this was to be expected (Jones, 1995c). To clarify the relative performance of the strains in relation to temperature would also necessitate specific experimentation.
The shape of the size distributions, particularly at harvest has some important economic implications. Flat distributions as exemplified by Gregory, are less desirable, as they represent a greater spread of sizes which is disadvantageous for marketing. Flinders and Mitchell displayed the most uniformity of size, although the mean size of Flinders (41g) was substantially greater than Mitchell (32g).

Reproductive characteristics were also generally similar for each strain. Small differences in sex ratio are not likely to be significant, although the increased proportion of intersex crayfish for Mitchell is disadvantageous. Sexual dimorphism was clearly demonstrated for each strain, but there were no consistent differences between strains. Abdominal width was consistently greater for females by a factor of 22% on average. Such a dimorphism is common amongst decapod crustaceans, and reflects the requirement of females to carry eggs (Felder and Lovett, 1989; Hardwick and Cline, 1990; Jones, 1990; Gu et al., 1994; Lutz and Wolters, 1995; Sarda et al., 1995). Similarly, more subtle but clear differences in abdominal length, and telson length and width reflect the same capacity. Chela dimensions were also clearly different between the sexes. The relatively greater size of the chelae and presence of the red patch for males, are likely to be attributable to a sexual recognition function rather than a requirement for greater strength, or crushing capacity. Similar dimorphisms have been demonstrated for other freshwater crayfish (Weagle and Ozburn, 1970; Gu et al., 1994).

Size at maturity estimates for the five strains were confounded by the variability between methods employed. Wenner et al. (1985) have discussed the difficulties of generating such estimates for crustaceans, and the anomalies that different methods possess. Estimates of size at maturity are important in managing captive populations and particularly for a reproductively liberal species such as redclaw. Minimising reproduction during growout is a critical requirement, and necessitates good estimates of the size at which reproduction becomes possible. Moreover, using specific stock which possess a relatively larger size at maturity may be advantageous. For stock to achieve an acceptable market size prior to reaching sexual maturity is a desirable and economically important characteristic. Unfortunately, the estimates from this study were so variable (Figure 7.17) they precluded effective comparison between strains. More exhaustive examination of size at maturity for redclaw based on larger samples and a greater size range are warranted.

Such examinations would be best made on gonad development. Despite the utility of morphological characters for estimating size at maturity for a range of other crustaceans (Grey, 1979; Hartnol, 1985; Jewett et al., 1985; Aiken and Waddy, 1989; Felder and Lovett, 1989; Montgomery, 1992), those examined for redclaw appear to be unhelpful. Assessment of red patch development gave much smaller estimates than assessment of morphometric discontinuities. The link between the appearance of the red patch on the chelae of male redclaw and sexual maturity has only been surmised. It would appear on the strength of these data that the red patch may develop well before the attainment of sexual maturity. For Mitchell and Gilbert strains in particular, substantial proportions of very small crayfish possessed the red patch, and it is unlikely that such small individuals would have been sexually mature. Similarly, the morphometric discontinuities examined were generally unconvincing. Where such discontinuities have been used to estimate size at maturity they were very clear and unambiguous (Grey, 1979; Somerton, 1980; Hartnoll, 1985; Montgomery, 1992). Although there are many other morphological characters which may be examined for redclaw, none are likely to possess the discontinuous growth attendant to maturity, so clearly evident for other species.

Gu et al. (1994) in an invetigation of size at maturity in redclaw found similar discontinuities in the growth of chela length and width for males. They generated estimates of size at maturity of 43mm and 45mm total carapace length, based on chela length and width respectively. Their estimates correspond to measurements of 30.3 and 31.7mm OCL and 18.8g and 20.9g total weight. These estimates are well below those determined in this study (Table 7.X), and highlight the danger of using one method only in generating such estimates.

Fecundity relationships were quite variable within each strain, and no difference between strains could be ascertained. Growth rate estimates derived from recaptured tagged crayfish provide useful information about redclaw. However, they were not sufficiently exhaustive to provide a comprehensive comparison between strains. Mitchell did appear to have the poorest growth rate, but the superior growth rate of Gregory is likely to have been unduly influenced by a few data for smaller crayfish. Furthermore, the mean growth rate of

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

Gregory stock may have been positvely influenced by the lower density of this strain. The lower density of Gregory resulted in lower biomass and yield, and from this perspective this strain was inferior.

The complexity of interactions between the various biological and population dynamics cannot be overlooked in drawing conclusions from this study. To account for the impact of such interactions, further more intensive research, involving considerable replication, is required to fully assess the relative merits of the strains examined. Nevertheless, the study has generated useful baseline information about a range of biological parameters for redclaw, and provides a strong indication that of the strains assessed, Flinders and Gilbert possess several advantageous characteristics, and Mitchell display several inferior and disadvantageous characteristics.

7.5 References

Aiken, D.E. and Waddy, S.L. 1989. Allometric growth and onset of maturity in male American lobsters (*Homarus americanus*): The crusher propodite index. Journal of Shellfish Research, 8(1):7-11.

Austin, C.M. (1986) Electrophoretic and morphological systematic studies of the genus *Cherax* (Decapoda: Parastacidae) in Australia. Ph.D. Dissertation, University of Western Australia, Perth.

Benzie, J.A.H., Frusher, S. and Ballment, E. 1992. Geographical variation in allozyme frequencies of populations of *Penaeus monodon* (Crustacea: Decapoda) in Australia. Australian Journal of Marine and Freshwater Research, 43(4):715-726.

Bosworth, B.G., Wolters, W.R. and Saxton, A.M. 1994. Analysis of diallel cross to estimate effects of crossing on performance of red swamp crawfish, *Procambarus clarkii*. Aquaculture, 121:301-312.

Boyd, C.E. 1990. Water Quality in Ponds for Aquaculture. Auburn University, Auburn, Alabama, USA.

Busack, C.A. 1988. Electrophoretic variation in the red swamp (*Procambarus clarkii*) and white river crayfish (P.acutus)(Decapoda: Cambaridae). Aquaculture, 69:211-226.

Campbell, N.J.H., Geddes, M.C. and Adams, M. 1994. Genetic variation in yabbies, *Cherax destructor* and *C. albidus* (Crustacea, Decapoda, Parastacidae), indicates the presence of a single, highly sub-structured species. Australian Journal of Zoology, 42(6):745-760.

Clayton, D.A. 1990. Crustacean allometric growth: A case for caution. Crustaceana, 58(3):270-290.

Cohen, D., Raanan, Z. and Brody, T. 1981. Population profile development and morphotypic differentiation in the giant freshwater prawn *Macrobrachium rosenbergii* (de Man). Journal of the World Mariculture Society, 12:231-243.

Craig, R.J. and Wolters, W.R. 1988. Sources of variation in body size traits, dressout percentage and their correlations for the crayfish, *Procambarus clarkii*. Aquaculture, 72:49-58.

Felder, D.L. and Lovett, D.L. 1989. Relative growth and sexual maturation in the ghost shrimp *Callianassa louisianensis* Schmitt. Journal of Crustacean Biology, 9:540-553.

Fetzner, J.W.J. 1996. Biochemical systematics and evolution of the crayfish genus *Orconectes* (Decapoda: Cambaridae). Journal of Crustacean Biology, 16(1):111-141.

Fevolden, S.E., Taugbol, T. and Skurdal, J. 1994. Allozymic variation among populations of noble crayfish, *Astacus astacus* L., in southern Norway: implications for management. Aquaculture and Fisheries Management, 25:927-935.

Fielder, D.R. 1990. Research to focus on future needs. In: Macreadie, M. (ed) Australian Fisheries: Aquaculture Special: Redclaw. Australian Government Publishing Service, Canberra, Vol.49(11):44-45.

Grey, K.A. 1979. Estimates of the size at first maturity of the western rock lobster *P.cygnus* using secondary sex characters. Australian Journal of Marine and Freshwater Research, 30(6):785-791.

Gu, H., Mather, P.B. and Capra, M.F. 1994. The relative growth of chelipeds and abdomen and muscle production in male and female redclaw crayfish, *Cherax quadricarinatus* von Martens. Aquaculture, 123:249-257.

Hardwick, C.W.J. and Cline, G.B. 1990. Reproductive status, sex ratios and morphometrics of the slipper lobster *Scyllarides nodifer* (Stimpson)(Decapoda: Scyllaridae) in the northeastern Gulf of Mexico. Northeast Gulf Science, 11(2):131-136.

Hartnoll, R.G. 1985. Growth, sexual maturity and reproductive output. In: Wenner, A.M. (ed) Factors in Adult Growth, Crustacean Issues Vol.3. A.A.Balkema, Rotterdam.:101-128.

Hedgecock, D. 1983. Maturation and spawning of the American lobster, *Homarus americanus*. In: McVey, J.P. (ed) CRC Handbook of Mariculture, Vol 1. Crustacean Aquaculture. CRC Press Inc., Florida.:261-270.

Herbert, B. 1987. Note on *Cherax quadricarinatus* from the Jardine River, Cape York

Peninsula. Queensland Naturalist, 28(1-4):19-21.

Hutchings, R. 1988. Aquaculture of *Cherax quadricarinatus*. Small Farmers (Queensland), 1988:9-10.

Jewett, S.C., Sloam, W.A. and Somerton, D.A. 1985. Size at sexual maturity and fecundity of the fjord-dwelling golden king crab *Lithodes aequispina* Benedict from Northern British Columbia. Journal of Crustacean Biology, 5(3):377-385.

Jones, C.M. 1990a. The Biology and Aquaculture Potential of the Tropical Freshwater Crayfish, *Cherax quadricarinatus*. In: Queensland Department of Primary Industries Information Series, QI90028: . Queensland Department of Primary Industries, Brisbane:109p.

Jones, C.M. 1990b. Morphological characteristics of Bay Lobsters (Decapoda, Scyllaridae) (*Thenus* spp.) from Northern Australia. Crustaceana, 59(3):265-275.

Jones, C.M. 1995a. Effect of temperature on growth and survival of the tropical freshwater crayfish, *Cherax quadricarinatus* (von Martens)(Decapoda, Parastacidae). Freshwater Crayfish, 8:391-398.

Jones, C.M. 1995b. Production of juvenile redclaw crayfish, *Cherax quadricarinatus* (von Martens)(Decapoda, Parastacidae) I. Development of hatchery and nursery procedures. Aquaculture, 138(1995):221-238.

Jones, C.M. 1995c. Production of juvenile redclaw crayfish, *Cherax quadricarinatus* (von Martens)(Decapoda, Parastacidae) II. Juvenile nutrition and habitat. Aquaculture, 138(1995):239-245.

Jones, C.M. and Curtis, M.C. eds 1994. Redclaw Farming. Proceedings of the Redclaw Farming Workshops, Feb.12-17, 1994, Walkamin, Rockhampton, Nambour. Queensland Department of Primary Industries,

Jones, C. and McPhee, C. 1993. Selection processes in the aquaculture of redclaw. Austasia Aquaculture, 7(3):49-50.

Lobegeiger, R. 1995. Aquaculture Production Survey Queensland 1994/95. Report to Farmers. Queensland Australia, Aquaculture Information Series: Queensland Department of Primary Industries.

Lutz, C.G. and Wolters, W.R. 1995. Multivariate morphological variation in a population of red swamp crawfish, *Procambarus clarkii* (Girard). Freshwater Crayfish, 8:56-67.

Macaranas, J.M., Mather, P.B., Hoeben, P. and Capra, M.F. 1995. An investigation of the population genetics of the freshwater crayfish, *Cherax quadricarinatus* using allozyme and

RAPD-PCR markers. Marine and Freshwater Research, 46(1995):1217-1228.

Maguire, G.B. and Leedow, M.I. 1983. A study of optimum stocking density and feed rate for school prawns *Metapenaeus macleayi* (Haswell) in some Australian brackish water farming ponds. Aquaculture, 30:285-297.

Malecha, S.R. 1983. Crustacean genetics and breeding: an overview. Aquaculture, 33:395-413.

Montgomery, S.S. 1992. Sizes at first maturity and at onset of breeding in female *Jasus verreauxi* (Decapoda: Palinuridae) from New South Wales waters, Australia. Australian Journal of Marine and Freshwater Research, 43(6):1373-1392.

Payne, R.W., Lane, P.W., Digby, P.G.N., Harding, S.A., Leech, P.K., Morgan, G.W., Todd, A.D., Thompson, R., Tunnicliffe Wilson, G., Welham, S.J. and White, R.P. 1993. Genstat 5 Release 3 Reference Manual. Oxford University Press, Oxford

Redfield, J.A., Hedgecock, D., Nelson, K. and Salini, J.P. 1980. Low heterozygosity in tropical marine crustaceans of Australia and the trophic stability hypothesis. Marine Biology Letters, 1:303-313.

Sagi, A., Khalaila, I., Barki, A., Hulata, G. and Karplus, I. 1996. Intersex red claw crayfish, *Cherax quadricarinatus* (von Martens): Functional males with pre-vitellogenic ovaries. Biological Bulletin, 190:16-23.

Sarda, F., Bas, C. and LLeonart, J. 1995. Functional morphometry of *Aristeus antennatus* (Risso, 1816) (Decapoda, Aristeidae). Crustaceana, 68(4):461-471.

Somerton, D.A. 1980. A computer technique for estimating the size of sexual maturity in crabs. Canadian Journal of Fisheries and Aquatic Science, 37:1488-1494.

Tave, D. 1992. Creating a synthetic strain. Aquaculture Magazine, 18(5):72-74.

Thacker, R.W., Hazlett, B.A., Esman, L.A., Stafford, C.P. and Keller, T. 1993. Color morphs of the crayfish *Orconectes virilis*. American Midland Naturalist, 129(1):182-199.

Weagle, K.V. and Ozburn, G.W. 1970. Sexual dimorphism in the chela of *Orconectes virilis*. Canadian Journal of Zoology, 48:1041-1042.

Wenner, A.M., Page, H.M. and Siegel, P.R. 1985. Variation in size at onset of egg production. In: Wenner, A.M. (ed) Factors in Adult Growth, Crustacean Issues Vol.3. A.A.Balkema, Rotterdam.:149-164.

8. Polyculture of redclaw crayfish, *Cherax quadricarinatus* and silver perch, *Bidyanus bidyanus*, in earthen ponds, in northern Australia.

8.1 Introduction

Redclaw *Cherax quadricarinatus*, is a tropical freshwater crayfish endemic to north-eastern Australia, which has been recognised as an excellent candidate for aquaculture (Gillespie, 1990; Jones, 1990; Treadwell et al., 1991; Jones and Barlow, 1992). Aquaculture production of redclaw in Australia now exceeds 80 tonnes per year (Curtis and Jones, 1995b) and offshore production, particularly from Ecuador and parts of south-east Asia, is also likely to become significant (Rouse, 1995; Jones, 1995b). In Australia, redclaw aquaculture is characterised by a semi-intensive approach in purpose-built earthen ponds (Curtis and Jones, 1995b). Yields in excess of 2,000 t/ha/yr and as high as 3,500 t/ha/yr are achievable when a best practice management regime as defined by Jones (1995b; 1995c; 1996) is applied.

Economic circumstances prevailing in Australia demand that such yields are achieved to maintain commercial viability. Relatively high establishment and labour costs (Treadwell, et al., 1991; Hinton, 1994) necessitate that returns per hectare of ponds be maximised, and current research is aimed at improving yields through development of nutritionally complete and cost-effective diets (Jones, 1995a), and development of superior genetic lines of stock through selection and hybridisation (Jones and McPhee, 1993). A further possibility for increasing returns per area of production is to polyculture redclaw with another compatible species.

There are currently few suitable candidates for which production technology is established. Recent developments in Australia of silver perch (*Bidyanus bidyanus*) aquaculture (Rowland, 1995a; 1995b; Rowland et al., 1995) suggest that this species has great potential as a monoculture species. Many of its attributes however also suggest that it may be suited to polyculture with redclaw. The basic growout technology is now established, silver perch perform well on a pellet diet, the uneaten portion of which is likely to benefit redclaw production, it is hardy and prefers water quality conditions similar to those of redclaw, and some market demand for the product has been established (Rowland and Bryant, 1995).

Notwithstanding these positive attributes, an additional advantage of polyculturing silver perch with redclaw is the potential for the fish to control recruitment of juvenile crayfish to the pond population. Silver perch is omnivorous and will consume a variety of materials including plankton, aquatic vegetation and benthic invertebrates (Barlow et al., 1986). Although Barlow et al. (1986) did not find any yabbies (*Cherax destructor*) in the guts of silver perch from farm dams, subsequent investigations have confirmed the capacity of silver perch to predate on small yabbies (Barlow,

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

pers.comm.) and marron (*C.tenuimanus*) (Whisson, 1995). Although Whisson (1995) found that larger silver perch predated upon large marron in tanks, subsequent pond studies contradicted this. Barlow (pers.comm.) contends that because silver perch has a relatively small mouth, only small yabbies (<5g) can be ingested by silver perch up to 1kg in weight. The larger marron predated by silver perch in Whissons (1995) tank study are likely to have been consumed while in soft, post-moult condition. On the basis of these previous studies, silver perch stocked with larger redclaw, or at least stocked as juveniles together in ponds, are unlikely to predate on the crayfish stocked, but may consume any juveniles generated from reproduction of the primary crop. The precosiouness of redclaw has been well documented (Curtis and Jones, 1994; 1995a), and a control mechanism which minimises the recruitment of secondary stock and provides direct economic benefits would be advantageous.

Although silver perch is endemic to north-eastern New South Wales, it suitability to a much broader geographic area has been demonstrated (Rowland, 1995b). Silver perch have previously been spawned and reared at Walkamin in far north Queensland (Barlow, pers.comm.) and fingerlings are available from numerous commercial hatcheries throughout Queensland. To evaluate the suitability of redclaw and silver perch polyculture, a preliminary assessment was made in 1993 to establish appropriate production protocols, followed by a more comprehensive production trial in 1994/95. Both studies are reported here.

Specific objectives were to determine base production levels of redclaw and silver perch when grown together, to quantify the comparative production level of redclaw and silver perch when grown in isolation and together, and to evaluate the impact silver perch have on juvenile redclaw production in polyculture ponds.

8.2 Methods and Materials

8.2.1 Preliminary Assessment

This work was conducted at the Freshwater Fisheries and Aquaculture Centre, Walkamin (17.1°S, 145.5°E) over the period January to October 1993. Four 1,000m^2 earthen ponds were prepared with applications of lime, inorganic and organic fertiliser and crayfish shelters as specified in Table 8.1. Two treatments with two replicates were applied to the ponds; i) redclaw monoculture; ii) redclaw and silver perch (free range) polyculture.

Table 8.1 ***Applications (per 1,000m^{2}pond) made to redclaw / silver perch polyculture ponds prior to filling.***

Material	Quantity
Agricultural Lime	100kg
Diammonium phosphate fertiliser	20kg
Urea	20kg
Lucerne chaff	100kg
Crayfish shelters - pipe stacks	50
Crayfish shelters - mesh bundles	60

Each pond was equipped with an equivalent number and specification of artificial shelters. These consisted of 50 pipe stacks and 60 mesh bundles. The pipe stack was a fixed structure consisting of twenty-four 250mm lengths of 80mm diameter corrugated polyethylene pipe, placed in a stack 3 high by 8 wide. Steel fencing clips were used to secure each pipe to adjacent pipes. A 240mm x 640mm piece of rigid plastic mesh was attached to one side of the structure so that crayfish access was from one end only. One pipe on the bottom row was filled with concrete to facilitate sinking and to ensure that the habitat remained upright. The mesh bundle shelter was made from strips of a synthetic mesh (Oyster Mesh, Southcorp Industrial Textiles Pty Ltd.) attached to a rope which was weighted at one end, and suspended from the pond surface at the other. Each bundle was of an equivalent size and was made from 12 strips of material (1m x 10cm lengths) tied on their longitudinal centres to the main rope.

Redclaw were stocked as a combination of juveniles (330 per pond, mean weight 6.0g) and berried females (55 per pond, mean weight 70g).

Silver perch fry (mean weight 0.5g) were purchased from a commercial hatchery in southern Queensland. Upon arrival at Walkamin, they were released into fibreglass tanks and treated with sodium chloride at 10g/l for one hour and methylene blue at 1mg/l for 24 hours. Fish were then released into their designated ponds at a density of 1,000 fish per pond (10,000/ha).

Aeration was provided in the form of 6 airlift pumps per pond. Each airlift consisted of a 1.5m length of 90mm diameter PVC pipe, secured to a concrete weight, and supplied with approximately 80 l/min of air at 0.4kPa through a 12mm diameter polyethylene pipe at a depth of approximately 1.0m. Airlifts were operated continuously.

Ponds were maintained according to established practices (Jones and Curtis, 1994) with regular measurements of water quality parameters and regular applications of fertiliser to maintain a plankton bloom. pH, dissolved oxygen, minimum and maximum temperature and secchi depth were measured once per week. Total ammonia nitrogen, was measured once per month.

Both the silver perch and redclaw were fed according to established practices (Rowland 1995a and Jones and Curtis, 1994 respectively). For the silver perch, a 2mm crumble (Kinta silver perch diet) was used for the first 7 weeks, followed by a 3mm extruded pellet (Kinta). Fish were fed once per day (pm) (7 days per week) at a fixed feeding point, and according to a notional feed schedule. Crayfish were fed (Athmaize crayfish diet) independently at an equivalent rate in all ponds, once per day (pm) (5 days per week) broadcast around the pond, at a rate specified in a notional feed schedule. Feed rates were adjusted on the basis of observation of feeding activity and uneaten food, and amounts recorded.

Although this trial was planned to run over 12 months, strong evidence of significant bird predation prompted harvesting after 9 months. Harvesting was achieved by complete drainage of the pond. Crayfish were captured in a flow trap (Jones and Curtis, 1994) and fish were removed with hand nets from a concrete fish-out box in the base of the pond. Total weight of fish and crayfish harvested was measured, and individual weight and length measurements were taken from samples of each.

An index of economic return (after Maguire and Leedow, 1983) was also calculated to provide a suitable parameter for comparing monoculture and polyculture.

Economic return = Value of crop (Y_C) - Cost of original stock (Y_S) - Cost of feed provided (Y_F)

Cost of original stock Y_S was estimated to be \$0.10 each for the juvenile redclaw and \$15.00 per kg for the broodstock. Silver perch fingerlings were purchased for \$0.15 each. Cost of feed Y_F = \$0.40 per kg for redclaw and \$0.90 per kg for silver perch. Value of the crayfish crop Y_C was based on an average price of \$14.00 per kg (Lobegeiger, 1995). Silver perch were valued at \$10.00 per kg, an average price paid at the Sydney Fish Market.

8.2.2 Production Trial

The production trial was conducted in the same pond facility at the Freshwater Fisheries and Aquaculture Centre, Walkamin (17.1°S, 145.5°E) over the period October 1995 to April 1996. An additional two ponds were allocated to a third treatment, and all ponds were enclosed in a bird-proof netting enclosure. The treatments were i) redclaw monoculture, ii) silver perch monoculture and iii) redclaw and silver perch (free range) polyculture. There were two replicates for each treatment.

Silver perch fry (0.5g) were purchased from a commercial hatchery in southern Queensland. Upon arrival at Walkamin, they were released into fibreglass tanks and treated with sodium chloride at 10g/l for one hour and methylene blue at 1mg/l for 24 hours. The fry were then introduced to a prepared pond in which a zooplankton bloom has been established. Stocking rate was 10,000 fry to one 1,000m^2 pond (100,000 /ha). Fry were fed Kinta

silver perch crumble twice per day (0900 and 1500) at approximately 5% of body weight. Fingerlings were harvested after 7 months and graded. Four equivalent batches of 1,000 fish of uniform size (mean 18g) were then separated for stocking to the experiment. To minimise handling and expedite re-stocking of the fish, they were not salt-bathed prior to stocking.

Redclaw were stocked as berried females. Each redclaw pond received 100 berried females (mean weight 70g). Based on previous experience (Jones, 1995d; Jones et al., 1996), the release of 100 berried females is likely to have resulted in a juvenile (>1g) stocking density of between 5 and 10 per m^2 within six weeks of release. Stocking of both fingerling fish and berried female redclaw occurred on October 12, 1995. Ponds were prepared and maintained as described previously (Table 8.1).

At the completion of the trial, each pond was drained and harvested over successive days using a flowtrap (Jones and Curtis, 1994) for crayfish and manual removal of fish from a concrete fish-out box in the base of the pond. Total yield (i.e. total weight) was determined for both crayfish and fish, and a representative sample of approximately 500 crayfish was examined for individual determination of sex and weight. All fish were weighed and measured for standard length.

8.3 Results

8.3.1 Preliminary Assessment

Water quality data for the culture period are presented in Appendix 10.7.1. All parameters measured remained within normal tolerances of both redclaw (Jones and Curtis, 1994) and silver perch (Rowland, 1995c). As had been anticipated, bird predation of silver perch primarily attributed to cormorants *Phalacrocorax* spp., was significant. For the two polyculture ponds, one yielded only 10kg of fish and the other 201kg (Table 8.2).

Table 8.2 ***Harvest statistics for preliminary assessment of redclaw / silver perch polyculture.***

Statistic	Redclaw monoculture	Redclaw monoculture	Redclaw polyculture	Redclaw polyculture	Silver Perch polyculture	Silver Perch polyculture
Pond	3	5	4	6	4	6
Yield (kg)	99.6	140.9	62.2	67.3	10	201
Number (>1g)	1,911	3,874	1,110	1,710	16	473
Number (<1g)	2,771	1,512	4,736	383		
Mean Wt (g)	50.9	35.8	54.4	39.0	618	424
Maximum Wt (g)	379	267	214	257	740	654
Minimum Wt (g)	< 1	< 1	< 1	< 1	325	69
Berried (%)	26	6	25	11		
Survival (%)					1.6	47.3

Size frequency distributions for each pond are presented in Figure 8.1. Due to the variability within treatments and the small amount of replication, statistical analysis was not possible. Nevertheless, yield of redclaw was clearly reduced in the presence of silver perch. Under monoculture, mean yield of redclaw was 120kg (1.2 t/ha), while from polyculture ponds, mean yield was almost 50% lower at 65kg (0.65 t/ha). Differences between treatments in regard to population structure were less clear. Total number of crayfish less than 10g averaged 2,142 in the monoculture ponds, however, under polyculture the results were extremely variable ranging from 383 to 4,736. This disparity was clearly attributable to the significant difference in fish survival. Differences between treatments for total number of crayfish greater than 10g were also significant. For monoculture, a mean of 2,893 crayfish per pond were harvested, in comparison with 1,410 crayfish from polyculture ponds.

There appeared to be some impact of silver perch presence on juvenile redclaw in polyculture ponds. Figure 8.1 reveals that the number of juveniles less than 10g for pond 6 was significantly lower than for the monoculture ponds. These juveniles represent recruitment of a secondary cohort of redclaw generated by reproduction of the primary cohort. However, the primary cohort represented in size classes over 10g appeared to be unaffected.

From an economic perspective, the yield from pond 6 (67.3kg redclaw and 201kg silver perch) was more valuable than either monoculture pond (Figure 8.2). However, once stock and feed costs were accounted for, the economic return was considerably less attractive (Figure 8.3). Nevertheless, economic return for this polyculture pond remained intermediate to the two monoculture ponds.

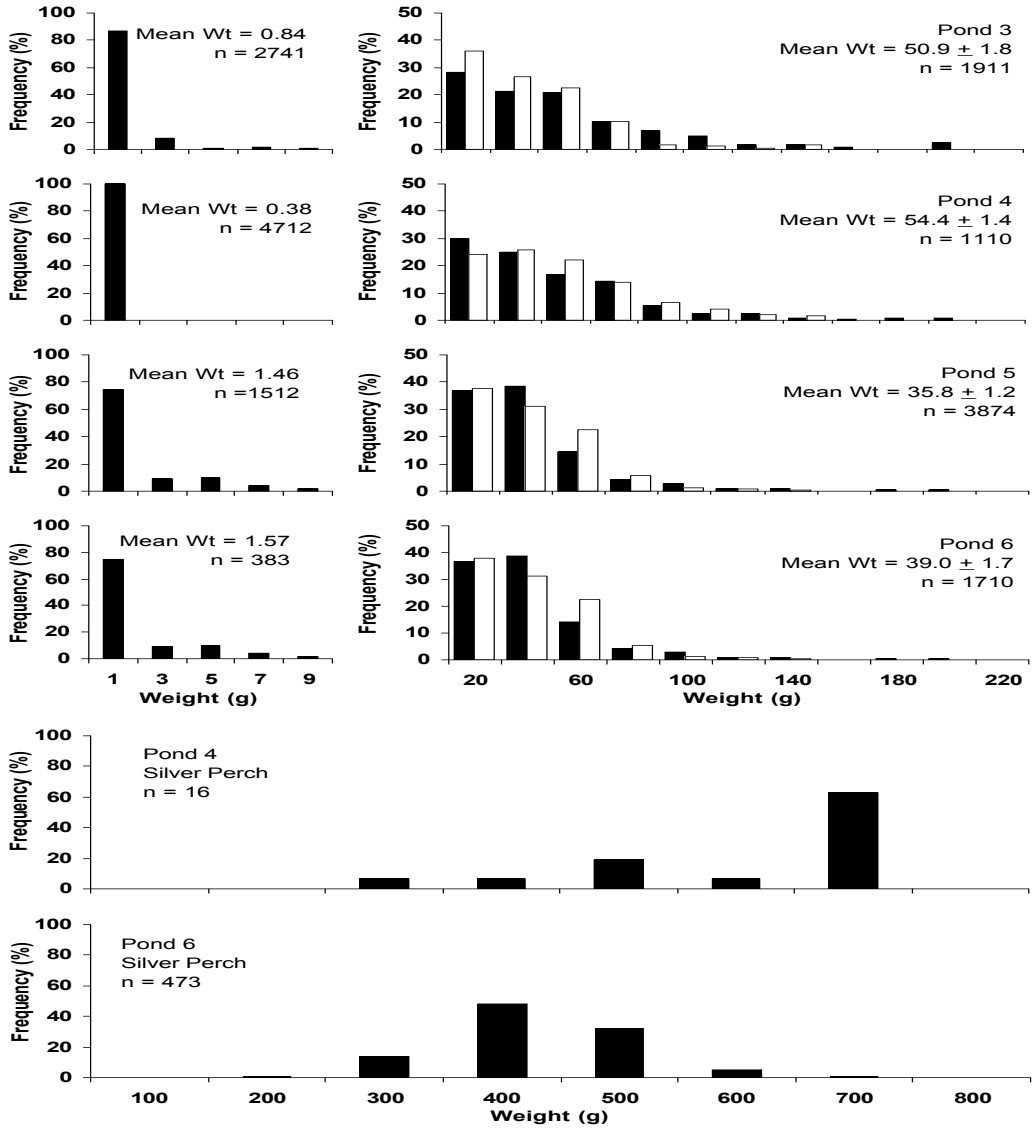


Figure 8.1 ***Size frequency distributions for redclaw and silver perch at harvest. Redclaw less than 10g and over 10g are depicted on separate axes for clarity. Data for male (solid) and female (open) redclaw are shown separately.***

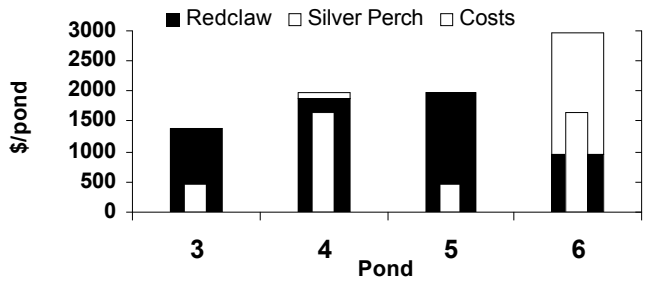


Figure 8.2 ***Value and costs ($ per pond) for monoculture of redclaw (ponds 3 and 5) and polyculture of redclaw and silver perch (ponds 4 and 6).***

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

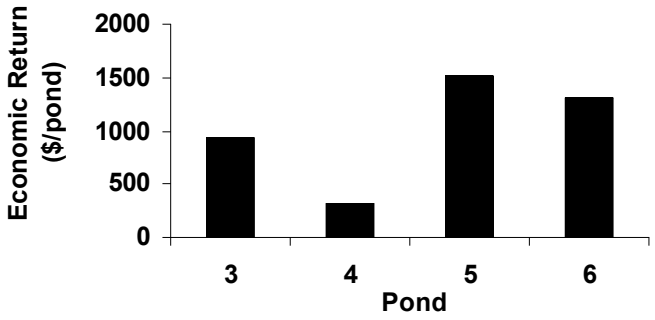


Figure 8.3 ***Economic return ($/pond) for monoculture of redclaw (ponds 3 and 5) and polyculture of redclaw and silver perch (ponds 4 and 6).***

8.3.2 Production Trial

Water quality data for the culture period are presented in Appendix 10.7.2. All parameters measured remained within normal tolerances of both redclaw (Jones and Curtis, 1994) and silver perch (Rowland, 1995c). Harvest statistics are presented in Table 8.3. Harvest quantities of crayfish were reasonably high, however, silver perch survival was generally low. Bird predation was eliminated, and poor survival was attributed to post-stocking mortality and in particular to the omission of salt-bathing after grading. Although fingerlings were not examined in the week following stocking, significant mortality was evident at this time and is most likely attributable to unidentified parasitic infection. While the remaining density of fish (1 - 2,500/ha) was somewhat lower than typical commercial densities (5 - 20,000 /ha) (Rowland, 1995d), it was sufficient to examine the compatibility of the two species in polyculture.

Figure 8.4 shows the mean weight of redclaw and silver perch at harvest. Due to the small degree of replication, statistical analyses were not applied, however, it is clear that the growth of both fish and crayfish were not affected by the culturing approach. Total quantities harvested and mean harvest weight were equivalent for both species in all treatments.

Size frequency distributions of redclaw and silver perch are presented in Figure 8.5. Crayfish populations appeared to be unaffected by the presence of silver perch. Both mean weight and population structure were essentially the same for both monoculture and polyculture treatments. Relatively large but consistent numbers of redclaw in the smallest size grade (<15g) in both treatments suggests that the silver perch had no impact on recruitment from the primary stocking (i.e. juveniles released from the berried females stocked). The low incidence of berried females at harvest (Table 8.3) indicates that secondary reproduction had not occurred and the impact of larger fish on secondary recruitment was not adequately assessed.

Silver perch population structure was considerably more variable, however this is likely to be entirely attributable to density effects and not the treatments. The mean size and variance of weight were significantly larger for monoculture pond 6 where survival (9.2%) and therefore density was lowest. As survival and density increased progressively for ponds 3, 1 and 4, mean size and variance decreased.

Economic factors of crop value and production costs are illustrated in Figures 8.6 and 8.7. Based on the results, silver perch monoculture was uneconomic, while redclaw monoculture and polyculture generated equivalent positive returns.

Table 8.3 ***Harvest statistics for redclaw and silver perch grown in monoculture and polyculture.***

		Pond 1	Pond 2	Pond 3	Pond 4	Pond 5	Pond 6
Redclaw	Total weight (kg)	233.1	199.6	238.4		257.4	
	Total number	13008	11762	17338		16008	
	Min.Wt (g)	0.8	1.1	0.3		0.5	
	Max.Wt (g)	73.1	59.8	68.1		86.2	
	Mean weight (g)	17.92	16.97	13.75		16.08	
	SE Mean	0.13	0.13	0.11		0.12	
	1 Chela missing (%)	3.70	4.27	4.70		8.36	
	2 Chelae missing (%)	0.69	0.84	0.83		1.24	
	legs missing (%)	1.23	1.07	1.95		6.75	
	Berried (%)	0.00	0.22	0.22		0.00	
Silver Perch	Total weight (kg's)	48.33		49.94	82.59		40.64
	Total Number	143		143	255		92
	Survival (%)	14.3		14.3	25.5		9.2
	Min.Wt (g)	189		179	226		270
	Max.Wt (g)	520		572	473		659
	Mean weight (g)	337.99		349.22	323.88		441.71
	SE Mean	5.47		6.73	2.71		7.94

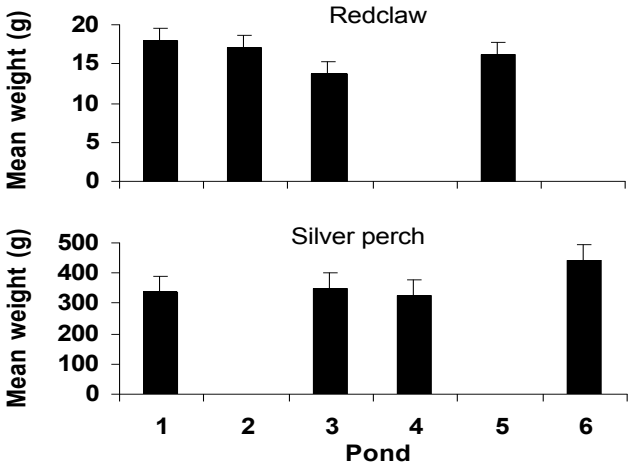


Figure 8.4 ***Mean weight (g)(±SE) of redclaw and silver perch at harvest under monoculture and polyculture production.***

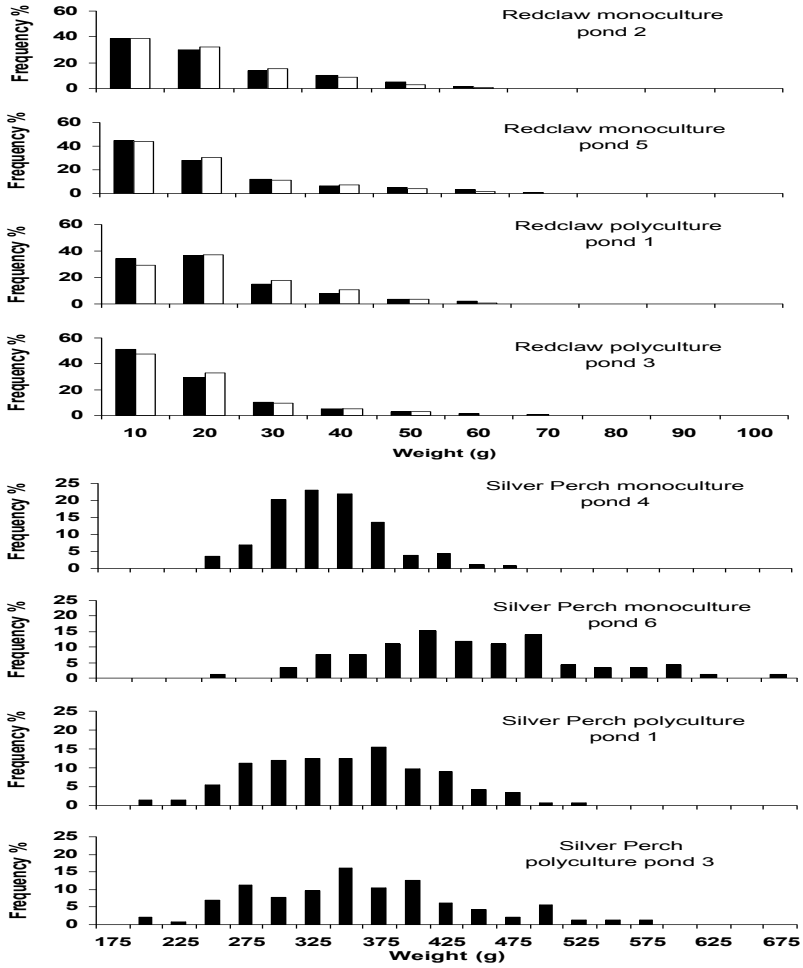


Figure 8.5 ***Size frequency distributions for redclaw and silver perch at harvest from monoculture and polyculture. Data for male (solid) and female (open) redclaw are shown separately.***

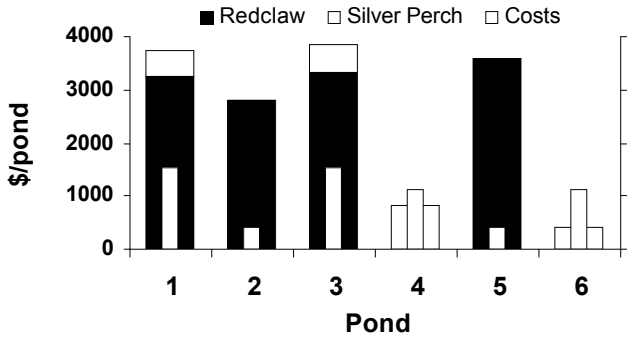


Figure 8.6 ***Value and costs ($ per pond) for redclaw (ponds 2 and 5) and silver perch (ponds 4 and 6) monoculture and polyculture (ponds 1 and 3).***

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

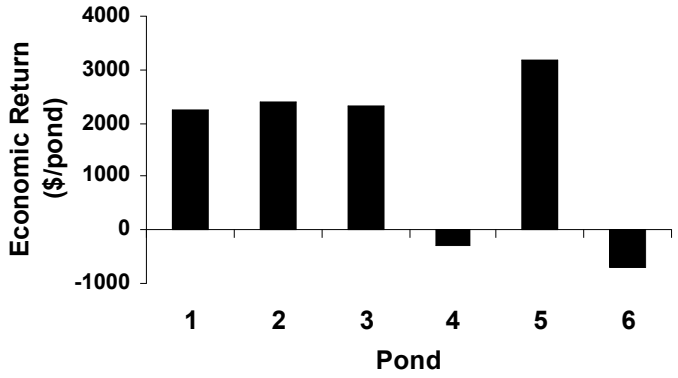


Figure 8.7 ***Economic return ($ per pond) for redclaw (ponds 2 and 5) and silver perch (ponds 4 and 6) monoculture and polyculture (ponds 1 and 3).***

8.4 Discussion

The utility of polyculturing fish and benthic crustaceans together in earthen ponds is well documented (Green et al., 1979; Buck et al., 1981; Miltner et al., 1983; Costa-Pierce et al., 1985; Wohlfarth et al., 1985; Cange et al., 1986; Perry and Tarver, 1987), and several combinations of species have resulted in significantly increased yields over monoculture of the same species. However, previous attempts at polyculturing redclaw with fish species have not been encouraging (Brummett and Alon, 1994; Karplus et al., 1995). The trials reported here document the first attempts at polyculturing redclaw with silver perch.

Although the result of the preliminary trial was compromised by significant bird predation in one of the polyculture ponds, it was evident that redclaw and silver perch were generally compatible. Presence of silver perch in the redclaw pond appeared to have some effect on yield and population structure of redclaw, however, at a density of approximately 0.5 fish per m^2 and a mean size of 424g, silver perch did not prevent recruitment of secondary cohorts of juvenile redclaw.

Similarly, the secondary production trial which involved the stocking of larger, size-graded fingerling silver perch and included a silver perch monoculture treatment, supported the compatibility of the species in polyculture. For this trial there appeared to be no impact of silver perch on either yield or population structure of redclaw. Although the primary cohort of the production trial had not begun to reproduce at the time of harvest, the absence of any impact on the primary crop itself suggests silver perch predation on juvenile redclaw is minimal, at least for smaller fish. This is supported to some extent by the statistics for missing chelae and limbs for redclaw (Table 8.3) which were not significantly different for monoculture and polyculture. This is in contrast to Karplus et al. (1995) who described significant physical damage and loss of limbs of redclaw polycultured with *Tilapia* and carp.

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

Through both supplementary feeding and natural pond productivity (plankton and other vegetation), food was likely to have been in over-supply for silver perch in the production trial. Under higher fish stocking densities or reduced levels of supplementary feeding, the impact on crayfish populations may be different. The results for pond 6 in the preliminary trial indicate that silver perch can have some impact. The density of fish in this pond at harvest ($0.5/m^2$) was the highest of all polyculture ponds in both trials. The number of new juvenile recruits of redclaw for this pond was over 80% less than the mean for the other 3 ponds, suggesting significant silver perch predation on juvenile redclaw. Mouth size of silver perch may physically preclude the consumption of small crayfish, by small fish. Beyond a size of 100 to 200g total weight however, the mouth may be sufficiently large to predate newly hatched redclaw. The absence of any noticeable impact on juvenile recruitment for pond 4 of the preliminary trial can be attributed to the very low density of fish and relative abundance of alternative food.

Release of berried females to the pond is a stocking strategy used for juvenile production of redclaw, but generally not for growout (Jones et al., 1996). These trials have effectively demonstrated that for juvenile production of redclaw, polyculturing with silver perch is feasible, providing the fish are stocked at a relatively small size. For growout of redclaw, where advanced juveniles (5 to 20g) are stocked, polyculturing with silver perch is also likely to be effective. Under such growout circumstances for redclaw, secondary reproduction of the primary crop can be a problem, as new recruits compete for resources and retard the progress of the primary crop to market size. The efficacy of larger silver perch controlling such reproduction by predating on small crayfish was not adequately assessed by these trials. Further investigations involving the stocking of advanced juvenile redclaw and advanced fingerling silver perch (10 to 30g) are necessary.

From an economic perspective, the return from redclaw / silver perch polyculture appeared to be equivalent to redclaw monoculture under the conditions prevailing. However, fish production in these trials was not particularly high due to predation and stock handling factors. Under more rigorous management, significantly higher yields of silver perch under polyculture with redclaw are likely. Yields as high as 10 t/ha/yr are achievable for silver perch monoculture (Rowland, 1995b). Even at yields substantially lower than this, but higher than those achieved in these trials, the economic return of silver perch / redclaw polyculture is likely to exceed that of either redclaw or silver perch monoculture.

8.5 References

Barlow, C.G., McLoughlin, R. and Bock, K. 1986. Complementary feeding habits of golden perch *Macquaria ambigua* (Richardson)(Percichthyidae) and silver perch Bidyanus bidyanus (Mitchell)(Teraponidae) in farm dams. Proceedings

of the Linnean Society of NSW, 109(3):143-152.

Brummett, R.E. and Alon, N.C. 1994. Polyculture of Nile tilapia (*Oreochromis niloticus*) and Australian red claw crayfish (*Cherax quadricarinatus*) in earthern ponds. Aquaculture, 122:47-54.

Buck, H., Malecha, S.R. and Baur, R.J. 1981. Polyculture of the freshwater prawn (*Macrobrachium rosenbergii*) with two combinations of carps in manured ponds. Journal of the World Aquaculture Society, 12(2):203-213.

Cange, S.W., Pavel, D. and Avault, J., Jr. 1986. Pilot study on prawn/catfish polyculture with rice/crayfish rotation. Freshwater Crayfish, 6:274-281.

Costa-Pierce, B.A., Malecha, S.R. and Laws, E.A. 1985. Effects of polyculture and manure fertilisation on water quality and heterotrophic productivity in *Macrobrachium rosenbergii* ponds. Transactions of the American Fisheries Society, 114:826-836.

Curtis, M.C. and Jones, C.M. 1995a. Observations on monosex culture of redclaw crayfish *Cherax quadricarinatus* von Martens (Decapoda: Parastacidae) in earthen ponds. Journal of the World Aquaculture Society, 26(2):154-159.

Curtis, M.C. and Jones, C.M. 1995b. Overview of redclaw crayfish, *Cherax quadricarinatus*, farming practices in northern Australia. Freshwater Crayfish, 10:447-455.

Gillespie, J. 1990. Redclaw - a hot new prospect. In: Macreadie, M. (ed) Australian Fisheries: Aquaculture Special: Redclaw. Australian Government Publishing Service, Canberra, Vol.49(11):2-3.

Green, L.M., Tuten, J.S. and Avault, J.J.W. 1979. Polyculture of red swamp crawfish (*Procambarus clarkii*) and several north American fish species. Freshwater Crayfish, 4:287-298.

Hinton, A. 1994. Redclaw Farming - An Economic Perspective. In: Redclaw Crayfish Aquaculture. Choices: New Opportunities for the Atherton Tablelands. Department of Primary Industries, Queensland, Mareeba:22-35.

Jones, C.M. 1990. The Biology and Aquaculture Potential of the Tropical Freshwater Crayfish, *Cherax quadricarinatus*. In: Queensland Department of Primary Industries Information Series, QI90028: . Queensland Department of Primary Industries, Brisbane:109p.

Jones, C.M. 1995a. Evaluation of six diets fed to redclaw, *Cherax quadricarinatus* (von Martens), held in pond enclosures. Freshwater Crayfish, 10:469-479.

Jones, C.M. 1995b. Farming the redclaw crayfish. In: Nambiar, K.P.P. and Singh, T. (eds) Proceedings of Infofish-Aquatech '94 International Conference on Aquaculture, Colombo, Sri Lanka, 29-31 August 1994: Aquaculture Towards the 21st Century. Infofish, Kuala Lumpur:103-105.

Jones, C.M. 1995c. Aquaculture of the Australian Redclaw Crayfish*, Cherax quadricarinatus*. In: Proceedings of the 3rd Ecuadorian Aquaculture Congress, Oct 27 to Nov 1, 1995, Guayaquil, Ecuador., Guayaquil.

Jones, C.M. 1995d. Production of juvenile redclaw crayfish, *Cherax quadricarinatus* (von Martens)(Decapoda, Parastacidae) I. Development of hatchery and nursery procedures. Aquaculture, 138(1995):221-238.

Jones, C.M. 1996. The Redclaw Experience? Lessons for Marron Aquaculture. In: Evans, L.H. and Whisson, G. (eds) Proceedings of the Marron Growers Association Open Seminar, May 25 1996, Perth, Australia. Marron Growers Association of Western Australia, Perth:9-20.

Jones, C.M. and Barlow, C.G. 1992. The Australian redclaw - a rosy outlook. Infofish International, 2:44-47.

Jones, C.M. and Curtis, M.C. eds 1994. Redclaw Farming. Proceedings of the Redclaw Farming Workshops, Feb.12-17, 1994, Walkamin, Rockhampton, Nambour. Queensland Department of Primary Industries,

Jones, C. and McPhee, C. 1993. Selection processes in the aquaculture of redclaw. Austasia Aquaculture, 7(3):49-50.

Jones, C., Grady, J. and Ruscoe, I. 1996. Production of juvenile redclaw at two demonstration sites in North Queensland. Freshwater Farmer (Australia), 3(4):8-10.

Karplus, I., Barki, A., Cohen, S. and Hulata, G. 1995. Culture of the Australian red-claw crayfish (*Cherax quadricarinatus*) in Israel. I.Polyculture with fish in earthen ponds. The Israeli Journal of Aquaculture - Bamidgeh, 47(1):6-16.

Lobegeiger, R. 1995. Queensland Australia, Aquaculture Information Series: Aquaculture Production Survey Queensland 1994/95. Report to Farmers. Queensland Department of Primary Industries.

Miltner, M.R., Granados, A.E., Romaire, R.P., Avault, J.W.J., Ra'anan, Z. and Cohen, D. 1983. Polyculture of the prawn *Macrobrachium rosenbergii*, with fingerling and adult channel catfish, *Ictalurus punctatus*, and Chinese carp,

Hypothalmichthys molitrix and *Ctenopharyngodon iddela* in earthen ponds in South Louisiana. Journal of the World Mariculture Society, 14:127-134.

Perry, W.G. and Tarver, J. 1987. Polyculture of *Macrobrachium rosenbergii* and *Notemigonus crysoleucas*. Journal of the World Aquaculture Society, 18(1):1-5.

Rouse, D.B. 1995. Australian crayfish culture in the Americas. Journal of Shellfish Research, 14:569-572.

Rowland, S.J. 1995a. High density pond culture of silver perch, *Bidyanus bidyanus*. Asian Fisheries Science, 8:73-79.

Rowland, S.J. 1995b. Production of Fingerling and Market-size Silver Perch in Earthen Ponds. In: Rowland, S.J. and Bryant, C. (eds) Silver Perch Culture. Proceedings of Silver Perch Aquaculture Workshops, Grafton and Narrandera, April, 1994. Austasia Aquaculture, Hobart, Australia:41-50.

Rowland, S.J. 1995c. The Silver Perch, *Bidyanus bidyanus*, and its Potential for Aquaculture. In: Rowland, S.J. and Bryant, C. (eds) Silver Perch Culture. Proceedings of Silver Perch Aquaculture Workshops, Grafton and Narrandera, April, 1994. Austasia Aquaculture, Hobart, Australia:9-12.

Rowland, S.J. 1995d. Water Quality in the Intensive Pond Culture of Silver Perch. In: Rowland, S.J. and Bryant, C. (eds) Silver Perch Culture. Proceedings of Silver Perch Aquaculture Workshops, Grafton and Narrandera, April, 1994. Austasia Aquaculture, Hobart, Australia:51-66.

Rowland, S.J., Allan, G.L., Hollis, M. and Pontifex, T. 1995. Production of the Australian freshwater silver perch, *Bidyanus bidyanus* (Mitchell), at two densities in earthen ponds. Aquaculture, 130:317-328.

Treadwell, R., McKelvie, L. and Maguire, G. 1991. Discussion Paper 91.11: Profitability of selected aquacultural species. Australian Bureau of Agricultural and Resource Economics, Canberra.

Whisson, G. 1995. Silver perch and marron polyculture research. ACWA Newsletter, 11:28.

Wohlfarth, G.W., Hulata, G., Karplus, I. and Halevy, A. 1985. Polyculture of the freshwater prawn *Macrobrachium rosenbergii* in intensively manured ponds, and the effect of stocking rates of prawns and fish on their production characteristics. Aquaculture, 46:143-156.

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

9. General Discussion

Considerable advances were made in the production technology for redclaw through the conduct of this project and the results generated from the trials performed. While considerable discussion was provided in the presentation of results for each trial, the practical outcomes of each have been extracted here and combined with general observations and suggestions as to the most appropriate technology and methodology to achieve maximum returns from the aquaculture of redclaw.

9.1 Redclaw Farming Technology

9.1.1 Production Facilities

Economic imperatives necessitate that in Australia redclaw aquaculture takes a semi-intensive approach. Both juvenile production and growout are performed in earthen ponds, usually of 1,000 to 2,000 m in area, and with a depth in the range of about 1.2 to 2.5 metres. These ponds are constructed in clay soils, so a compacted and impervious base can be formed. In some instances, the clay lining is covered with coarse river gravel to provide a hard base which can be washed out between crops, although the cost-effectiveness of this addition in terms of increased yield has not be adequately assessed. Ponds are shaped so they can be quickly and completely drained, usually with a distinct V-shape. Predator-proof netting and fencing is provided, primarily to prevent entry of cormorants, herons and water rats, and to prevent crayfish walking out of ponds.

Artificial shelters must be provided, and these may take the form of bundles of netting or mesh, stacks of pipes or old car tyres. Gravel lined ponds provide an abundance of shelter in the crevices between stones, although these may become obstructed as a detritus layer builds up in the pond throughout the culture period. Water is normally supplied from a bore or river. Ponds are kept full, but there is rarely any water exchange. Aeration is usually provided, through the application of airlift pumps, paddle-wheels or aspirators. In addition to ponds, a tank facility is needed for holding harvested stock prior to marketing, or re-stocking to ponds.

9.1.2 Juvenile Production

Production of redclaw juveniles is managed as a separate process to growout. A hatchery as such is not required, and production is normally achieved in earthen ponds which are essentially the same as those used for growout in terms of specification and shape. Ponds are prepared with applications of lime, inorganic and organic fertilisers

to initiate a bloom of both phytoplankton and zooplankton. The zooplankton is essential as the primary food source for the juveniles.

Broodstock should be specifically selected for superior characteristics, primarily fast growth rate, and are stocked to ponds at a rate of between 100 and 200 females per 1,000m^2 pond. Sometimes berried females are available and these are stocked alone, or if mature un-berried females are used, males are stocked at the same rate or a little less. Broodstock would normally be selected from a growout crop at harvest, where crayfish are of a known pedigree and age. Reproduction is entirely natural, there are no artificial stimuli required. Redclaw will breed while water temperature is above 23°C.

Approximately 3 to 4 months after stocking, the pond is drained and harvested, and will normally produce between 50 and 100 advanced juveniles of 5 to 15g each per female stocked. Harvesting is achieved by draining the pond and flow-trapping. Timing of juvenile production is critical. Too short a culture period will result in small juveniles less than 5g which are delicate and easily damaged at harvest. Too long a culture period may allow secondary breeding by the original broodstock, resulting in secondary age-classes of crayfish which become mixed with the primary crop.

Complete drainage of the pond and removal of all stock is essential. Broodstock may be re-used in freshly prepared ponds. Juveniles are graded and re-stocked for growout.

9.1.3 Growout

Growout ponds are also prepared with applications of lime, inorganic fertilisers and some organic material such as hay or manure. This initiates a plankton bloom which provides additional food and minimises light penetration. Advanced juveniles are stocked at densities which may range between 5 and 15 per square metre. Size grading of juveniles is essential. Stock for a pond should not have a size range of more than 10g. Often male crayfish are manually selected and stocked. This is because males grow faster and are more attractive, and it minimises breeding in the growout pond. Avoiding, or at least minimising reproduction in growout ponds is a critical factor in the effective management of redclaw.

Feed provided is usually in the form of a pelleted ration, made primarily from grains, with a protein content of around 20%. It is broadcast over the pond 3 to 5 times per week. Water quality is actively managed to ensure optimal pH, plankton turbidity and dissolved oxygen. Measurements of water hardness and ammonia are also taken regularly. Growout is normally completed within 6 to 9 months, at which time the redclaw are between 50 and 100g, and are ready for market. Ponds should be dried for a week or two between crops to permit breakdown of organic compounds and ultra-violet sterilisation.

9.1.4 Harvest

Nearly all harvesting, for both juveniles and grow out crayfish, is done by draining the pond completely. Usually draining is combined with the application of a flow trap which will generally capture 95% of the crayfish in the pond. Other harvesting methods which are less often applied include baited traps and removal of shelters, or draining and manual collection of stock. Harvested redclaw are usually held in tanks with a flow through water system, prior to being packed for transport, or re-stocked to other ponds.

9.2 Redclaw Aquaculture: Best Practice

9.2.1 Farm Design

In terms of farm design, a systematic layout is important to optimise the cost effectiveness of the farms operation. This applies particularly to use of gravity for filling and draining ponds. As most farms begin small and expand slowly, some fore-thought to future expansion is essential. Positioning of operational facilities centrally can make a significant difference to distances travelled for water and air, farm staff and stock, and this can have a significant impact on operational costs.

9.2.2 Scale of Operation

Because of the high capital cost of establishing a redclaw operation, the scale of the farm is important. In Australia, 3 to 4 hectares of growout production area is considered minimum for commercial viability for a stand-alone business. Smaller areas may be equally viable if other income is available.

9.2.3 Pond Specification

Optimal pond specifications are 1,000 square metres pond area, 1.2 to 2 metres depth, and pond shape which permits complete and quick drainage. Dimensions of 50m by 20m are very effective. A maximum width of 20m permits easy broadcasting of feed across the entire pond. Gentle batters which slope evenly from the bank to the centre, providing a V-shape have proven to be the most productive.

9.2.4 Shelter

Shelter for the crayfish is essential. Shelters should be abundant, at least one substantial shelter per $4m^2$, or 250 shelters per pond. Their shape, specification and positioning should permit water to drain out freely and completely as the pond is drained, and ample open space around each shelter must be provided. Thick bundles of synthetic mesh have been found to be more effective than other commonly used materials such as pipes, corrugated sheets or car tyres.

9.2.5 Aeration / Circulation

Aeration is also essential. For redclaw aquaculture it is most often provided through airlift pumps, at least 6 x 90mm diameter airlifts per 1,000 m^2 pond with an air supply of around 80 l/min and a pressure of 0.4 kPa, and an air injection level of no less than 80cm. Other forms of aeration such as paddle-wheels and aspirators can be and are used, but these are all considerably more expensive than the airlift system. The aeration system should provide both oxygen input to the water and circulation of water from bottom to top and around the pond. Because of the low cost of operation, airlift pumps can be run continuously.

9.2.6 Managed Juvenile Production (Nursery Phase)

In order to provide the advanced juveniles required for growout, and to make effective use of the superior broodstock selected, a managed juvenile production program or nursery phase is essential.

It involves dedicated juvenile production ponds, stocking with selected broodstock at a rate of 100 to 200 females per pond, with a male/female ratio of no more than 1 to 4. Depending on temperature and whether berried females or mature broodstock are used, a culture period of 3 to 4 months is necessary to achieve a mean size of juveniles of 5 to 15g.

Two critical factors in juvenile production are shelter and food. Shelter is provided in the form of synthetic mesh bundles. A managed bloom of zooplankton provides the best food. Careful water quality management, involving regular applications of soluble fertilisers is required.

Regular sampling of the juvenile production ponds is necessary after the first 2 months of cultivation to forecast the best harvest time and minimise any secondary breeding.

9.2.7 Active Stock Management (Growout)

An active stock management approach in achieving growout is very important. Because redclaw breed so readily and profusely, the pond populations must be managed intensively. This includes stocking with known numbers of advanced juveniles of at least 5g mean weight. Uniformity of size is very important. Maximum size range at stocking should be 10g. Better production will be achieved if a group of juveniles of 5 to 20g are stocked separately in two ponds at 5 to 12g and 12 to 20g, than if they were unsorted. Stocking density of between 5 and 15 per m^2 is recommended.

Careful handling is also critical. Despite redclaws robustness, stocking mortality can be very high if juveniles are not well handled. Because the stock can't be seen, the effect of stocking mortality from careless handling won't be realised until harvest. The maximum growout period should be 6 months to minimise the possibility of un-managed reproduction. At each harvest, the stock must be graded and re-distributed as breeding stock, market grades, further growout or cull and discard.

The key factors are: maximise growth and survival, and avoid reproduction.

9.2.8 Food

The food used will have an important bearing on production. Several commercial crayfish pellets are available, which have proven to be effective. Chicken layer pellets are not recommended. The most effective diets have a protein content of approximately 20% and are composed primarily of grains. Until such time as a complete redclaw diet is formulated, a variety of materials including existing pellets may be the beneficial.

Freshness of food is important, whether it is a pellet or some other material. Old or poorly stored feed can become contaminated with fungi which may be toxic, and vitamins can be quickly lost. Feed should therefore be stored at low temperature, and only left at ambient temperature for short periods.

9.2.9 Feeding

There are several factors in regard to feeding which should also be considered. Crayfish are not particularly mobile, so feed should be broadcast over the entire pond. Ponds no wider than 20m will facilitate this. Feeding very frequently as is practiced for prawn aquaculture appears not to be necessary. A frequency of 3 to 5 times per week is adequate, preferably at dusk when crayfish are active. Use of a feeding schedule is critical. This can only be achieved when the entire farming approach is a managed one, as accurate data for the size and number of crayfish in each pond must be known. The

feeding schedule is generated with a computer spreadsheet and accounts for the number of crayfish stocked, their mean size, their estimated growth rate, an estimated mortality and a feeding rate in terms of percentage of biomass per day. The rate would usually start at 5% per day for small juveniles, and reduce progressively to 2% for the largest sizes.

The feeding schedule provides an accurate starting point for feeding, but must be adjusted according to observations at the pond for under or over-feeding. A feeding tray is effective for this. Feeding should be stopped immediately if a water quality or crayfish health problem arises.

9.2.10 Active Pond Management

The pond environment must also be actively managed. There should be weekly monitoring of pH, dissolved oxygen and secchi; monthly monitoring of hardness, alkalinity and ammonia. All measurements must be made at the water / soil interface on the bottom, and some contingency plan must be developed to counter water quality which falls outside of preferred ranges. This may involve applications of lime or fertiliser, or flushing of the pond with fresh water.

The benthos, the surface of the pond floor, must be particularly well managed. This may involve liming, applications of nitrate and aeration. Through normal pond management practices nitrogen may become concentrated on the pond floor where the crayfish live. Nitrogen in the form of ammonia, ammonium and nitrite is toxic to crayfish. It is not until nitrogen is transformed into nitrate that it is non-toxic to crayfish. Excessive levels of ammonia and nitrite are also accompanied by low oxygen concentrations and low pH. Such conditions are unsuitable for crayfish and will lead to dirty crayfish, unhealthy crayfish, poor growth etc. To minimise toxic nitrogen and maintain optimal conditions on the bottom, artificial aeration is essential and should ensure circulation of oxygenated water completely down to the soil surface. pH should be kept above 7.0 through regular applications of lime. In addition, nitrogenous fertilisers such as urea and ammonium phosphates (eg DAP) should be avoided in preference to nitrate fertilisers. Plankton abundance must be maintained, particularly for juvenile production. This will involve regular small applications of soluble fertiliser.

Drying of ponds between crops is essential to sterilise and re-vitalise the bottom. There is often a considerable build-up of organic waste after a culture period. The most effective management of this is to dry the pond for 1 to 2 weeks until cracks appear. Toxic compounds are broken down and useful nutrients are released.

9.2.11 Predation Control

Protection against birds, rats, and eels, and any other potential predator must be provided. Complete enclosure netting and fencing is essential. Recent economic analysis indicated that the cost of netting (including materials and installation) is equivalent to 15% of one crop. As losses to predators may be well in excess of this, netting is very cost-effective.

9.2.12 Harvesting

Harvesting is generally quite straightforward, however if it is not managed carefully, the previous several months of production management can be wasted. Some form of sampling prior to harvest is important to gauge the size and number of crayfish expected. Harvesting should involve 95% drainage of the pond over 24 hours from dawn to dawn. There should be several thousand litres of water remaining in the deepest part of the pond when you arrive at dawn to remove the stock. The slow drainage enables the crayfish to move out of shelters and with the main body of water, so they concentrate and respond most effectively to the flow trap. Even where a flow trap is not used, gradual drainage will minimise stress and ensure crayfish leave shelters. If a flow trap is used, it should be set up centrally in the pond, facing the outlet. Both the flow trap and the last remaining water must be well aerated. This is critical. The entire harvest can be easily lost if the flow trap or remaining pond water are not aerated. The stock should be quickly removed and transported to clean water in the tank system. Care should be taken to minimise crushing by not exceeding 15kg of stock per transport container.

9.2.13 Broodstock Selection / Culling

Breeding stock must be carefully selected. Significant improvements can be achieved through good broodstock selection. Generally, the biggest weight for age and healthiest crayfish from each harvest should be used for breeding.

Just as importantly, from each harvest, small crayfish which are known to be slow growing should be culled and discarded.

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

10. Appendices

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

10.1 List of publications arising from the project

Curtis, M.C. and Jones, C.M. 1995. Overview of redclaw crayfish, *Cherax quadricarinatus*, farming practices in northern Australia. Freshwater Crayfish, 10:447-455.

Jones, C.M. 1994a. Introduction to Redclaw - its suitability for aquaculture. In: Redclaw Crayfish Aquaculture. Choices: New Opportunities for the Atherton Tablelands. Queensland Department of Primary Industries, Mareeba:2-5.

Jones, C.M. ed 1994b. Redclaw Crayfish Aquaculture. Notes from the Redclaw Crayfish Aquaculture Seminar, August 11 1994, Cunnamulla. Unpublished,

Jones, C.M. 1994c. Redclaw production systems. In: Redclaw Crayfish Aquaculture. Choices: New Opportunities for the Atherton Tablelands. Queensland Department of Primary Industries, Mareeba:6-11.

Jones, C.M. 1995a. 1995 Redclaw Workshop Notes. Unpublished,

Jones, C.M. 1995b. Aquaculture of the Australian Redclaw Crayfish, *Cherax quadricarinatus*. In: Proceedings of the 3rd Ecuadorian Aquaculture Congress, Oct 27 to Nov 1, 1995, Guayaquil, Ecuador., Guayaquil

Jones, C. 1995c. Clean crayfish - how sweet! Freshwater Farmer (Australia), 3(2):13.

Jones, C.M. 1995d. Evaluation of six diets fed to redclaw, *Cherax quadricarinatus* (von Martens), held in pond enclosures. Freshwater Crayfish, 10:469-479.

Jones, C.M. 1995e. Farming the redclaw crayfish. In: Nambiar, K.P.P. and Singh, T. (eds) Proceedings of Infofish-Aquatech '94 International Conference on Aquaculture, Colombo, Sri Lanka, 29-31 August 1994: Aquaculture Towards the 21st Century. Infofish, Kuala Lumpur:103-105.

Jones, C.M. 1996a. The Redclaw Experience? Lessons for Marron Aquaculture. In: Evans, L.H. and Whisson, G. (eds) Proceedings of the Marron Growers Association Open Seminar, May 25 1996, Perth, Australia. Marron Growers Association of Western Australia, Perth:9-20.

Jones, C.M. 1996b. World developments in the aquaculture of Cherax with particular reference to redclaw (*Cherax quadricarinatus*). In: Proceedings of World Aquaculture '96, January 29 to February 2, 1996, Bangkok, Thailand. not yet

published,

Jones, C.M. and Curtis, M.C. eds 1994. Redclaw Farming. Proceedings of the Redclaw Farming Workshops, Feb.12-17, 1994, Walkamin, Rockhampton, Nambour. Queensland Department of Primary Industries,

Medley, P.B., Jones, C.M. and Avault, J.W.J. 1994. A global perspective of the culture of Australian redclaw crayfish, *Cherax quadricarinatus*: production, economics and marketing. World Aquaculture, 25(4):6-13.

Medley, P.B., Jones, C.M. and Avault, J.W.J. 1995. A bibliography of the Australian redclaw crayfish, *Cherax quadricarinatus* (von Martens 1868) (Decapoda: Parastacidae). Freshwater Crayfish, 10:532-549.

10.2 *Summary of harvest statistics for tank based evaluation of six diets (Chapter 3).*

Tank 2	Male	Female	Both sex
N	4	1	5
Mean wt (g)	16.78	18.70	17.16
Min wt (g)	13.80	18.70	13.80
Max wt (g)	20.20	18.70	20.20
S.E.	1.37	0.00	1.13

Tank 3	Male	Female	Both sex
N	5	5	10
Mean wt (g)	11.68	11.76	11.72
Min wt (g)	9.40	9.00	9.00
Max wt (g)	14.20	14.30	14.30
S.E.	0.88	0.91	0.59

Tank 4	Male	Female	Both sex
N	5	5	10
Mean wt (g)	16.62	17.62	17.12
Min wt (g)	13.00	13.10	13.00
Max wt (g)	19.30	21.40	21.40
S.E.	1.10	1.33	0.83

Tank 7	Male	Female	Both sex
N	4	2	6
Mean wt (g)	17.98	19.80	18.58
Min wt (g)	9.20	18.70	9.20
Max wt (g)	25.20	20.90	25.20
S.E.	3.41	1.10	2.21

Tank 9	Male	Female	Both sex
N	5	5	10
Mean wt (g)	18.82	15.68	17.25
Min wt (g)	13.70	14.70	13.70
Max wt (g)	27.20	17.40	27.20
S.E.	2.58	0.47	1.34

Tank 8	Male	Female	Both sex
N	5	5	10
Mean wt (g)	13.26	16.68	14.97
Min wt (g)	11.00	12.60	11.00
Max wt (g)	18.00	20.50	20.50
S.E.	1.29	1.56	1.11

Tank 11	Male	Female	Both sex
N	5	5	10
Mean wt (g)	13.18	15.74	14.46
Min wt (g)	11.60	13.80	11.60
Max wt (g)	14.80	18.80	18.80
S.E.	0.65	1.00	0.71

Tank 10	Male	Female	Both sex
N	5	3	8
Mean wt (g)	14.50	14.83	14.63
Min wt (g)	11.20	12.70	11.20
Max wt (g)	20.80	18.60	20.80
S.E.	1.69	1.89	1.18

Tank 12	Male	Female	Both sex
N	3	5	8
Mean wt (g)	15.23	20.64	18.61
Min wt (g)	14.90	16.50	14.90
Max wt (g)	15.70	26.40	26.40
S.E.	0.24	1.82	1.47

Tank 13	Male	Female	Both sex
N	5	5	10
Mean wt (g)	14.64	15.52	15.08
Min wt (g)	12.70	12.40	12.40
Max wt (g)	15.80	19.60	19.60
S.E.	0.52	1.28	0.67

Tank 14	Male	Female	Both sex
N	1	2	3
Mean wt (g)	18.40	21.95	20.76
Min wt (g)	18.40	18.20	18.20
Max wt (g)	18.40	25.70	25.70
S.E.	0.00	3.75	2.47

Tank 15	Male	Female	Both sex
N	5	5	10
Mean wt (g)	15.14	15.12	15.13
Min wt (g)	10.00	11.30	10.00
Max wt (g)	19.80	16.70	19.80
S.E.	1.89	1.00	1.01

Tank 17	Male	Female	Both sex
N	4	4	8
Mean wt (g)	13.73	18.78	16.25
Min wt (g)	10.30	17.70	10.30
Max wt (g)	18.00	20.40	20.40
S.E.	1.62	0.58	1.24

Tank 18	Male	Female	Both sex
N	5	5	10
Mean wt (g)	12.36	14.30	13.33
Min wt (g)	9.90	11.20	9.90
Max wt (g)	14.00	17.20	17.20
S.E.	0.76	0.98	0.67

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

10.3 *Summary of harvest statistics in cage based evaluation trial for six diets (Chapter 4).*

Cage 1	M	F	M & F
N	31	30	61
Min Wt (g)	30.40	21.50	21.50
Max Wt (g)	109.10	71.10	109.10
Mean Wt (g)	67.24	43.64	55.64
SE Mean	4.06	2.30	2.79

Cage 2	M	F	M & F
N	27	28	55
Min Wt (g)	23.60	27.10	23.60
Max Wt (g)	106.00	88.70	106.00
Mean Wt (g)	63.83	45.89	54.70
SE Mean	4.54	2.83	2.90

Cage 3	M	F	M & F
N	28	19	47
Min Wt (g)	25.60	17.80	17.80
Max Wt (g)	145.50	83.90	145.50
Mean Wt (g)	69.76	47.18	60.64
SE Mean	4.94	4.34	3.77

Cage 4	M	F	M & F
N	7	8	15
Min Wt (g)	51.70	32.10	32.10
Max Wt (g)	128.70	75.00	128.70
Mean Wt (g)	103.73	48.56	74.31
SE Mean	10.22	5.38	9.10

Cage 5	M	F	M & F
N	22	25	47
Min Wt (g)	29.50	23.20	23.20
Max Wt (g)	106.40	93.90	106.40
Mean Wt (g)	50.44	47.08	48.65
SE Mean	3.34	2.94	2.20

Cage 6	M	F	M & F
N	19	20	39
Min Wt (g)	26.80	25.30	25.30
Max Wt (g)	108.30	91.30	108.30
Mean Wt (g)	67.69	50.04	58.64
SE Mean	5.45	3.56	3.49

Cage 7	M	F	M & F
N	26	18	44
Min Wt (g)	26.60	29.10	26.60
Max Wt (g)	115.60	90.80	115.60
Mean Wt (g)	60.17	48.42	55.36
SE Mean	4.63	4.13	3.30

Cage 8	M	F	M & F
N	25	22	47
Min Wt (g)	27.90	22.70	22.70
Max Wt (g)	122.60	81.30	122.60
Mean Wt (g)	68.51	50.48	60.07
SE Mean	4.82	3.94	3.40

Cage 9	M	F	M & F
N	22	24	46
Min Wt (g)	23.90	23.00	23.00
Max Wt (g)	117.80	76.10	117.80
Mean Wt (g)	59.27	41.72	50.11
SE Mean	5.53	3.10	3.33

Cage 10	M	F	M & F
N	26	22	48
Min Wt (g)	25.30	18.50	18.50
Max Wt (g)	118.20	91.80	118.20
Mean Wt (g)	65.95	46.50	57.03
SE Mean	4.15	4.17	3.24

Cage 11	M	F	M & F
N	27	21	48
Min Wt (g)	21.80	20.70	20.70
Max Wt (g)	108.00	79.60	108.00
Mean Wt (g)	59.58	45.10	53.25
SE Mean	3.90	3.01	2.74

Cage 12	M	F	M & F
N	24	18	42
Min Wt (g)	37.40	24.50	24.50
Max Wt (g)	161.00	94.50	161.00
Mean Wt (g)	64.48	47.29	57.12
SE Mean	5.18	4.11	3.65

Cage 13	M	F	M & F
N	25	21	46
Min Wt (g)	20.10	18.30	18.30
Max Wt (g)	177.60	92.40	177.60
Mean Wt (g)	66.44	41.66	55.13
SE Mean	7.16	3.89	4.62

Cage 14	M	F	M & F
N	24	20	44
Min Wt (g)	30.20	24.80	24.80
Max Wt (g)	87.60	85.90	87.60
Mean Wt (g)	54.71	45.50	50.52
SE Mean	3.32	4.35	2.74

Cage 15	M	F	M & F
N	25	19	44
Min Wt (g)	25.00	21.20	21.20
Max Wt (g)	135.00	67.70	135.00
Mean Wt (g)	63.54	42.15	54.30
SE Mean	5.25	2.55	3.54

Cage 16	M	F	M & F
N	41	20	61
Min Wt (g)	25.90	20.90	20.90
Max Wt (g)	126.20	84.20	126.20
Mean Wt (g)	65.49	55.94	62.36
SE Mean	3.43	4.45	2.77

Cage 17	M	F	M & F
N	32	27	59
Min Wt (g)	20.70	23.80	20.70
Max Wt (g)	125.00	83.50	125.00
Mean Wt (g)	54.93	46.39	51.02
SE Mean	3.85	3.06	2.56

Cage 18	M	F	M & F
N	30	21	51
Min Wt (g)	26.40	27.40	26.40
Max Wt (g)	115.20	84.00	115.20
Mean Wt (g)	54.26	45.57	50.68
SE Mean	4.02	3.15	2.74

Cage 19	M	F	M & F
N	22	17	39
Min Wt (g)	20.90	26.20	20.90
Max Wt (g)	121.80	65.30	121.80
Mean Wt (g)	63.51	42.00	54.13
SE Mean	5.98	2.90	3.96

Cage 20	M	F	M & F
N	29	23	52
Min Wt (g)	23.00	23.80	23.00
Max Wt (g)	124.80	77.50	124.80
Mean Wt (g)	58.88	43.93	52.27
SE Mean	4.28	3.00	2.90

Cage 21	M	F	M & F
N	23	18	41
Min Wt (g)	20.00	18.70	18.70
Max Wt (g)	206.10	91.40	206.10
Mean Wt (g)	72.59	45.47	60.68
SE Mean	8.38	5.27	5.60

Cage 22	M	F	M & F
N	26	17	43
Min Wt (g)	28.00	27.80	27.80
Max Wt (g)	126.50	79.30	126.50
Mean Wt (g)	67.45	47.24	59.46
SE Mean	4.65	3.60	3.47

Cage 23	M	F	M & F
N	20	24	44
Min Wt (g)	21.40	19.70	19.70
Max Wt (g)	148.60	74.00	148.60
Mean Wt (g)	64.43	42.80	52.63
SE Mean	7.39	2.72	3.98

Cage 24	M	F	M & F
N	28	26	54
Min Wt (g)	21.00	24.40	21.00
Max Wt (g)	93.00	66.00	93.00
Mean Wt (g)	53.83	44.33	49.25
SE Mean	3.38	2.48	2.20

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

10.4 *Summary statistics for harvest in the stocking size/density trial (chapter 5)*

Cage 1	M	F	M & F
N	60	58	118
Min Wt (g)	20.90	24.50	20.90
Max Wt (g)	97.50	74.10	97.50
Mean Wt (g)	17.92	12.25	15.33
SE Mean	2.31	1.61	1.41

Cage 2	M	F	M & F
N	19	19	38
Min Wt (g)	24.00	21.70	21.70
Max Wt (g)	85.40	85.90	85.90
Mean Wt (g)	17.51	17.08	17.06
SE Mean	4.02	3.92	2.77

Cage 3	M	F	M & F
N	94	107	201
Min Wt (g)	16.10	19.30	16.10
Max Wt (g)	106.10	69.40	106.10
Mean Wt (g)	19.41	11.45	15.66
SE Mean	2.00	1.11	1.10

Cage 4	M	F	M & F
N	101	100	201
Min Wt (g)	7.20	9.90	7.20
Max Wt (g)	56.90	71.40	71.40
Mean Wt (g)	13.14	12.66	12.91
SE Mean	1.31	1.27	0.91

Cage 5	M	F	M & F
N	13	19	32
Min Wt (g)	21.80	24.20	21.80
Max Wt (g)	91.40	55.40	91.40
Mean Wt (g)	24.13	8.52	16.80
SE Mean	6.69	1.95	2.97

Cage 6	M	F	M & F
N	68	62	130
Min Wt (g)	10.40	11.20	10.40
Max Wt (g)	74.60	44.70	74.60
Mean Wt (g)	15.37	8.11	12.67
SE Mean	1.86	1.03	1.11

Cage 7	M	F	M & F
N	13	24	37
Min Wt (g)	35.40	30.20	30.20
Max Wt (g)	113.40	83.20	113.40
Mean Wt (g)	25.55	11.84	18.40
SE Mean	7.09	2.42	3.02

Cage 8	M	F	M & F
N	58	71	129
Min Wt (g)	19.50	22.00	19.50
Max Wt (g)	98.30	76.90	98.30
Mean Wt (g)	18.36	11.07	14.75
SE Mean	2.41	1.31	1.30

Cage 9	M	F	M & F
N	42	43	85
Min Wt (g)	13.50	14.00	13.50
Max Wt (g)	70.00	64.40	70.00
Mean Wt (g)	14.49	10.14	12.40
SE Mean	2.24	1.55	1.35

Cage 10	M	F	M & F
N	57	61	118
Min Wt (g)	10.50	11.40	10.50
Max Wt (g)	62.90	68.10	68.10
Mean Wt (g)	13.03	11.93	12.45
SE Mean	1.73	1.53	1.15

Cage 11	M	F	M & F
N	17	21	38
Min Wt (g)	25.30	21.90	21.90
Max Wt (g)	95.80	71.90	95.80
Mean Wt (g)	19.96	12.92	16.61
SE Mean	4.84	2.82	2.69

Cage 12	M	F	M & F
N	19	24	43
Min Wt (g)	27.10	30.40	27.10
Max Wt (g)	112.90	81.50	112.90
Mean Wt (g)	26.78	12.34	20.59
SE Mean	6.14	2.52	3.14

Cage 13	M	F	M & F
N	59	62	121
Min Wt (g)	20.60	24.20	20.60
Max Wt (g)	117.30	76.40	117.30
Mean Wt (g)	24.42	10.98	18.95
SE Mean	3.18	1.39	1.72

Cage 14	M	F	M & F
N	93	114	207
Min Wt (g)	15.20	17.70	15.20
Max Wt (g)	105.00	82.40	105.00
Mean Wt (g)	19.87	14.25	16.96
SE Mean	2.06	1.33	1.18

Cage 15	M	F	M & F
N	106	107	213
Min Wt (g)	19.60	18.50	18.50
Max Wt (g)	90.60	83.60	90.60
Mean Wt (g)	16.78	13.82	15.43
SE Mean	1.63	1.34	1.06

Cage 16	M	F	M & F
N	84	112	196
Min Wt (g)	7.20	7.10	7.10
Max Wt (g)	74.20	66.60	74.20
Mean Wt (g)	14.82	11.79	13.14
SE Mean	1.62	1.11	0.94

Cage 17	M	F	M & F
N	61	50	111
Min Wt (g)	21.30	18.10	18.10
Max Wt (g)	102.10	70.30	102.10
Mean Wt (g)	23.28	10.34	18.75
SE Mean	2.98	1.46	1.78

Cage 18	M	F	M & F
N	90	94	184
Min Wt (g)	13.40	19.40	13.40
Max Wt (g)	91.90	76.40	91.90
Mean Wt (g)	17.77	11.87	15.02
SE Mean	1.87	1.22	1.11

Cage 19	M	F	M & F
N	19	20	39
Min Wt (g)	16.00	22.00	16.00
Max Wt (g)	122.50	64.80	122.50
Mean Wt (g)	25.60	12.59	19.91
SE Mean	5.87	2.82	3.19

Cage 20	M	F	M & F
N	21	22	43
Min Wt (g)	31.50	29.80	29.80
Max Wt (g)	161.30	67.20	161.30
Mean Wt (g)	29.48	10.47	25.51
SE Mean	6.43	2.23	3.89

Cage 21	M	F	M & F
N	72	48	120
Min Wt (g)	12.20	17.80	12.20
Max Wt (g)	74.70	59.90	74.70
Mean Wt (g)	14.45	9.31	12.61
SE Mean	1.70	1.34	1.15

Cage 22	M	F	M & F
N	25	20	45
Min Wt (g)	17.10	15.70	15.70
Max Wt (g)	68.80	54.50	68.80
Mean Wt (g)	13.80	11.09	13.00
SE Mean	2.76	2.48	1.94

Cage 23	M	F	M & F
N	28	17	45
Min Wt (g)	24.10	40.40	24.10
Max Wt (g)	122.10	108.70	122.10
Mean Wt (g)	28.11	17.86	24.61
SE Mean	5.31	4.33	3.67

Cage 24	M	F	M & F
N	104	103	207
Min Wt (g)	9.70	12.20	9.70
Max Wt (g)	73.10	64.70	73.10
Mean Wt (g)	14.24	10.69	12.57
SE Mean	1.40	1.05	0.87

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

10.5 *Shelter trial (Chapter 6).*

10.5.1 Summary statistics for Shelter trial.

Cage 1	Male	Female	Both
N	65	67	132
Mean	35.44	29.91	32.63
Max	80.80	55.80	80.80
Min	14.00	11.00	11.00
S.E.	1.93	1.16	1.61

Cage 2	Male	Female	Both
N	13	19	32
Mean	36.18	28.55	31.65
Max	76.90	41.80	76.90
Min	9.90	17.90	9.90
S.E.	2.44	0.86	1.72

Cage 3	Male	Female	Both
N	70	74	144
Mean	31.29	27.35	29.26
Max	79.90	55.70	79.90
Min	7.20	5.50	5.50
S.E.	2.04	1.34	1.73

Cage 4	Male	Female	Both
N	4	3	7
Mean	37.03	33.60	35.56
Max	60.10	39.40	60.10
Min	9.60	25.80	9.60
S.E.	2.93	0.85	2.14

Cage 5	Male	Female	Both
N	14	21	35
Mean	29.88	28.78	29.22
Max	71.90	61.00	71.90
Min	11.50	6.50	6.50
S.E.	2.15	1.88	1.96

Cage 6	Male	Female	Both
N	43	32	75
Mean	42.11	26.03	35.25
Max	105.40	43.60	105.40
Min	8.50	10.70	8.50
S.E.	2.79	1.05	2.41

Cage 7	Male	Female	Both
N	23	21	44
Mean	46.22	35.68	41.19
Max	88.20	56.30	88.20
Min	16.70	17.00	16.70
S.E.	2.19	1.22	1.89

Cage 8	Male	Female	Both
N	65	79	144
Mean	29.06	29.53	29.32
Max	81.50	59.10	81.50
Min	5.20	5.20	5.20
S.E.	2.00	1.54	1.75

Cage 9	Male	Female	Both
N	40	45	85
Mean	38.35	31.97	34.97
Max	96.50	63.90	96.50
Min	9.30	9.70	9.30
S.E.	2.78	1.59	2.25

Cage 10	Male	Female	Both
N	14	11	25
Mean	33.51	23.85	29.26
Max	73.70	31.70	73.70
Min	13.10	15.10	13.10
S.E.	2.25	0.74	1.82

Cage 11	Male	Female	Both
N	28	47	75
Mean	38.13	31.07	33.70
Max	77.90	53.20	77.90
Min	9.30	15.50	9.30
S.E.	2.66	1.24	1.93

Cage 12	Male	Female	Both
N	6	21	27
Mean	35.62	28.07	29.75
Max	59.20	43.00	59.20
Min	12.10	9.80	9.80
S.E.	2.20	1.27	1.53

Cage 13	Male	Female	Both
N	21	27	48
Mean	32.66	28.40	30.26
Max	80.50	48.30	80.50
Min	14.80	9.40	9.40
S.E.	2.29	1.37	1.83

Cage 14	Male	Female	Both
N	22	44	66
Mean	55.51	31.39	39.43
Max	101.60	71.10	101.60
Min	17.50	9.90	9.90
S.E.	3.15	1.48	2.57

Cage 15	Male	Female	Both
N	23	28	51
Mean	33.18	27.48	30.05
Max	53.70	51.40	53.70
Min	13.30	10.80	10.80
S.E.	1.50	1.31	1.43

Cage 16	Male	Female	Both
N	13	23	36
Mean	31.35	30.36	30.72
Max	85.00	55.00	85.00
Min	12.60	11.30	11.30
S.E.	2.40	1.37	1.78

Cage 17	Male	Female	Both
N	81	78	159
Mean	29.01	29.41	29.21
Max	87.40	49.60	87.40
Min	6.50	11.60	6.50
S.E.	1.85	1.18	1.55

Cage 18	Male	Female	Both
N	64	62	126
Mean	35.64	29.03	32.38
Max	88.40	49.40	88.40
Min	9.40	10.10	9.40
S.E.	2.37	1.23	1.93

Cage 19	Male	Female	Both
N	29	35	64
Mean	40.89	27.82	33.74
Max	94.80	55.50	94.80
Min	9.40	13.90	9.40
S.E.	2.81	1.23	2.22

Cage 20	Male	Female	Both
N	62	66	128
Mean	41.13	25.90	33.28
Max	99.00	55.20	99.00
Min	5.90	6.40	5.90
S.E.	2.14	0.90	1.86

Cage 21	Male	Female	Both
N	75	79	154
Mean	34.16	30.28	32.17
Max	80.80	58.80	80.80
Min	9.40	6.50	6.50
S.E.	2.12	1.33	1.77

Cage 22	Male	Female	Both
N	4	12	16
Mean	55.55	33.47	38.99
Max	76.30	54.60	76.30
Min	34.70	21.10	21.10
S.E.	2.29	1.25	1.90

Cage 23	Male	Female	Both
N	32	38	70
Mean	40.42	28.06	33.71
Max	86.50	55.70	86.50
Min	9.10	7.80	7.80
S.E.	2.38	1.40	2.04

Cage 24	Male	Female	Both
N	21	21	42
Mean	40.16	29.44	34.80
Max	77.40	57.10	77.40
Min	10.50	9.80	9.80
S.E.	2.79	1.31	2.25

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

10.5.2 Photographs of shelter types (Chapter 6).

Photographs: (1) Tyres, (2) Mesh habitat, (3) Elevated sheets, (4) Flat sheets, (5) Pipe stacks.

10.6 Summary of Morphometric statistics for 5 strains of Redclaw.

10.6.1 Mitchell River strain

ABDOMINAL LENGTH	SEX		
Data	F	M	M+F
N	48	40	88
Mean	42.6	46.5	44.4
Max	60.7	62.6	62.6
Min	32.6	30.2	30.2
StdErr	0.83	1.22	0.74

ABDOMINAL WIDTH	SEX		
Data	F	M	M+F
N	48	40	88
Mean	22.2	23.5	22.8
Max	43.2	32.2	43.2
Min	15.0	14.4	14.4
StdErr	0.66	0.70	0.48

CARAPACE DEPTH	SEX		
Data	F	M	M+F
N	48	40	88
Mean	22.8	26.0	24.2
Max	32.1	36.1	36.1
Min	13.3	16.4	13.3
StdErr	0.50	0.76	0.47

CHELA LENGTH	SEX		
Data	F	M	M+F
N	48	40	88
Mean	33.2	44.9	38.5
Max	53.1	79.5	79.5
Min	22.6	23.4	22.6
StdErr	0.92	2.09	1.24

CHELA WIDTH	SEX		
Data	F	M	M+F
N	48	39	87
Mean	8.9	14.3	11.3
Max	14.2	26.0	26.0
Min	5.8	5.4	5.4
StdErr	0.26	0.77	0.47

CEPHALON WIDTH	SEX		
Data	F	M	M+F
N	48	40	88
Mean	19.5	22.1	20.7
Max	27.4	31.2	31.2
Min	12.5	15.0	12.5
StdErr	0.45	0.62	0.40

DACTYL LENGTH	SEX		
Data	F	M	M+F
N	48	40	88
Mean	15.8	19.9	17.7
Max	26.8	33.4	33.4
Min	8.4	12.6	8.4
StdErr	0.52	0.79	0.51

OCULAR CARAPACE LENGTH	SEX		
Data	F	M	M+F
N	48	40	88
Mean	35.3	40.2	37.5
Max	48.6	55.7	55.7
Min	26.5	27.0	26.5
StdErr	0.73	1.16	0.71

PROPODAL MEMBRANE LENGTH	SEX		
Data	F	M	M+F
N	1	41	41
Mean	27.7	20.9	20.9
Max	27.7	47.4	47.4
Min	27.7	0.0	0.0
StdErr		1.86	1.86

TOTAL CARAPACE LENGTH	SEX		
Data	F	M	M+F
N	48	41	89
Mean	51.0	57.6	54.1
Max	71.3	80.7	80.7
Min	39.4	40.0	39.4
StdErr	1.10	1.67	1.03

TELSON LENGTH	SEX		
Data	F	M	M+F
N	48	40	88
Mean	17.5	19.8	18.5
Max	26.5	27.6	27.6
Min	11.1	12.5	11.1
StdErr	0.48	0.60	0.40

TELSON WIDTH	SEX		
Data	F	M	M+F
N	48	40	88
Mean	12.6	14.0	13.2
Max	18.5	19.5	19.5
Min	9.8	9.6	9.6
StdErr	0.27	0.40	0.24

THORAX WIDTH	SEX		
Data	F	M	M+F
N	48	40	88
Mean	21.8	25.0	23.3
Max	31.1	34.6	34.6
Min	11.3	15.7	11.3
StdErr	0.51	0.76	0.47

WEIGHT	SEX		
Data	F	M	M+F
N	48	41	89
Mean	28.3	45.9	36.4
Max	73.0	129.0	129.0
Min	11.8	11.2	11.2
StdErr	1.81	4.31	2.39

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

10.6.2 Gilbert River strain

ABDOMINAL LENGTH	SEX		
Data	F	M	M+F
N	44	49	93
Mean	50.3	55.9	53.3
Max	74.0	78.7	78.7
Min	24.4	34.6	24.4
StdErr	1.51	1.57	1.13

ABDOMINAL WIDTH	SEX		
Data	F	M	M+F
N	32	28	60
Mean	29.4	28.4	28.9
Max	39.5	38.9	39.5
Min	21.9	21.1	21.1
StdErr	0.80	0.96	0.61

CARAPACE DEPTH	SEX		
Data	F	M	M+F
N	44	49	93
Mean	27.5	31.1	29.4
Max	40.5	44.6	44.6
Min	15.5	16.6	15.5
StdErr	0.85	1.02	0.70

CHELA LENGTH	SEX		
Data	F	M	M+F
N	44	49	93
Mean	43.7	56.7	50.5
Max	69.1	97.9	97.9
Min	21.2	22.0	21.2
StdErr	1.55	2.52	1.65

CHELA WIDTH	SEX		
Data	F	M	M+F
N	44	49	93
Mean	11.8	17.0	14.6
Max	15.6	30.0	30.0
Min	6.1	8.1	6.1
StdErr	0.38	0.83	0.54

CEPHALON WIDTH	SEX		
Data	F	M	M+F
N	44	49	93
Mean	22.5	26.6	24.7
Max	35.1	40.0	40.0
Min	11.4	11.9	11.4
StdErr	0.88	0.96	0.69

DACTYL LENGTH	SEX		
Data	F	M	M+F
N	44	49	93
Mean	20.1	24.7	22.5
Max	32.3	39.1	39.1
Min	10.1	11.2	10.1
StdErr	0.83	1.00	0.70

OCULAR CARAPACE LENGTH	SEX		
Data	F	M	M+F
N	44	49	93
Mean	42.2	48.9	45.7
Max	61.5	70.1	70.1
Min	24.6	28.6	24.6
StdErr	1.24	1.55	1.06

PROPODAL MEMBRANE LENGTH	SEX		
Data	F	M	M+F
N	1	49	50
Mean	41.2	27.7	28.0
Max	41.2	62.5	62.5
Min	41.2	0.0	0.0
StdErr		2.01	1.99

TOTAL CARAPACE LENGTH	SEX		
Data	F	M	M+F
N	44	48	92
Mean	61.3	70.0	65.8
Max	90.2	101.9	101.9
Min	34.3	40.1	34.3
StdErr	1.88	2.29	1.56

TELSON LENGTH	SEX		
Data	F	M	M+F
N	44	49	93
Mean	19.2	22.1	20.8
Max	29.4	34.3	34.3
Min	11.0	10.5	10.5
StdErr	0.75	0.81	0.57

TELSON WIDTH	SEX		
Data	F	M	M+F
N	44	49	93
Mean	15.3	17.4	16.4
Max	22.6	25.7	25.7
Min	8.7	9.5	8.7
StdErr	0.52	0.59	0.41

THORAX WIDTH	SEX		
Data	F	M	M+F
N	44	49	93
Mean	26.1	30.2	28.3
Max	38.5	44.7	44.7
Min	14.6	12.8	12.8
StdErr	0.82	1.07	0.71

WEIGHT	SEX		
Data	F	M	M+F
N	44	49	93
Mean	51.0	88.4	70.7
Max	141.4	243.6	243.6
Min	9.7	15.1	9.7
StdErr	4.58	8.07	5.13

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

10.6.3 Flinders River Strain

ABDOMINAL LENGTH	SEX		
Data	F	M	M+F
N	36	42	78
Mean	51.5	50.1	50.7
Max	74.5	70.1	74.5
Min	29.0	30.6	29.0
StdErr	1.78	1.39	1.11

ABDOMINAL WIDTH	SEX		
Data	F	M	M+F
N	36	42	78
Mean	28.3	26.6	27.4
Max	43.5	37.6	43.5
Min	14.6	16.0	14.6
StdErr	1.16	0.79	0.69

CARAPACE DEPTH	SEX		
Data	F	M	M+F
N	36	41	77
Mean	28.4	28.8	28.6
Max	42.1	41.8	42.1
Min	16.0	17.6	16.0
StdErr	1.05	0.90	0.68

CHELA LENGTH	SEX		
Data	F	M	M+F
N	35	42	77
Mean	42.5	48.8	46.0
Max	62.1	90.4	90.4
Min	22.8	24.0	22.8
StdErr	1.64	2.37	1.53

CHELA WIDTH	SEX		
Data	F	M	M+F
N	35	42	77
Mean	11.3	14.1	12.8
Max	17.5	28.4	28.4
Min	5.5	5.3	5.3
StdErr	0.48	0.76	0.49

CEPHALON WIDTH	SEX		
Data	F	M	M+F
N	36	41	77
Mean	23.3	23.5	23.4
Max	33.8	34.3	34.3
Min	13.5	14.9	13.5
StdErr	0.84	0.78	0.57

DACTYL LENGTH	SEX		
Data	F	M	M+F
N	35	42	77
Mean	20.9	22.3	21.6
Max	30.4	39.4	39.4
Min	12.5	11.5	11.5
StdErr	0.80	0.98	0.64

OCULAR CARAPACE LENGTH	SEX		
Data	F	M	M+F
N	36	42	78
Mean	44.8	45.3	45.1
Max	65.5	66.0	66.0
Min	25.7	28.9	25.7
StdErr	1.61	1.40	1.05

PROPODAL MEMBRANE LENGTH	SEX		
Data	F	M	M+F
N	0	42	42
Mean		15.1	15.1
Max		50.7	50.7
Min		0.0	0.0
StdErr		2.48	2.48

TOTAL CARAPACE LENGTH	SEX		
Data	F	M	M+F
N	36	41	77
Mean	63.7	64.2	63.9
Max	93.0	92.8	93.0
Min	37.1	42.0	37.1
StdErr	2.32	2.03	1.52

TELSON LENGTH	SEX		
Data	F	M	M+F
N	36	42	78
Mean	22.2	21.9	22.0
Max	32.7	30.6	32.7
Min	13.3	14.8	13.3
StdErr	0.79	0.68	0.51

TELSON WIDTH	SEX		
Data	F	M	M+F
N	36	42	78
Mean	16.0	15.8	15.9
Max	23.0	22.7	23.0
Min	8.7	9.9	8.7
StdErr	0.60	0.50	0.38

THORAX WIDTH	SEX		
Data	F	M	M+F
N	36	41	77
Mean	27.8	28.0	27.9
Max	40.1	41.3	41.3
Min	15.3	17.1	15.3
StdErr	1.02	0.93	0.68

WEIGHT	SEX		
Data	F	M	M+F
N	36	42	78
Mean	61.2	67.4	64.5
Max	161.0	200.0	200.0
Min	10.0	14.0	10.0
StdErr	6.40	6.74	4.66

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

10.6.4 Leichhardt River strain

ABDOMINAL LENGTH	SEX		
Data	F	M	M+F
N	58	75	133
Mean	45.7	43.3	44.4
Max	74.5	81.1	81.1
Min	32.8	24.8	24.8
StdErr	1.53	1.54	1.10

ABDOMINAL WIDTH	SEX		
Data	F	M	M+F
N	58	75	133
Mean	23.6	21.3	22.3
Max	40.5	42.5	42.5
Min	12.8	11.2	11.2
StdErr	0.92	0.85	0.63

CARAPACE DEPTH	SEX		
Data	F	M	M+F
N	58	75	133
Mean	24.1	23.4	23.7
Max	40.0	48.7	48.7
Min	17.1	12.0	12.0
StdErr	0.83	0.92	0.63

CHELA LENGTH	SEX		
Data	F	M	M+F
N	58	75	133
Mean	38.7	43.8	41.6
Max	68.8	112.6	112.6
Min	26.6	21.7	21.7
StdErr	1.38	2.23	1.41

CHELA WIDTH	SEX		
Data	F	M	M+F
N	58	75	133
Mean	10.5	14.5	12.7
Max	19.1	38.5	38.5
Min	6.8	6.6	6.6
StdErr	0.38	0.80	0.51

CEPHALON WIDTH	SEX		
Data	F	M	M+F
N	58	75	133
Mean	21.3	20.5	20.8
Max	33.0	38.2	38.2
Min	13.9	11.9	11.9
StdErr	0.67	0.70	0.49

DACTYL LENGTH	SEX		
Data	F	M	M+F
N	58	73	131
Mean	17.6	18.5	18.1
Max	30.2	47.0	47.0
Min	10.9	9.1	9.1
StdErr	0.66	0.93	0.59

OCULAR CARAPACE LENGTH	SEX		
Data	F	M	M+F
N	58	75	133
Mean	37.9	38.3	38.1
Max	62.2	75.2	75.2
Min	27.2	21.8	21.8
StdErr	1.23	1.38	0.94

PROPODAL MEMBRANE LENGTH	SEX		
Data	F	M	M+F
N	1	75	76
Mean	27.7	22.1	22.1
Max	27.7	72.4	72.4
Min	27.7	0.0	0.0
StdErr		1.84	1.82

TOTAL CARAPACE LENGTH	SEX		
Data	F	M	M+F
N	57	73	130
Mean	53.3	53.2	53.3
Max	87.2	103.9	103.9
Min	28.9	31.1	28.9
StdErr	1.77	2.02	1.37

TELSON LENGTH	SEX		
Data	F	M	M+F
N	57	75	132
Mean	18.3	17.4	17.8
Max	30.7	35.4	35.4
Min	11.8	9.7	9.7
StdErr	0.69	0.69	0.49

TELSON WIDTH	SEX		
Data	F	M	M+F
N	57	75	132
Mean	14.3	13.7	14.0
Max	23.1	26.2	26.2
Min	10.2	8.0	8.0
StdErr	0.50	0.49	0.35

THORAX WIDTH	SEX		
Data	F	M	M+F
N	58	75	133
Mean	22.9	22.5	22.7
Max	38.0	45.9	45.9
Min	16.0	12.4	12.4
StdErr	0.82	0.91	0.63

WEIGHT	SEX		
Data	F	M	M+F
N	58	75	133
Mean	41.8	51.3	47.2
Max	148.0	329.0	329.0
Min	11.9	7.1	7.1
StdErr	4.58	7.58	4.72

10.6.5 Gregory River strain

ABDOMINAL LENGTH	SEX		
Data	F	M	F+M
N	41	26	67
Mean	50.0	54.2	51.6
Max	61.4	80.8	80.8
Min	39.6	37.1	37.1
StdErr	0.82	2.38	1.07

ABDOMINAL WIDTH	SEX		
Data	F	M	F+M
N	42	26	68
Mean	27.8	27.6	27.7
Max	34.9	40.7	40.7
Min	19.4	15.7	15.7
StdErr	0.56	1.35	0.62

CARAPACE DEPTH	SEX		
Data	F	M	F+M
N	42	26	68
Mean	28.4	30.9	29.4
Max	35.7	47.0	47.0
Min	21.5	19.8	19.8
StdErr	0.49	1.54	0.67

CHELA LENGTH	SEX		
Data	F	M	F+M
N	42	26	68
Mean	46.5	59.7	51.5
Max	63.1	110.0	110.0
Min	32.2	33.2	32.2
StdErr	1.07	4.73	2.06

CHELA WIDTH	SEX		
Data	F	M	F+M
N	42	26	68
Mean	12.0	18.0	14.3
Max	16.4	34.5	34.5
Min	8.6	10.4	8.6
StdErr	0.27	1.50	0.69

CEPHALON WIDTH	SEX		
Data	F	M	F+M
N	42	26	68
Mean	23.1	25.5	24.0
Max	30.4	38.0	38.0
Min	16.5	16.9	16.5
StdErr	0.48	1.32	0.60

DACTYL LENGTH	SEX		
Data	F	M	F+M
N	42	26	68
Mean	21.8	26.6	23.6
Max	31.7	49.5	49.5
Min	13.6	15.3	13.6
StdErr	0.54	1.92	0.85

OCULAR CARAPACE LENGTH	SEX		
Data	F	M	F+M
N	42	26	68
Mean	43.7	48.5	45.5
Max	55.1	71.2	71.2
Min	31.7	33.4	31.7
StdErr	0.80	2.27	1.03

PROPODAL MEMBRANE LENGTH	SEX		
Data	F	M	F+M
N	0	26	26
Mean	0.0	31.0	31.0
Max	0.0	69.4	69.4
Min	0.0	4.7	0.0
StdErr	0.00	3.89	3.89

TOTAL CARAPACE LENGTH	SEX		
Data	F	M	F+M
N	39	26	65
Mean	62.8	68.8	65.2
Max	81.4	101.6	101.6
Min	45.1	46.6	45.1
StdErr	1.27	3.34	1.57

TELSON LENGTH	SEX		
Data	F	M	F+M
N	42	26	68
Mean	21.6	22.4	21.9
Max	27.6	32.1	32.1
Min	15.0	14.5	14.5
StdErr	0.45	1.06	0.49

TELSON WIDTH	SEX		
Data	F	M	F+M
N	42	26	68
Mean	15.8	16.8	16.2
Max	21.3	25.2	25.2
Min	11.1	11.2	11.1
StdErr	0.34	0.87	0.39

THORAX WIDTH	SEX		
Data	F	M	F+M
N	42	26	68
Mean	26.8	29.6	27.9
Max	35.3	44.7	44.7
Min	18.8	19.2	18.8
StdErr	0.57	1.56	0.71

WEIGHT	SEX		
Data	F	M	F+M
N	42	26	68
Mean	53.7	91.9	68.3
Max	104.5	285.0	285.0
Min	21.0	21.0	21.0
StdErr	3.09	15.59	6.59

Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

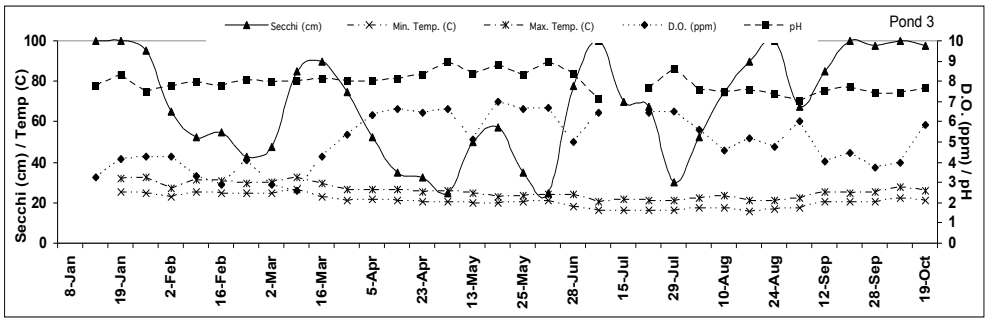
10.6.6 Summary of Tag / Recapture data

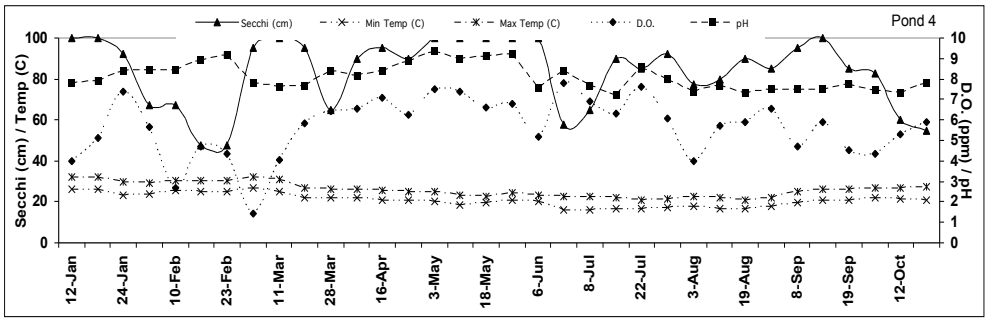
STRAIN	TAG NO.	SEX	TAGGING WT. (g)	TAGGING OCL (mm)	RECAP. WT (g)	RECAP. OCL (mm)	DAYS	GROWTH (g)	GROWT
	F22	M	98.2	50.3	97.4	50.5	122	-0.8	0.2
	F26	F	36	38.2	36	38.3	122	0	0.1
	F34	M	19.1	29.7	19.5	30.5	55	0.4	0.8
	E03	M	26.6	34.3	27	33.7	70	0.4	-0.6
	F35	F	17.5	30.2	18	30.5	55	0.5	0.3
Mitchell	F33	F	18	30.4	19.1	29.9	55	1.1	-0.5
	F40	F	27.5	34.3	28.9	34.7	55	1.4	0.4
	F20	F	21.8	31.4	28.6	31.5	55	6.8	0.1
	E10	M	41.8	38.7	51.5	42.4	67	9.7	3.7
	D57	F	38.3	39.5	48.5	41.4	67	10.2	1.9
	H24	M	37.6	38.1	49.2	42.7	67	11.6	4.6
	E10	M	28.6	35.2	41.8	38.7	125	13.2	3.5
	D57	F	16.1	30.2	38.3	39.5	179	22.2	9.3
	AC2	M	52.4	43.6	51.8	43.5	196	-0.6	-0.1
	AC5	F	39.6	39.4	39.3	39.2	196	-0.3	-0.2
	AL6	F	15.2	29.6	38.9	38.7	253	23.7	9.1
Gilbert	E96	F	32.6	36.2	28.8	35	126	-3.8	-1.2
	E99	F	29	35	31.2	36.2	126	2.2	1.2
	F14	M	27.9	34.7	27.2	34.6	126	-0.7	-0.1
	H41	M	28.5	35.1	35.1	35.1	70	6.6	0
	C89	F	4.5	20.6	63.6	46.5	281	59.1	25.9
	C96	F	3.7	19.3	77.5	49.4	281	73.8	30.1
Flinders	F73	M	41.3	40.3	41.6	40.3	118	0.3	0
	F82	F	36.6	38.3	38.3	38.2	118	1.7	-0.1
	F86	M	43.5	41.4	45.6	41.2	118	2.1	-0.2
	F89	F	48.5	43.2	48.7	42.9	118	0.2	-0.3
	F90	M	27.4	36.1	40.7	41.2	118	13.3	5.1
	H60	F	20.6	31.6	32.4	36.7	63	11.8	5.1
	C46	F	8.5	24.5	69.4	47.2	307	60.9	22.7
	E90	F	14.1	28.7	56	44.8	185	41.9	16.1
	F44	F	14.9	29.7	39	39.7	118	24.1	10
	E84	M	15	29.5	55	45.1	185	40	15.6
	D13	M	15.8	29.9	76.2	49	244	60.4	19.1
	D15	F	17.8	29.1	51.2	44.5	244	33.4	15.4
Leichhardt	F63	F	18	30.7	43.7	40.1	118	25.7	9.4
	F46	F	18.1	30.7	51.6	43.1	118	33.5	12.4
	H46	F	19.3	30.3	41.7	40	62	22.4	9.7
	F56	F	19.4	31.5	49.1	41.8	118	29.7	10.3
	F58	F	19.4	31.5	63.9	47.6	118	44.5	16.1
	H52	M	27.9	35.2	50.2	43.2	62	22.3	8
	D02	F	35.3	39.9	87.5	51.6	244	52.2	11.7
	E80	F	37.9	39.2	51.9	44	185	14	4.8
	E74	M	45.5	40.5	79.9	51.2	185	34.4	10.7
	D26	F	88.5	52.5	97.2	52.7	189	8.7	0.2
	E31	M	11.2	26.9	66.5	46.9	189	55.3	20
Gregory	E32	F	12	27.3	55.5	44.4	189	43.5	17.1
	E40	F	10	25.1	66.3	46.9	189	56.3	21.8
	H21	M	19.8	32.2	51.6	44.5	119	31.8	12.3
	H65	M	40.1	39.4	61	45.2	64	20.9	5.8

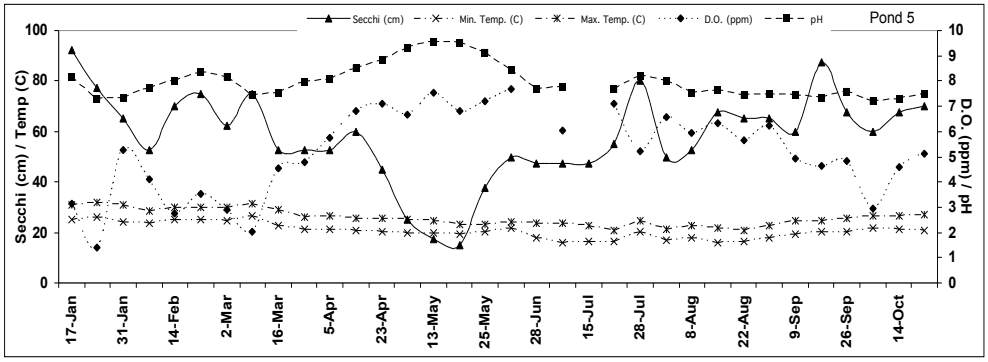
Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

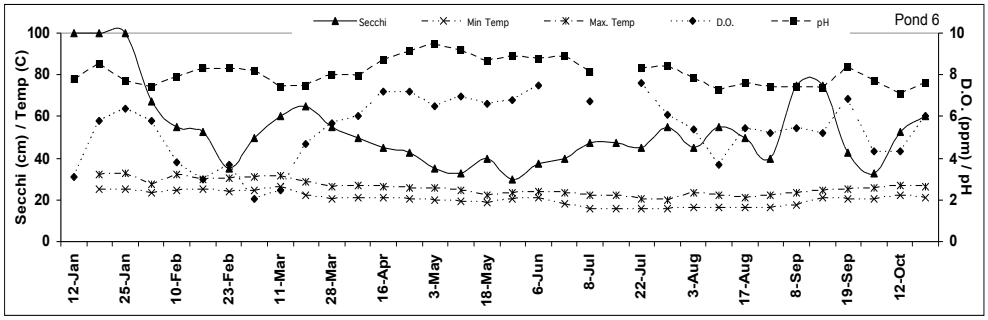
10.7 Water quality records for Polyculture trials

10.7.1 Preliminary assessment trial



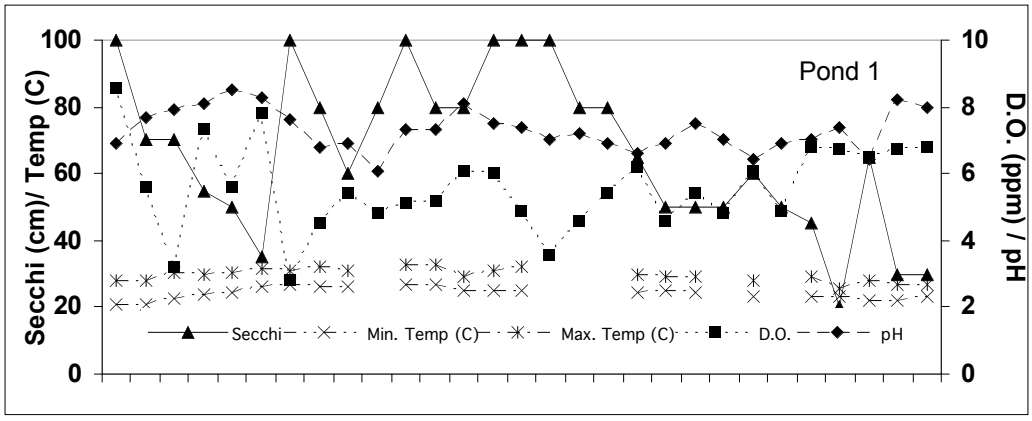


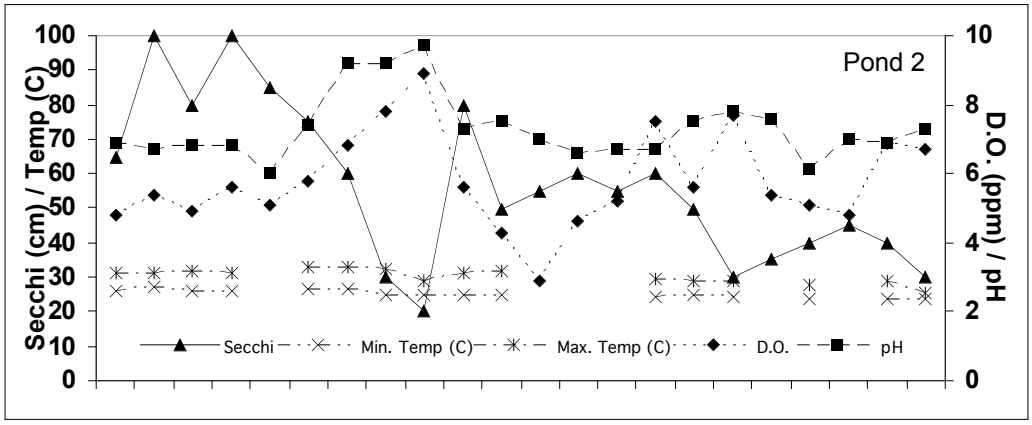


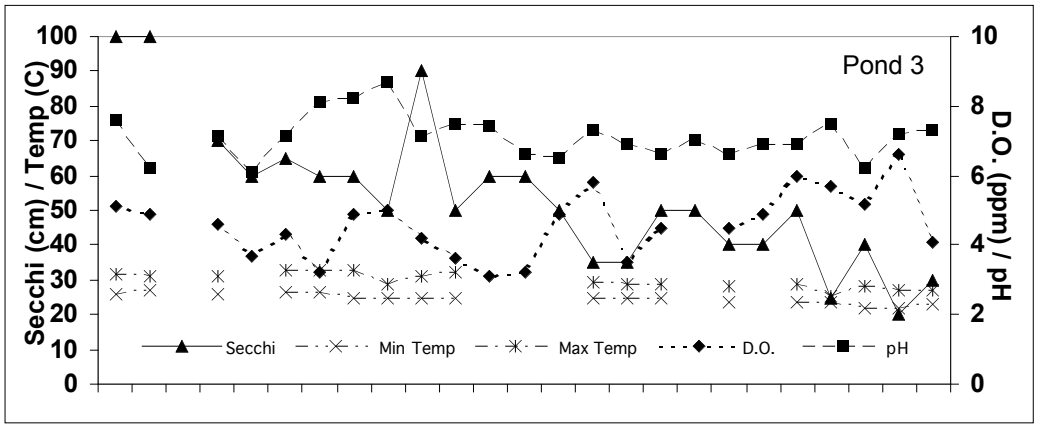


Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia

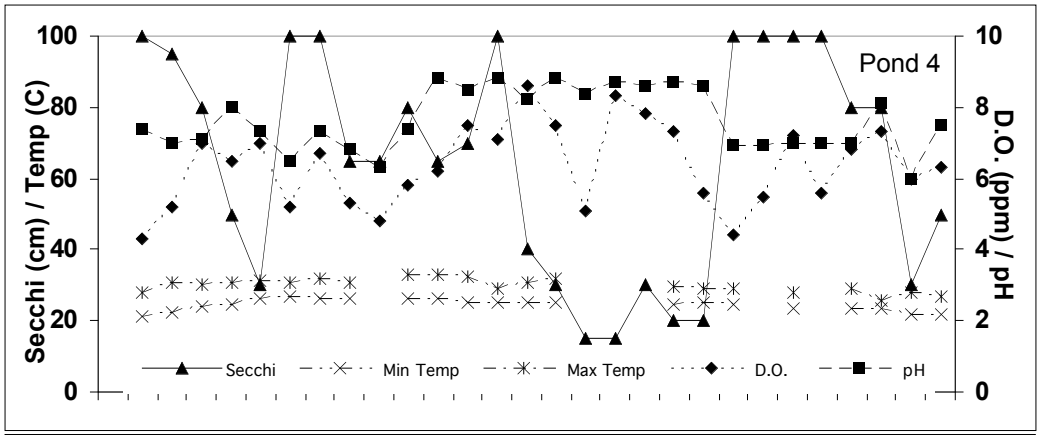
10.7.2 Production trial

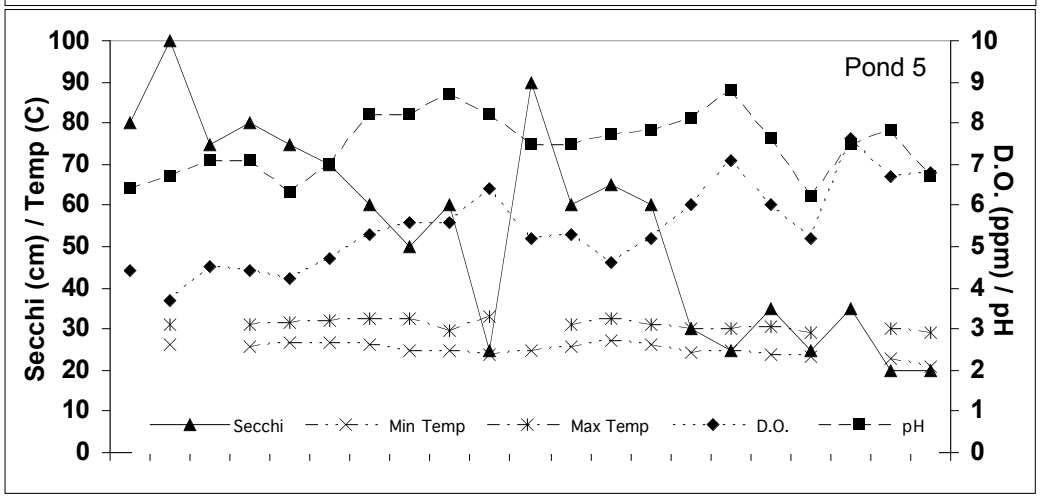


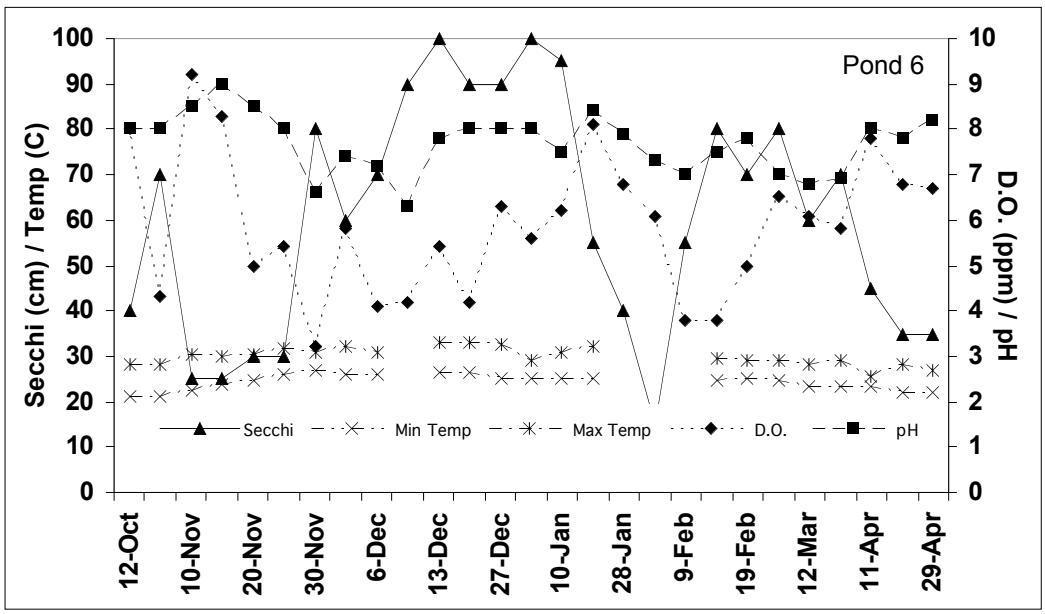




Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia







Freshwater Fisheries and Aquaculture Centre, Department of Primary Industries
Walkamin, Qld 4872, Australia