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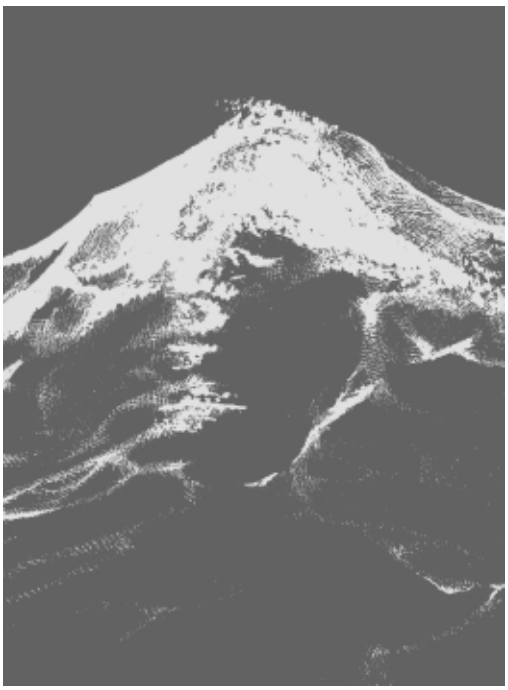

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Effect of density on growth and survival of ornate rock lobster, *Panulirus ornatus* (Fabricius, 1798), in a flow-through raceway system

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Abstract. Juvenile ornate rock lobsters (*Panulirus ornatus*) (3.24 ± 0.09 g; 13.8 ± 0.13 mm CL) captured from the wild were stocked at three densities (14, 29, and 43 m^{-2}) within each of four 4000-L fibreglass raceway tanks with flow-through seawater supply. Lobsters were provided with shelters consisting of opaque polyethylene platforms, 600 mm × 600 mm, supported on six 100-mm legs and were fed continually through the night with a commercial penaeid prawn (*P. japonicus*) pellet supplemented with prawn flesh once per day. Growth and survival were monitored by means of a monthly sample of 20 lobsters from each experimental unit. After 272 days, density treatments did not differ significantly in survival, which averaged 52.5% (± 2.8). Lobster size was also unaffected by density, and mean size for all lobsters was 225.3 ± 4.68 g (61.8 ± 4.7 mm CL) at harvest. Mortality was consistent through time and was almost entirely attributable to cannibalism of postmoult individuals. The cannibalism may have been due to inappropriate shelter and feeding strategy. Despite higher mortality than anticipated, growth was rapid, representing a specific growth rate of 1.56% day^{-1}, sufficient to permit growth from 3 g to 1 kg within 18 months. The experiment confirmed the excellent potential of *P. ornatus* for commercial aquaculture.

Introduction

The ornate rock lobster, *Panulirus ornatus* (Decapoda: Palinuridae), is a tropical species with an Indo-West Pacific distribution. It is particularly abundant in the north-east of Australia, where it supports a commercial fishery that lands approximately 500 t (whole weight) of lobsters per year (Pitcher *et al*. 1997). Fishers have traditionally tailed and frozen the catch, but an increasing proportion is now shipped live to Cairns in north Queensland, where it is held, graded, packed, and exported live by air freight to markets in Asia. Live *P. ornatus* regularly fetch prices in excess of \$A45 kg^{-1} in markets in northern China. The live-lobster sector of the industry has expressed strong interest in growing out small lobsters between 500 and 900 g to a more valuable, larger size over 1 kg. Furthermore, in light of recent advances in larval rearing (Illingworth *et al*. 1997; Kittaka 1997), industry demands more information on production technologies to close the life cycle.

Development of production technologies for the captive grow-out of tropical rock lobsters will necessitate a sound understanding of the environmental and biological requirements of the species and identification of optimal conditions for maximizing growth and survival. Previous studies (Geddes *et al*. 2001) indicated *P. ornatus* has a broad tolerance to temperature and salinity, which would be advantageous given the constraints of captive grow-out systems. Economics of production require that reasonably high densities be maintained in culture systems that provide for good growth and high survival. We set out to determine the effect of density on the production of *P. ornatus*, for densities representing a range from low to high for the type of culture system employed.

Materials and methods

Our experiment was performed at the aquaculture facilities of the Northern Fisheries Centre, Cairns, in northeastern Australia. Experimental lobsters were captured from the wild either by hand collecting from wharf pylons in Trinity Inlet, Cairns, or from artificial shelters (oyster baskets filled with netting material) deployed at various sites along the coast in the vicinity of Cairns. All stocks were acclimated to captive conditions on flow-through seawater for at least 7 days prior to their allocation to the experiment.

We applied a randomized block design to assess the effect of density on growth and survival. Three densities (14, 29, 43 m^{-2}) were assigned to separate compartments in each of four fibreglass tanks (blocks) (4500 mm × 1750 mm × 500 mm), each holding 3000 L of water. Tanks were supplied with flow-through seawater, pumped directly from Trinity Inlet, filtered through a sand filter, and supplied to each tank at 50 L per minute. Each tank was divided across its width into three compartments 2500, 1200, and 800 mm in length and 4.38, 2.10, and 1.40 m^2 in area, respectively. The position of the compartments was allocated randomly to each tank. The barriers were made of 4-mm polyethylene mesh mounted in an aluminium frame. Each compartment was equipped with a shelter consisting of an opaque

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polyethylene platform, 600 mm × 600 mm, supported on six 100-mm legs. A plastic tray of coral rubble was placed in each compartment as a nutritional supplement.

Each tank compartment (experimental unit) was stocked with 60 lobsters of a mean weight of 3.24 ±.21 g randomly selected from the pool of available stock. Sex, weight, and carapace length were recorded at stocking. Weight was measured with an electronic balance, to the nearest 1 g, for lobsters that had been removed from water and allowed to drip dry onto a towel for 30 seconds. Carapace length was measured with vernier callipers to the nearest 0.1 mm, from between the rostral horns to the posterior margin of the carapace. At approximately 1 month intervals, lobsters in each experimental unit were counted, and a sample of 20 were randomly chosen for measurement of weight and carapace length.

Penaeus japonicus prawn pellets (Higashimaru Ebistar No.12) were provided from approximately 1600 hrs until 0400 hrs by 12-hour belt feeders each day at an initial rate of 4% of biomass per day, adjusted according to observations of feed intake. Lobsters were fed to excess and the remainder removed daily. Feeding rate remained consistent for each density and was recorded daily. Supplementary feeding of prawn flesh, once per day, 5 days per week was applied consistently across all compartments.

The experiment was run for 272 days (October 1999 through June 2000) under ambient conditions of seawater quality and temperature. Water temperature was measured hourly and recorded by a marine-grade temperature logger (Hastings, Tinyview). Salinity was measured once daily with a portable meter (YSI 63). Statistical analyses were performed with Genstat 5 (Lawes Agricultural Trust). One-way analysis of variance (randomized block) was performed on both final survival and final weight, with tank as a blocking factor.

At the completion of the experiment, lobsters were frozen and transported to the Department of Primary Industries, Centre for Food Technology, Brisbane, for formal sensory evaluations by a trained panel of 13 experienced seafood tasters. Individuals from the experiment were compared with wild-caught *P. ornatus* and wild-caught western rock lobster *Panulirus cygnus*. Sample lobsters were placed in boiling water with 0.3% salt in a gas-fired prawn cooker until the internal temperature reached 80°C. Once cooked, the lobsters were removed and placed in ice slurry until the internal temperature dropped to 15°C so they could be handled. Lobster shells were removed, and samples were cut widthways across the animal.

A standard rating test was applied (Anon. 1988). For each attribute examined, average panellist scores for each sample at each session were compared in a randomized-block analysis of variance. At each of two sessions all samples were compared, and session was considered a blocking factor in the analysis. Where a significant ($P < 0.05$) F ratio was found, pairwise comparisons were made according to Fisher's least-significant-difference procedure.

Results

Water quality remained at an acceptably high level for the duration of the experiment. Although salinity dropped to levels of between 25 and 35 (Practical Salinity Scale 1978) for brief periods during heavy wet-season rain, this fluctuation did not appear to affect the experimental stock adversely, as evidenced by uninterrupted activity patterns and feeding. Water temperature ranged from 23 to 31°C and averaged 27°C for the experimental period.

A summary of yield statistics is presented in Table 1. After 9 months (272 days), although survival and mean weight were highest in the low-density treatment, neither survival nor weight differed significantly ($P > 0.01$) with density. Blocking (tanks) was not a significant factor in the ANOVA. Mean survival for the three densities ranged from 58.3% (low density) to 44.6% (high density). Mortalities occurred consistently through the experimental period (Fig. 1) and followed a similar trend for each treatment. Only postmoult individuals died, and we saw no indication of disease or health-related deaths.

Growth over the experimental period (Fig. 2) was exponential and was equivalent for each density. Final weight averaged 225.3 g across all densities, representing a specific growth rate [SGR = (Ln Wt_f – Ln Wt_i)/t ×x 100] of 1.56% day^{-1}.

An examination of the size frequency of lobsters at each density (Fig. 3) indicated that larger individuals were more numerous at the low density and that a significant difference in mean weight might have become apparent if the experiment had continued for a longer period. Nevertheless, all three densities were well represented at both extremes of the size range.

Male (231.2 ± 6.5 g) and female (219.0 ± 6.7 g) lobsters did not differ significantly ($P > 0.05$) in weight at harvest (Fig. 4).

Table 1. Size, biomass, and survival statistics for *P. ornatus* at stocking and harvest, cultured at three densities over 272 days

Statistics with the same superscript letter are not significantly different ($P > 0.05$)

	Density	Low	Medium	High
Initial	Density (# m^{-2})	14	29	43
	Mean weight (g ± s.e.)	3.25 ± 0.03[a]	3.32 ± 0.05[a]	3.15 ± 0.05[a]
	Mean carapace length (mm ± s.e.)	13.78 ± 0.06[a]	13.86 ± 0.07[a]	13.71 ± 0.06[a]
Final	Mean density (# m^{-2} ± s.e.)	7.95 ± 0.32	15.60 ± 0.48	19.11 ± 1.01
	Mean weight (g ± s.e.)	235.1 ± 6.3[a]	225.9 ± 6.3[a]	214.7 ± 4.8[a]
	Mean carapace length (mm ± s.e.)	62.78 ± 0.40[a]	62.03 ± 0.60[a]	60.63 ± 0.51[a]
	Biomass (kg m^{-2} ± s.e.)	1.85 ± 0.04[a]	3.50 ± 0.09[b]	4.05 ± 0.12[c]
	Survival (% ± s.e.)	58.3 ± 2.3[a]	54.6 ± 1.7[a]	44.6 ± 2.3[a]

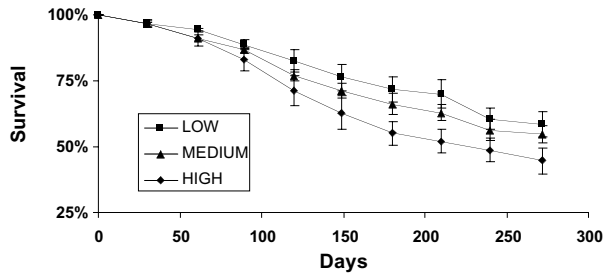

Fig. 1. Mean (for 3 replicates) (± s.e.) survival of ornate rock lobsters at three densities over 272 days.

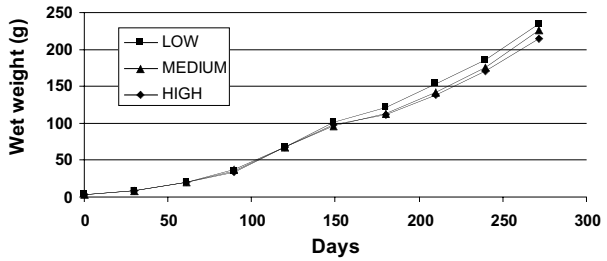

Fig. 2. Mean weight (g) of ornate rock lobsters at three densities cultured over 272 days.

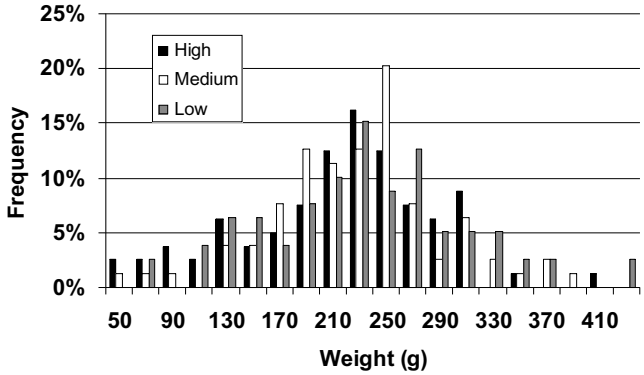

Fig. 3. Size frequency (weight) of ornate rock lobsters at three densities over 272 days.

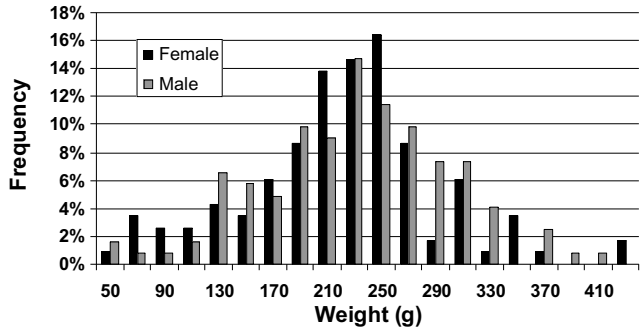

Fig. 4. Size frequency of male and female ornate rock lobsters (pooled for replicates) after 272 days of growth.

Sensory evaluations found no significant differences ($P > 0.05$) between samples in flavour, aftertaste, or overall quality characteristics. The aquacultured ornate rock lobster and the wild-caught western rock lobster were firmer than the wild caught ornate rock lobster, although this difference may be attributable to the size of the lobsters rather than to treatment differences. The wild-caught ornate rock lobster was paler in colour than the aquacultured ornate and western rock lobsters.

Discussion

Our experiment provides valuable information on the biology of *P. ornatus*. Further, it helps to define conditions necessary to grow ornate rock lobsters in tank systems and contributes significantly to realizing the excellent aquaculture potential suggested for this species (Linton 1998). Ornate rock lobsters are clearly tolerant of high-density conditions and grew well at all the densities applied (maximum 43 m^{-2}) and the biomass levels that those densities represented (maximum 4.7 kg m^{-2}). Given the lack of any significant differences between densities in either survival or weight at harvest, even higher grow-out densities might be feasible. From a commercial perspective, higher densities would be more economic and might offset the slight decrease in survival.

Although substantial mortality occurred over the duration of the experiment, it was not strongly influenced by density, so other factors were probably responsible. Even though survival averaged 52% for the 272 days of the experiment, the absolute density of lobsters at harvest was relatively high, between 8 and 19 lobsters m^{-2}. This density is equivalent to the highest suggested as suitable for other palinurids (Lee and Wickins 1992; Booth and Kittaka 1994; Rahman and Srikrishnadhas 1994). Because of the novelty of culturing palinurid lobsters, few documented data address production methods and the effects of production variables like density on growth and mortality. Published data (Booth and Kittaka 1994; Lee and Wickins 1992) are indicative only and based on observation and general experience rather than controlled experimentation. Comparisons with other cultured crustaceans (Lee and Wickins 1992) indicate that the densities sustained in this experiment are at the high end of the spectrum.

Few data on growth of juvenile palinurids under controlled conditions are available for comparisons. Dennis *et al.* (1997) presented data for growth of juvenile *P. ornatus* from both wild populations and laboratory studies. Their laboratory studies, which examined the effect of temperature on growth of juveniles (6 to 93 g at stocking) over one year, showed a maximum growth rate of 0.88 mm CL $week^{-1}$. In those units, the growth of lobsters in our study was >1.2 mm CL $week^{-1}$ at higher densities. Indeed, the growth rate achieved in this study was equivalent to the

growth of wild juveniles (1.3 mm CL week^{-1}) whose density was extremely low (≤0.0074 m^{-2}).

Juinio-Menez and Ruinata (1996) examined growth of small (~90 g) *P. ornatus* to determine the effect of eyestalk ablation on growth. The best growth achieved in their experiment was for bilaterally ablated lobsters and represented a specific growth rate of 0.87% d^{-1}, about half that achieved in our experiment. Furthermore, the densities applied to their experiment were substantially lower. They attributed the relatively poor performance to deficient diet.

Growth of lobsters in the experiment covered a sufficiently broad range of size and duration to provide for a useful assessment of commercial potential for grow-out. The specific growth rate of 1.56% and the likelihood of continued linear growth to maturity (Skewes *et al.* 1997*a*, *b*) indicate that growth from 3 g to 1 kg is likely to be achievable in less than 18 months. For a high-value species like *P. ornatus*, the process is likely to be economically viable. Growth rate from first-instar juvenile to 3 g, however, is less certain, as there are no reliable data over this size range. The data from Phillips *et al.* (1992) and Dennis *et al.* (1997) suggest this phase takes several months, but as the growth reported in this experiment was significantly better than that in previous laboratory studies, the conditions applied (system, diet, etc) may permit completion of the early juvenile phase in a relatively shorter period.

The good growth generated in the experiment was achieved to a large extent on a commercial penaeid prawn diet. As feeding was deliberately provided to excess to ensure that food availability did not affect the outcome, food-conversion ratios were not calculated. Nevertheless, the apparent adequacy of this diet suggests that development of a specific formulated diet for *P. ornatus* should not be problematic. Furthermore, the artificial diet and culture conditions did not adversely affect the sensory characteristics of the lobsters.

Factors most probably responsible for the mortality that occurred are feeding strategy and shelter. It was clear from general observations that *P. ornatus* displays a crepuscular activity/foraging pattern similar to those of many large benthic marine crustaceans (Phillips *et al.* 1980; Barshaw and Spanier 1994). Automatic belt feeders were used to extend the availability of food throughout the night, but as the feeders had a maximum operation time of 12 hours, and were generally set before 1700 hrs, feeding ceased before 0500 hrs, when foraging is likely to have been significant. This schedule may have contributed to greater cannibalism than might have occurred if food had been available between 0500 and 0800 hrs (i.e. dawn).

Shelter was provided to each experimental unit so as to ensure it did not differentially influence the lobsters at different densities. At the outset, when the experimental lobsters were small, the shelter appeared to be ample, but once lobsters exceeded 100 g mean weight, crowding in the shelters was evident. Close proximity of individual lobsters may not be very important for this species, as it displays gregarious behaviour in nature (Bell *et al.* 1987; Trendall and Bell 1989), as documented for other palinurids (Lee and Wickins 1992; Booth and Kittaka 1994; Childress and Herrnkind 1997). Likely to be more significant is the unavailability of suitable refuge sites for moulting individuals. Premoult lobsters often seek out sites distant from their conspecifics, but not necessarily cryptic, to complete ecdysis (Dall 1977; Aiken 1980). Once their shells are hard enough to permit mobility, they move back to normal sites among other intermoult individuals. The absence of such refuges within the experimental set-up may have increased cannibalism.

Alternatively, mortality after moult may be attributable to stress induced by conspecifics or other factors, followed by consumption of the dead carcass, but this scenario was not supported by observations that suggested only live postmoult individuals were attacked. On a few occasions (<10), dead and intact individuals were found that had died during ecdysis, suggesting that conspecifics will not consume already-dead lobsters. Further examination of the behavioural aspects of the perceived cannibalism is warranted, perhaps through use of video surveillance.

Although our experiment was performed in a flow-through seawater system where water quality remained relatively uniform, previous experiments using recirculating systems to examine temperature and salinity tolerances (Geddes *et al.* 2001) also achieved good growth and survival for this species. An optimal temperature range of 25 to 28°C was identified, and a moderate tolerance of salinities of 25 to 35 (Practical Salinity Scale) was revealed. The potential for economically viable grow-out of this species in land-based systems appears to be excellent.

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