ELSEVIER

Aquaculture 189 (2000) 63–71

Aquaculture

www.elsevier.nl/locate/aqua-online

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

Clive M. Jones *, Ian M. Ruscoe

Queensland Department of Primary Industries, Freshwater Fisheries and Aquaculture Centre, Kennedy Highway, Walkamin, Queensland 4872, Australia

Received 23 September 1999; received in revised form 15 February 2000; accepted 25 February 2000

Abstract

Redclaw crayfish, *Cherax quadricarinatus* (von Martens) (Decapoda: Parastacidae),were cultured for 140 days within 24 net pens in a 0.2-ha earthen pond at densities of 3, 9 and 15 m^{-2}, with mean stocking sizes of either 4.71 g or 16.89 g. Crayfish were fed a formulated supplemental pellet diet. An economic evaluation accounted for price paid per individual at stocking, value of the individual at harvest, and amount of food fed. There was no significant effect of density or stocking size on survival that ranged from 76.6% to 87.5%. As density increased, significant decreases in mean harvest size and specific growth rate occurred for both stocking sizes. Mean food quotients (FQs), yields, and economic returns significantly increased as stocking size and density increased, with large-stocked animals at 15 m^{-2} having the highest FQ, yield and economic return. This experiment shows that when stocking with well-advanced juveniles at densities between 9 and 15 m^{-2}, yields in excess of 5 t ha are achievable in 140 days of culture.

Keywords: *Cherax quadricarinatus*; Density; Crayfish; Husbandry; Yield

* Corresponding author. Tel.: +61-7-4092-9929; fax: +61-7-4093-3903.
E-mail address: jonescm@dpi.qld.gov.au (C.M. Jones).

0044-8486/00/$ - see front matter
PII: S0044-8486(00)00359-8

1. Introduction

The aquaculture of redclaw, *Cherax quadricarinatus* (von Martens) (Decapoda: Parastacidae), is a developing industry in northeastern Australia. Official annual production for the state of Queensland is about 60 t (1996–1997) from approximately 20 farms, most of which have less than 2 ha of productive area (Lobegeiger, unpubl. data). The approach taken by individual farmers varies considerably and this is reflected in significant variability in yield (i.e. t ha^{-1}). 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 (1995b,c,d). For growout, juveniles of between 20 mg (i.e. weight at hatching) and 25 g are stocked at densities between 1 and 50 m^{-2} 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 (e.g. Allan and Maguire, 1992; Geddes et al., 1993; Daniels et al., 1995; Morrissy et al., 1995; Tidwell et al., 1999), further investigation of these variables for redclaw aquaculture was considered important. To assist in identifying the stocking size and density that result in optimum yield, an experiment was 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. Villarreal et al. (1999) used stocking densities up to 20 m^{-2}, but only for nursery stages. This trial was designed to examine a more extensive range for the growout stage, including densities above those commonly applied by commercial aquaculturists.

2. Materials and methods

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

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

Each pen was furnished with an equivalent amount of two artificial shelter types. The first consisted of bundles of plastic oyster mesh (Southcorp Industrial Textiles) (similar to that used for onion bags), attached to rope and secured to the pond bottom with a concrete weight. Each mesh bundle was made from 20 strips (1 m × 100 mm) 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, 1995c). Four of these mesh bundles were placed in each pen, equivalent to one per 4 m^2.

The second shelter type was a fixed structure comprised of twenty-four 250-mm lengths of 80-mm diameter corrugated polythene agricultural pipe, 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 240 mm × 640 mm piece of rigid plastic mesh (6 mm, Nylex) 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 pen, resulting in a combined shelter density of 1 per 2 m^2.

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

Twenty-four pens were used to accommodate six treatments with four replicates. The treatments consisted of three stocking densities (3, 9 and 15 crayfish m^{-2}) and two stocking sizes (means of 4.71 and 16.89 g) in a randomised block design. Blocking was on the basis of four rows of six pens across the pond at various depths. Experimental crayfish were harvested with a flowtrap (Jones, 1994b) from a pond that had been stocked 4 months previously with broodstock (Gilbert River strain).

A commercial crayfish diet (17% protein, 4% fat: Athmaize™), previously established as a good supplemental feed for redclaw (Jones, 1995a), was used for the duration of the trial. A feeding schedule was generated for each treatment that 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 crayfish). Actual feeding rate was then adjusted on the basis of observation of uneaten food, with pens within each treatment receiving the same rate of feed. Food was introduced on 3 non-consecutive days each week between 1500 and 1700 h. Actual feed amounts were recorded.

The experiment was initiated on June 21 (early winter) and ran for a period of 140 days. Crayfish samples from each pen were taken using baited traps at days 56 and 106. At final harvest on November 8 (late spring), all crayfish were removed, and their sex and individual weight recorded.

The experimental pond used was initially prepared with applications of dolomite at 1000 kg ha^{-1}, diammonium phosphate at 250 kg ha^{-1} and mulching hay at 1000 kg ha^{-1}. Additional applications of both fertiliser types were applied outside the pens throughout the experiment to maintain a plankton bloom. Water was maintained at a constant depth of between 1.3 and 1.8 m for the four rows of pens. Water was added only to replace evaporation and seepage. Dissolved oxygen concentration and pH at the pond bottom were measured each Monday between 0800 and 0830 h with an FL90 water quality meter (TPS). Maximum and minimum temperature, as well as Secchi depth, were also measured.

Although a substantial proportion of the food consumed by redclaw may be naturally occurring organisms in the benthos (Jones, 1995a; 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 and benthic productivity. A food quotient

(FQ) was therefore calculated to measure the efficiency of supplemental food conversion (Maguire and Leedow, 1983) where

$$\text{FQ} = \text{Weight of formulated feed provided (g)} / \text{Increase in crayfish wet weight (g)}$$

An index of economic return (ER) (after Maguire and Leedow, 1983) was also calculated to provide a suitable parameter for determining the optimal stocking size and density combination. Only those factors of economic significance related to this experiment, as shown below, were considered.

$$\text{ER} = (Y_C) - [(Y_J) + (Y_F)]$$

where Y_C is the value of the crop, Y_J is the cost of juveniles, and Y_F is the cost of feeding.

Cost of original juveniles (Y_J) was estimated to be Aus\$0.05 for the small size and Aus\$0.10 for the large size. Cost of supplemental feed (Y_F) was Aus\$0.40 kg^{-1}. 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. A regression, based on known market prices for different size grades, was used to determine individual crayfish value. The size-dependent price (Y_P) was

$$Y_P \text{ Aus\$ kg}^{-1} = 0.0983 W_F + 4.35$$

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

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 on growth. Analysis of weight specific growth rate (SGR%), as recommended by Evans and Juissila (1997), was therefore used to determine treatment effects. Data for yield and economic return were converted to t ha^{-1} as a standard term of reference.

All statistical computations were performed at the 0.05 probability level. Data for sample and harvest weight, SGR, FQ, survival, yield and economic return were analysed by two-way analysis of variance carried out using Statistix 4.0 analysis software. Homogeneity of variance was established amongst the four replicate cages allocated to each size/density treatment. Before accepting analysis of variance results for percentage data (survival and SGR), residuals were examined and found to be randomly distributed (Sokal and Rohlf, 1981). Where $P < 0.05$, a least significant difference comparison of means test was performed.

3. Results

Conditions in the pond during the experiment remained reasonably stable and conducive to redclaw production. At the beginning of the trial, in mid-winter, the diurnal temperature range was 16–21°C; however, these values steadily increased throughout

Table 1
Mean weight (g) (±SE) of redclaw crayfish at stocking, interim samples and harvest from stocking size/density trials. Values within columns with the same superscripts are not significantly different

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

the experiment to peak at 22–27.5°C in the week of harvest. Dissolved oxygen ranged between 3.3 and 7.4 mg l^{-1} with an average of 6.2 mg l^{-1} for the duration of the experiment. pH ranged between 7.2 and 9.4 with an average of 8.3. Secchi depth ranged between 90 and 150 cm.

Statistics for samples taken during the conduct of the trial and at harvest are presented in Table 1. Means (±SE) for survival, SGR, FQ, yield and economic return (ha^{-1}) are presented in Table 2. With the exception of one cage, survival rates were high for all treatments (range 76.6–87.5%), and there was no significant ($P > 0.05$) effect of density or stocking size on survival.

As stocking density increased, significant ($P < 0.001$) decreases in mean harvest weight and SGR occurred for both stocking sizes of crayfish. Larger-stocked crayfish had significantly heavier harvest weights than the smaller-stocked animals; however, the smaller treatments always had higher SGRs than the larger-stocked treatments, irrespective of density. There was no significant ($P > 0.05$) interaction between stocking size and density in relation to either mean weight or SGR.

Table 2
Production parameters (±SE) for redclaw crayfish stocked at two stocking sizes and three densities when cultured in pens within an earthen pond over 140 days. Values within rows with the same superscript are not significantly different

Density	3		9		15	
Stocking size	Small	Large	Small	Large	Small	Large
Survival (%)	76.6 ± 3.34^a	87.53 ± 3.61^a	78.63 ± 6.79^a	83.15 ± 2.56^a	83.93 ± 1.33^a	83.90 ± 2.61^a
SGR (%)	1.58 ± 0.023^a	0.88 ± 0.024^d	1.31 ± 0.023^b	0.67 ± 0.013^e	1.23 ± 0.047^c	0.63 ± 0.014^e
Food quotient	1.35 ± 0.11^a	4.16 ± 0.52^c	2.07 ± 0.26^b	6.82 ± 0.28^d	2.17 ± 0.12^b	7.39 ± 0.38^e
Estimated yield (t ha^{-1})*	1.04 ± 0.06^a	1.59 ± 0.11^b	2.22 ± 0.19^c	3.46 ± 0.08^d	3.47 ± 0.17^d	5.52 ± 0.16^e
Economic return (Aus$ ha^{-1})*	7829 ± 670^a	12948 ± 1650^b	11749 ± 1602^b	18575 ± 1048^c	17281 ± 1555^c	27206 ± 1600^d

* Estimated yields and economic returns (see text) are based on production within 16 m^2 pens.

FQ was significantly ($P < 0.001$) influenced by both stocking size and density. For each density, FQ was more than three times greater for large-stocked crayfish than for small. For both stocking sizes, FQ increased significantly with density from 3 to 9 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.

Equivalent yield ranged from 1.04 to 5.52 t ha^{-1} (over 140 days), increasing with increased stocking size and density. 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. Of the treatments applied, the large stocking size and density of 15 m^{-2} produced the greatest economic return, equivalent to Aus$27,200 ha^{-1}.

4. Discussion

This trial demonstrated that by increasing stocking density, from 3 to 15 crayfish m^{-2}, and increasing stocking size from a mean of approximately 5–17 g, SGR declined, survival was unaffected and FQ, economic return and yield increased. These results are similar to those documented for other aquacultured crayfish (Mills and McCloud, 1983; Lutz and Wolters, 1986; Geddes et al., 1993; Brown et al., 1995; McClain, 1995; 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 in their study was uniformly high (73%) and mean growth rate was inversely correlated with density. Although their size at stocking was a little smaller than the small (5 g) size of this trial, culture periods were equivalent; and, at 3 crayfish m^{-2}, this study and that of Pinto and Rouse generated yields of 1039 and 1029 kg ha^{-1}, respectively.

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

The decline in growth with increasing stocking density and size is likely to be attributable to both 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 supplemental food was reasonably constant across all treatments. However, the significant positive correlation of FQ and density suggests that the crayfish were more reliant on the supplemental feed at higher densities than at lower densities. Previous studies have suggested the importance of natural food in the pond production of redclaw (Jones, 1995a). If the reduction in growth rate (SGR%) at the higher densities was attributable to decreased availability of natural food materials, as suggested by Allan and Maguire (1992) for a penaeid, it would be expected that the relative importance of the supplementary food would increase. The increased FQ at higher densities suggests that the supplemental feed has a poor direct nutritional value for the crayfish.

Lower growth at high densities may also be the result of behavioural factors, increased interaction and antagonism, and possibly deteriorated sediment conditions due to increased organic 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 that of the lower densities (Table 2), the lack of a significant difference in final mean weight between densities of 15 and 9 m^{-2} suggests that these higher densities are limiting. In view of the likelihood of deteriorated sediment conditions at higher densities applied across an entire pond, a maximum density for semi-intensive 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 generate less waste, higher densities may be sustainable.

FQ values for the small stocking size at all densities were economically attractive at around 2, and growth indices indicated that good growth was achieved. However, the much higher values (> 4) for FQ 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 Aus$0.40 kg^{-1} 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 supplemental feeds applied across the entire pond, over-feeding is also likely to contribute to deterioration of water quality.

Behavioural factors that 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 that occur and the importance of shelter for redclaw has been clearly demonstrated (Fielder and Thorne, 1990; Jones and Ruscoe, unpubl. data. Jones and Ruscoe (unpubl. data) demonstrated the adverse effect that insufficient or unsuitable shelter has on survival of redclaw. The uniform and high survival for this trial across all treatments, indicates that shelter type and availability are not likely to have been limiting. Mitigation of behavioural interactions that 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 that may provide scope for modification would be genetic selection, although such an approach would seem unjustified at present when economically acceptable yields are achievable.

Results of this experiment 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 the potential for achieving relatively high redclaw yields, in excess of 5 t ha^{-1} yr^{-1}, under semi-intensive culture conditions that include supplemental feeding. A key to generating such yields would appear to be the practice of stocking advanced juveniles of a uniform size above 5 g, and at densities of between 9 and 15 m^{-2}.

Acknowledgements

This work was funded by the Fisheries Research and Development grant number 92/119. The authors would like to thank Jo-Anne Grady, David Bull and Ian Wallace for technical support throughout this project.

References

Allan, G.L., 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, J.E. II, Hoene, B., 1995. Increased densities result in reduced weight gain in *Orconectes virilis*. J. World Aquacult. Soc. 26, 165–171.

Chien, Y.H., Lai, H.T., 1988. The effects of aged sediment and stocking densities on freshwater prawn *Macrobrachium rosenbergii* culture. J. World Aquacult. Soc. 19 (1), 22A–23A.

Daniels, W.H., D'Abramo, L.R., Fondren, M.W., 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. J. World Aquacult. Soc. 26 (1), 38–47.

Evans, L., Juissila, J., 1997. Freshwater crayfish growth under culture conditions: proposition for a standard reporting approach. J. World Aquacult. Soc. 28 (1), 11–19.

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

Geddes, M.C., Smallridge, M., 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, 109 pp.

Jones, C.M., 1994a. Airlift aeration. In: Jones, C.M., Curtis, M.C. (Eds.), Redclaw Farming. Proceedings of the Redclaw Farming Workshops, Feb. 12–17, 1994, Walkamin, Rockhampton, Nambour. Queensland Department of Primary Industries.

Jones, C.M., 1994b. Flowtrap harvesting. In: Jones, C.M., Curtis, M.C. (Eds.), Redclaw Farming. Proceedings of the Redclaw Farming Workshops, Feb.12–17, 1994, Walkamin, Rockhampton, Nambour. Queensland Department of Primary Industries.

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, 221–238.

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

Jones, C.M., 1995d. 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., Grady, J., 1996. Production of juvenile redclaw (*Cherax quadricarinatus*) at two demonstration sites in north Queensland. Freshwater Farmer (Australia) 4 (1), 12–13.

Lutz, C.G., Wolters, W.R., 1986. The effect of five stocking densities on growth and yield of red swamp crawfish *Procambarus clarkii*. J. World Aquacult. Soc. 17 (1–4), 33–36.

Maguire, G.B., Leedow, M.I., 1983. A study of optimum stocking density and feed rate for school prawns *Metapenaeus macleavi* (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., 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., Austin, C.M., 1995. A conceptual production model for freshwater crayfish pond culture incorporating detrital forage. Aquacult. Res. 26 (2), 117–128.

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

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

Smith, T.I.J., Sandifer, P.A., 1979. Observations on the behavior of the Malaysian prawn, *Macrobrachium rosenbergii* (de Man), to artificial habitats. Mar. Behav. Physiol. 6, 131–146.

Sokal, R.R., Rohlf, F.J., 1981. Biometry. In: The Principles and Practice of Statistics in Biological Research. 2nd edn. Freeman, San Francisco, CA.

Tidwell, J.H., Coyle, S., Weibel, C., Evans, J., 1999. Effects and interactions of stocking densities and added substrate on production and population structure of freshwater prawns *Macrobrachium rosenbergii*. J World Aquacult. Soc. 30 (2), 174–179.

Villarreal, H., Naranjo, J., Hinojosa, P., 1999. Effect of density on the growth, survival and biomass production of the Australian freshwater crayfish *Cherax quadricarinatus* (Redclaw) in gravel lined ponds in Ecuador. In: Annual International Conference and Exposition of the World Aquaculture Society, 26 April–2 May, Sydney, Australia. Book of abstracts.

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.