



Effects of dietary lipid level and source on growth and proximate composition of juvenile redclaw (*Cherax quadricarinatus*) reared under semi-intensive culture conditions

Martha Patricia Hernández-Vergara^{a,*}, David B. Rouse^b,
Miguel A. Olvera-Novoa^c, D. Allen Davis^b

^a *Instituto Tecnológico del Mar No. 1, Carr. Veracruz-Córdoba Km. 12 A. P. 68, C.P. 94290 Boca del Río, Veracruz, Mexico*

^b *Department of Fisheries and Allied Aquaculture, Auburn University, Auburn, AL 36849-5419, USA*

^c *Centro de Investigación y de Estudios Avanzados del I.P.N., Unidad Mérida. Apdo. Postal 73, Cordemex, 97310 Mérida Yucatán, Mexico*

Received 26 August 2002; received in revised form 4 February 2003; accepted 6 February 2003

Abstract

The influence of dietary lipid level on growth, survival, and proximate composition of juvenile redclaw crayfish was evaluated during a 12-week growth trial utilizing semi-intensive culture conditions. Four diets were formulated to be isoenergetic (17.58 kJ g^{-1}) and iso-nitrogenous (30% crude protein). Three of the diets were designed to contain 4.2% (L4), 8.2% (L8) and 12.3% (L12) lipid in a 1:1 ratio of corn oil/fish oil. A fourth diet was formulated to contain 8.7% (LC8) lipid, with corn oil as lipid supplement. A fifth treatment (UF) was included in which the redclaw were not fed in order to estimate the contribution of primary production. Juvenile redclaw ($4.08 \pm 0.2 \text{ g}$ initial weights) were stocked at a density of 10 per tank in 15, 2.5-m³ fiberglass tanks with three replicates per treatment. The trial was conducted in an outdoor flow-through water system. The redclaw in the unfed treatment gained 8.3 g whereas redclaw that received a prepared ration gained an average of 31.9 g. Hence, in this experiment natural productivity contributed about 26% of the weight gain of the redclaw maintained in outdoor tanks. Among the fed treatments, there were no significant differences in survival, final weight, growth, or feed utilization. The hepatosomatic index (HI) generally increased with lipid level and

* Corresponding author. Tel.: +52-229-986-01-89; fax: +52-229-986-01-89.

E-mail addresses: mphv@hotmail.com (M.P. Hernández-Vergara), molvera@mda.cinvestav.mx (M.A. Olvera-Novoa).

was influenced by the sex of the redclaw. Results indicated that in similar culture conditions, diets containing 4% lipid are sufficient for redclaw growth and survival when natural food is present.

© 2003 Elsevier Science B.V. All rights reserved.

Keywords: *Cherax quadricarinatus*; Lipid; Nutrition; Redclaw; Culture

1. Introduction

Three Australian species of the genus *Cherax*, *Cherax destructor* (yabbie), *Cherax tenuimanus* (marron), and *Cherax quadricarinatus* (redclaw) are currently used in aquaculture (Curtis and Jones, 1995; Pinto and Rouse, 1996). Recent studies on growth of these species have shown that of the three, redclaw crayfish has the highest potential for tropical and subtropical commercial aquaculture.

The Australian redclaw crayfish has several advantages over American crayfish species such as *Procambarus clarkii*. It is larger, available in both summer and fall, and has higher meat yield. Additionally, the possibility of redclaw production during the warmer months, which is the off-season for native North American crayfish species, could result in premium prices. During the off-season, high demand for crayfish coupled with a supply shortage of American crayfish, could provide an excellent opportunity for marketing Australian species. These factors could support further development of a redclaw industry in the US and in some countries of North and South America, for example Mexico, Cuba, Belize, Costa Rica, and Ecuador (Pinto and Rouse, 1996).

If redclaw is to be cultured commercially, it is necessary to have a good understanding of culture techniques as well as the nutritional requirements of this species (Boyd et al., 1996). Because most culture techniques for redclaw are semi-intensive, the contribution of natural food sources also should be considered (Goddard, 1988; Jones, 1990, 1995a; Jones and Ruscoe, 1996). Hence, optimizing intensive redclaw production will require a detailed understanding of this species' nutritional requirements as well as an understanding of the contribution of natural food (Mills and McCloud, 1983; Gu et al., 1996). Several studies have evaluated nutrient requirements under laboratory conditions (Jones and Ruscoe, 1996; Hernandez et al., 2000), but few of them have been conducted under more practical conditions where natural foods are available. Jones (1995a,b) and Jones and Ruscoe (1996), made some nutritional trials with redclaw in laboratory and natural conditions, where they found significant differences between the resulting data. These authors showed the important role of natural food as natural source of nutrient for this specie, and for that reason they recommended more research under natural conditions to determinate the practical nutritional requirements for redclaw. The present study was conducted to evaluate the effect of dietary lipid level on survival, growth, hepatosomatic index, and the proximate composition of the hepatopancreas of juvenile redclaw crayfish reared under semi-intensive culture conditions, when natural food source was present.

2. Material and methods

Juvenile redclaw crayfish (*C. quadricarinatus*, 4.08 ± 0.2 g mean weight) were selected from Auburn University redclaw stock for the 12-week trial conducted in the summer. They were placed in an outdoor flow-through culture system consisting of 15, circular fiberglass tanks (2.5-m diameter, 1-m water depth, with a 2-m bottom surface area) supplied with water from a local dam. A stocking density of 5 redclaw/m² was used in all treatments, with 10 redclaw per tank (150 total). Three replicates were utilized in a completely randomized design that allowed the evaluation of four diets with different lipid levels, as well as a fifth control treatment consisting of no supplemental feed. The latter treatment was used to estimate the contribution of naturally occurring food in the culture system on growth of juvenile redclaws.

The basal diet was formulated to contain 30% crude protein and 17.58 kJ g^{-1} gross energy with 4.2% lipid (L4) in relation with previous laboratory results (Hernandez et al., 2000) (Table 1). Two additional diets were supplemented with a 1:1 ratio of menhaden fish oil to corn oil to product diets containing 8.2% (L8) and 12.2% (L12) lipid. A fourth diet (LC8) was formulated to contain 8.2% lipid with corn oil as the sole lipid source.

Feeds were prepared by mixing the dry ingredients for 15 min in a mixer. The oils were added to the diets and mixed for another 15 min. Hot water was then added to the mix to create a homogeneous dough, which was passed through a grinder with a 4-mm hole, forming pellets which were placed on trays and dried at 40 °C for 12 h in a forced air dryer. Once dry (moisture <10%), the diets were crushed and sieved to obtain the appropriate particle size for the different developmental stages (2.5–3.5 mm diameter) of the redclaws during the growth trial, and stored at –10 °C until used.

Proximate composition of the diets and the hepatopancreas of selected redclaws was determined at the beginning and the end of the trial, respectively. All analyses were done in triplicate according to standard methods (AOAC, 1984). Water quality was monitored throughout the experiment. Temperature and dissolved oxygen were measured twice daily: (06:00 and 22:00 h) with a YSI meter (Yellow Springs Instrument, Yellow Spring, Ohio, USA). pH, total ammonia-nitrogen, nitrite-nitrogen and nitrate-nitrogen were measured weekly using a pH meter and kit (Hach, Loveland, CO, USA).

Feeds were offered twice daily at 06:00 and 22:00 h. At the beginning of the trial, feeding rates were 10% of the redclaws biomass and was gradually adjusted downward during the trial to about 2.5% of biomass at the end of the study. At the beginning and the end of the trial, the redclaws were individually measured from the tip of the rostrum to the telson using a vernier, individually weighed in a scout balance (Mod. SR2020) and counted. Additionally, every 2 weeks the redclaws in each tank were bulk weighted and counted for growth and survival calculations, feeding adjustment and efficiency estimations. On the second day of the experiment, all the animals that died after initial measurement were replaced with an equal size animal, with no further replacements made thereafter.

Suitability of the diets was evaluated based on initial and final weight, survival, growth performance, and feed efficiency (Utne, 1979; Hephper, 1988; Hopkins, 1992). Percent survival was expressed as: $S (\%) = 100(N_f/N_i)$. Where N_f was final number of experimental animals and N_i was the initial number of experimental animals. Percent weight gain: WG

Table 1

Ingredient composition and proximate analyses of the experimental diets formulated with different lipid levels

Ingredients (%)	Diet L4	Diet L8 ^a	Diet L12	Diet LC8 ^b
Fish meal ^c	25.00	25.00	25.00	25.00
Soybean meal ^d	12.50	12.50	12.50	12.50
Fish oil (menhaden) ^e	0.00	2.00	4.00	0.00
Corn oil	0.00	2.00	4.00	4.00
Wheat starch	8.00	4.00	0.00	4.00
Whole wheat meal	49.60	49.60	49.60	49.60
Mineral pre-mix ^f	0.50	0.50	0.50	0.50
Vitamin mix ^g	2.00	2.00	2.00	2.00
Rovimix Stay C-35 150 mg active C/kg (35% active)	0.20	0.20	0.20	0.20
di-calcium phosphate ^h	0.20	0.20	0.20	0.20
Soy-lecithin ⁱ	0.50	0.50	0.50	0.50
Cholesterol ^j	0.50	0.50	0.50	0.50
Cellufill ^k	1.00	1.00	1.00	1.00

^a L8 diet: 1:1 ratio of menhaden fish oil to corn oil.

^b LC8 diet: corn oil as the sole lipid source.

^c Special Select™. Omega Protein USA, Randeville, LA, USA.

^d Solvent extracted, Producers Coop. Bryan, TX, USA.

^e Fish oil Omega protein refined oils division. Reedville, VA USA.

^f Vitamin, (g kg⁻¹ premix) (Roche Chemistry): thiamin-HCL, 0.5; riboflavin, 3.0; pyridoxine, 1.0; Ca-pantothenate, 5.0; nicotinic acid, 5.0; biotin, 0.05; folic acid, 1.80; vitamin B₁₂, 0.002; choline chloride, 100.0; myo-inositol, 5.00 vitamin A acetate (20,000 IU/g) 5.0; vitamin D₃ (400,000 UI/g) 0.002; alfa-tocopheryl acetate (250 UI/g) 8.0; vitamin K menadione, 2.0; α-cellulose, 865.266 (Davis and Arnold, 2000).

^g Mineral Premix (g kg⁻¹ diet) (Roche Chemistry): cobalt chlorine, 0.004; cupric sulfate pentahydrate, 0.550; ferrous sulfate, 2.00; magnesium sulfate heptahydrate, 28.398; manganous sulfate monohydrate, 650; potassium iodide, 0.067; sodium selenite, 0.10; zinc sulfate heptahydrate, 13.193; α-cellulose, 69.664 (Davis and Arnold, 2000).

^h Cefkaphos^R. BASF, Mount Olive, NJ, USA.

ⁱ Aqualipid 95, Central soya Chermugy Division, Fort Wayne, IN, USA.

^j Cholesterol (USB) Amersham Life Science, International.

^k Carboxymethyl-cellulose (CMC, Sigma, USA).

(%) = 100(($W_f - W_o$)/ W_o). Where W_f was final weight and W_o was initial weight. Daily weight gain (mg day⁻¹) was determined as: DWG (mg day⁻¹) = (Σ weekly individual weight gain)/(days). Specific growth rate (SGR) was estimated as: 100*(ln final weight - ln initial weight)/(days). The feed conversion ratio (FCR) was estimated based on the feed offered (FO) on a dry matter basis and the total weight gain in all animals, determined as: FCR = FO/WG. Hepatosomatic index (HI) was expressed as the ratio of hepatopancreas weight to whole body weight.

The 12-week growth trial was completed without interruption or apparent problems. Average water quality parameters (mean ± standard deviation) were: temperature (06:00 h), 27.7 ± 1.2 °C (max 30.4 °C, min 23.9 °C); temperature (22:00 h), 30.2 ± 1.5 °C (max 33.3 °C, min 25.5 °C); dissolved oxygen (06:00 h), 5.2 ± 0.9 mg l⁻¹ (max 8.4 mg l⁻¹, min 2.4 mg l⁻¹); dissolved oxygen (22:00 h), 6.6 ± 1.0 mg l⁻¹ (max 8.6 mg l⁻¹, min 3.2 mg l⁻¹); total ammonium nitrogen, 4.2 ± 0.8 mg l⁻¹; nitrite nitrogen, 3.2 ± 1.6 mg l⁻¹; nitrate nitrogen, 54.0 ± 8.4 mg l⁻¹; pH, 6 ± 0.2.

2.1. Statistical analysis

Results were compared with one-way and multifactor analysis of variance (ANOVA) and considered significant at $P \leq 0.05$. Because of the potential for differential growth rates and differences in proximate composition between male and female crayfish, the data were analyzed by multifactor ANOVA using sex and treatment as factors. On the other way, the data were sorted by sex for growth gain and hepatosomatic index analysis too. Duncan's multiple range test was used to identify statistically significant differences among treatment means, with the StatGraphics Plus 4.1 Windows software (Manugistics, Rockville, MA, USA).

3. Results

Survival of juvenile redclaw was high in all treatments (>93%) and showed no statistically significant differences among treatments (Table 2). As expected, almost all parameters tested were significantly lower for crayfish that did not receive feed. Hence, the statistical analyses presented are for only the groups that received feed. For redclaw crayfish that received prepared feed, there were no significant differences in final weight, weight gain, and feed conversion ratio. Different lipid sources in the L8 and LC8 diets did not significantly affect growth parameters. FCR ranged from 1.26 for redclaw that received the L4 diet to 1.41 for redclaw that received the L8 diet, however, there were no significant differences among treatments. Natural productivity contributed approximately 26% of the growth. The final growth data were sorted by sex and analyzed. The ANOVA results showed that males in all treatments had a higher final mean growth than females fed with the same diets (Table 3).

The hepatosomatic index (HI) and proximate composition of the hepatopancreas are presented in Table 3. Based on multifactor ANOVA, both sex and dietary treatment were determined to be significant; consequently, the data were separated by sex and analyzed one by one. HI of females was higher than HI of males in all treatments. The ANOVA analyses for HI in females demonstrated no differences among treatments. In contrast, HI

Table 2
Growth and feed utilization of juvenile redclaw fed experimental diets in outdoor tanks with primary production

Treatments ¹	IW (g)	FW (g)	S (%)	WG (%)	DWG (mg day ⁻¹)	SGR (% day ⁻¹)	FCR	HI ²
Without fed ³	3.44	12.39	96.6	260.3	105.3	1.50	–	7.48
4% (L4)	4.08	37.88	96.6	831.2	397.8	2.62	1.26	8.93 ^b
8% (L8)	4.03	34.12	93.3	751.2	354.8	2.51	1.41	9.20 ^{ab}
12% (L12)	4.20	36.44	96.6	768.5	379.2	2.53	1.32	9.79 ^a
8% (LC8)	4.01	35.51	96.6	785.7	370.6	2.56	1.34	9.59 ^a
± SEM ⁴	0.20	1.3	2.2	36.2	16.31	0.06	0.06	0.25

¹ Means within the same column with different superscripts are significantly different ($P < 0.05$).

² Hepatosomatic index.

³ The unfed animal data were not included in the statistical analyses.

⁴ SEM: pooled standard error of the mean; $n = 3$ (three replicates with 10 redclaw by treatment).

Table 3

Hepatosomatic index and hepatopancreas composition of juvenile redclaw fed experimental diets in outdoor tanks with primary production

Treatments (lipid %)	Sex/FW (g)	Hepatosomatic index	Moisture	Protein	Lipid
<i>Females</i>					
4% (L4)	35.24 ± 2.09	9.61 ± 0.66	51.88 ^a	14.61	32.87 ^b
8% (L8)	32.97 ± 2.33	9.36 ± 1.03	44.91 ^b	13.96	40.42 ^a
12% (L12)	33.12 ± 2.09	10.31 ± 0.82	42.50 ^b	13.23	38.38 ^a
8% (LC8)	29.45 ± 2.02	10.03 ± 1.32	47.87 ^{ab}	15.43	36.43 ^{ab}
Without fed*	12.45 ± 3.32	7.38	73.59	12.67	13.58
± SEM**		1.19	21.05	1.76	13.29
<i>Males</i>					
4% (L4)	43.17 ± 2.82	8.24 ^c ± 0.63	48.18	14.86	34.29 ^b
8% (L8)	35.50 ± 2.82	9.01 ^b ± 0.58	47.78	12.28	31.75 ^c
12% (L12)	39.07 ± 2.82	9.61 ^a ± 0.73	42.86	13.77	35.52 ^a
8% (LC8)	40.40 ± 2.93	8.95 ^b ± 0.52	48.38	15.01	33.21 ^{bc}
Without fed*	12.41 ± 3.74	7.31	54.24	12.58	31.39
± SEM**		0.88	2.36	1.38	2.73

Means within the same column with different superscripts are significantly different ($P < 0.05$).

FW = Final Weight (g).

* The unfed animal data were not included in the statistical analyses.

** SEM ($n = 3$).

of males was significantly different among treatments, increasing as lipid level increased in the diets. There were not differences between 8% lipid diets. Carcass lipid content of males fed the L12 diet was significantly higher than that of males fed the other treatments.

Proximate analyses of the hepatopancreas indicated that the moisture content of UF females was higher than that of fed females, and the hepatopancreas lipid content of UF females was significantly lower than that of females fed the experimental diets. No differences in hepatopancreas protein content were noted among treatments or between sexes (Table 3).

4. Discussion

Water quality parameters measured during the feeding trial were within acceptable limits for good growth and survival of redclaw crayfish under semi-intensive culture conditions (Jones, 1995a). Average survival in the present study (93%) was higher than results reported in the literature, which range from 30% to 80% depending on crayfish stocking size, stocking density, water quality, and other environmental factors. Brummett and Alon (1994) reported 40% survival in polyculture of redclaw and Nile tilapia in earthen ponds with low-density culture. Jones (1990) found an inverse relationship between density and survival in earthen ponds, and reported 74% survival at a density of 5 org/m², and 54% survival at a density of 11.1 org/m². Nonetheless, these data do not constitute evidence supporting the effect of density on survival because in the same study 35.9% survival was recorded at a density of 9.3 org/m². Jones (1990) comments that

survival is related to stocking density, but there are other important factors, such as stocking size, that can also affect survival. Other reports also support the effect of stocking size on survival (Mills and McCloud, 1983; Geddes and Smallridge, 1993; Jones et al., 1995; Jones and Ruscoe, 2000), and indicate that small initial stocking weights (1–2 g) negatively affect survival and hence economic efficiency.

A similar survival (75%) has been reported for a semi-intensive redclaw culture system with a 5-g stocking size (Pinto and Rouse, 1996; Jones and Ruscoe, 2000). In these studies, stocking size was shown to be more important than stocking density, with no negative effects on survival as density increased from 9 to 15 org/m². In the present study, both the relatively low stocking density (5 org/m²) and large crayfish size (4 g) probably contributed to the high survival, even in the unfed treatment group.

Culture ponds usually have a significant supply of natural food items, which are often sufficient for redclaw nutritional requirements in extensive culture. However, under semi-intensive or intensive culture conditions some additional nutrients must be provided to promote maximum growth (D'Abramo and Sheen, 1994). Natural nutrient sources have a strong effect on redclaw growth and need to be considered in feeding rate determinations and diet formulation because they affect culture economics. In the present study, no significant differences in growth were observed among the dietary treatments, which could be explained by the effect of natural food in the culture system.

Hernandez et al. (2000) reported significant differences in growth of juvenile redclaw fed diets with varying lipid levels under laboratory culture conditions. In this growth trial, 26% of weight gain appeared to be from natural food in the culture system. Similar results were reported by Jones (1995a), Jones et al. (1995), Jones and Ruscoe (1996) when studying protein and carbohydrate requirements for redclaw cultured in ponds. In the different studies, Jones was unable to determine the optimum nutrient requirement, because of the ability of the species to use natural food as a nutrient source, but he did not account for the contribution of the natural productivity on the maintenance of the cultured animals. However, since growth and the nutrient profiles of unfed redclaw were significantly depressed, compared to redclaw that received feed, one can conclude that only a portion of the nutrient requirements were met by natural food under the experimental conditions used in this study.

In general, commercial diets for crustaceans contain 8–12% lipid. If a diet containing 4% lipid provides the same growth efficiency as one containing 12%, savings in operating costs can be made by reducing the lipid content of the diet. This is an opportunity to reduce the cost of artificial feed offered to crayfish under semi-intensive conditions. Some research (Jones, 1995a; Jones et al., 1995; Jones and Ruscoe, 1996; Austin et al., 1997; Geoffrey et al., 1998) emphasizes the importance of natural food as a nutrient source in redclaw culture, however, Jones and Ruscoe (2000) recommend the use of artificial feeds in semi-intensive or intensive culture for efficient economic results. Similar growth results have been reported for *Macrobrachium rosenbergii* prawns, which showed a preference for natural food much like that of the redclaw, and optimum growth efficiency when the culture system contributed natural nutrients, which could have compensated for deficiencies in the artificial feed (Tidwell et al., 1998; D'Abramo and New, 2000). Redclaw growth in the present study showed a 700% increase in weight gain in 85 days. Pinto and Rouse (1996) reported similar results in a 158-day growth trial with a density of 5 org/m².

There is limited information on the HI and proximate composition of the hepatopancreas of crustaceans reared with various nutrient sources. In general, HI is related to the nutritional state of fishes and crustaceans. It is also directly related to lipid content of the hepatopancreas and to energy requirements for growth and molting, and is considered an indicator of chronic stress (Jussila and Mannonen, 1997). Results of the present study demonstrate that redclaw females and males use lipids in different metabolic ways. Females in the different treatments did not exhibit significant differences in hepatopancreatic lipid content, which could be related to the use of lipids for ova development, or vitellogenesis. Different developmental stages of the gonads were found in all females in all treatments, including the unfed females. In contrast, males stored more lipid in the hepatopancreas when dietary lipid level increased because they did not have high lipid requirements for gonadic development. Though the effect of dietary lipid levels and lipid sources on redclaw health was not well documented in the present study, the results do demonstrate a direct effect of dietary lipid level on body lipid level in redclaw males. The noted increase in hepatopancreas lipid level in males is in relation with the increase of lipids in the carcass, and it could be used for growth, as in females this lipid storage aids in gonad development.

Based on the results of this study, the lipid content of practical diets designed for semi-intensive culture of redclaw crayfish could be reduced to levels as low as 4.2% without adverse effects on production when a natural food source is present and similar environmental culture conditions are available.

Acknowledgements

The research was supported by CINVESTAV-Mérida and the Mexican Science and Technology Council (CONACyT) within the Doctoral scholarship number 115175. The authors are grateful to Department of Fisheries and Allied Aquaculture, Auburn University, Fisheries's staff and Lukas Manomaitis for providing necessary facilities during the realization of the present research.

References

- AOAC, 1984. Official Methods of Analysis of the Association of Official Analytical Chemists, 14th ed. AOAC, Arlington, VA. 1141 pp.
- Austin, C.M., Jones, P.L., Stagnitti, F., Mitchell, B.D., 1997. Response of the yabby, *Cherax destructor* Clark, to natural and artificial diets: phenotypic variation in juvenile growth. *Aquaculture* 149, 39–46.
- Boyd, C.E., Rouse, D.B., Salamé, M.J., Tysoe, A.J., Díaz, E., Moura, J.G., 1996. Manual de la Técnica de Cultivo de la Langosta de Agua Dulce “Redclaw” Adaptada al Ecuador. Edit. INACUA, Guayaquil, Ecuador. 100 pp.
- Brummett, R.E., Alon, N.O., 1994. Polyculture of Nile tilapia (*Oreochromis niloticus*) and Australian redclaw crayfish (*Cherax quadricarinatus*) in earthen ponds. *Aquaculture* 122, 47–54.
- Curtis, M.C., Jones, C.M., 1995. Observation of monosex culture of redclaw crayfish *Cherax quadricarinatus* von Martens (Decapoda:Parastacidae) in earthen ponds. *J. World Aquacult. Soc.* 26, 154–159.
- D'Abramo, L.R., New, M.B., 2000. Nutrition, feeds and feeding. In: New, M.B., Cotroni, W.V. (Eds.), *Freshwater Prawn Culture: The Farming of *Macrobrachium rosenbergii**. Blackwell Science, Oxford, pp. 203–216.
- D'Abramo, L.R., Sheen, S.S., 1994. Requerimientos nutricionales, formulación de dietas prácticas alimenticias

- para el cultivo intensivo de langostino de agua dulce *Macrobrachium rosenbergii*. In: Cruz, S.E., Rique, M.D., Mendoza, A.R. (Eds.), Avances en Nutrición Acuícola, Memorias del Primer Symposium Internacional de Nutrición Acuícola, Monterrey, Nuevo León, México, pp. 81–101.
- Davis, A.D., Arnold, C.R., 2000. Replacement of fish meal in practical diets for the Pacific white shrimp, *Litopenaeus vannamei*. Aquaculture 185, 291–298.
- Geddes, M.C., Smallridge, M., 1993. Survival, growth and yield of the Australian freshwater crayfish *Cherax destructor* in extensive aquaculture ponds. Aquaculture 114, 51–70.
- Geoffrey, D., Jones, P.L., Austin, C.M., 1998. A comparison of natural and artificial diets for juveniles of the Australian freshwater crayfish *Cherax destructor*. J. World Aquacult. Soc. 29, 243–248.
- Goddard, J.S., 1988. Food and feeding. In: Holdich, D.M., Lowery, R.S. (Eds.), Freshwater Crayfish: Biology, Management and Exploitation. Croom Helm, London, pp. 145–166.
- Gu, H., Anderson, A.J., Mather, P.B., Capra, M.F., 1996. Effects of feeding level and starvation on growth, water, and protein content in juvenile redclaw crayfish, *Cherax quadricarinatus* (von Martens). Mar. Freshwater Res. 47, 745–748.
- Hepher, B., 1988. Nutrition of Pond Fishes. Cambridge Univ. Press, Cambridge. 388 pp.
- Hernandez, M.P., Olvera, M.A., Rouse, D.B., 2000. Optimum protein/lipid ratios for hatchling and juvenile redclaws *Cherax quadricarinatus*. 13th Biennial Symposium of the International Association of Astacology, 6–12 August 2000, Perth, Australia, p. 33.
- Hopkins, K.D., 1992. Reporting fish growth: a review of the basics. J. World Aquacult. Soc. 23, 173–179.
- Jones, C.M., 1990. The biology and aquaculture potential of the tropical freshwater crayfish *Cherax quadricarinatus*. Information Series, vol. QI90028. Queensland Department of Primary Industries. 109 pp.
- Jones, C.M., 1995a. Evaluation of six diets feed to redclaw, *Cherax quadricarinatus* (von Martens), held in pond enclosure. Freshwater Crayfish 10, 21–32.
- Jones, C.M., 1995b. Production of juvenile redclaw crayfish, *Cherax quadricarinatus* (von Martens) (Decapoda, parastacidae): III. Managed pond production trials. Aquaculture 138, 247–255.
- Jones, C.M., Ruscoe, I., 1996. Evaluation of six diets fed to redclaw crayfish, *Cherax quadricarinatus* (von Martens) (Decapoda:Parastacidae), under laboratory conditions. Production Technology for Redclaw Crayfish (*Cherax quadricarinatus*) Final Report FRDC Project 92/119. Fisheries Research and Development, Canberra, pp. 19–30.
- Jones, C.M., Ruscoe, I., 2000. Assessment of stocking size and density in the production of redclaw crayfish *Cherax quadricarinatus* (von Martens) (Decapoda: Parastacidae), cultured under earthen pond conditions. Aquaculture 189, 63–71.
- Jones, P., Austin, C., Mitchell, B., 1995. Growth and survival of juvenile *Cherax albidus* Clark, cultured intensively on natural and formulated diets. Freshwater Crayfish 10, 480–493.
- Jussila, J., Mannonen, A., 1997. Energy content of marron (*Cherax tenuimanus*) and noble crayfish (*Astacus astacus*) hepatopancreas and its relationship to hepatopancreas moisture content. Aquaculture 149, 159–161.
- Mills, B., 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.
- Pinto, G.F., Rouse, D.B., 1996. Growth and survival of the Australian redclaw crayfish *Cherax quadricarinatus* at three densities in earthen ponds. J. World Aquacult. Soc. 27, 187–193.
- Tidwell, J.H., Webster, C.D., Coyle, S.D., Daniels, W.H., D'Abramo, L.R., 1998. Fatty acid and amino acid composition of eggs, muscle and midgut glands of freshwater prawn, *Macrobrachium rosenbergii* (De Man), raised in fertilized ponds, unfertilized ponds of fed prepared diets. Aquacult. Res. 29, 37–45.
- Utte, F., 1979. Standard methods and terminology in finfish nutrition. Proc. Symp. On Finfish Nutrition and Fishfeed Technology II. Hamburg 20–23 June, 1978, pp. 437–443.