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Growth of juvenile southern rock lobsters, *Jasus edwardsii*, is influenced by diet and temperature, whilst survival is influenced by diet and tank environment

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Abstract

The growth and survival of juvenile (2–15 g) southern rock lobsters (*Jasus edwardsii*) were examined under various culture regimes. In Experiment 1, lobsters held at ambient (13–18°C) or 18°C were fed either fresh mussels, a commercial prawn diet or a moist diet. Growth (specific growth rate (SGR) = 1.2–1.32% BW day^{-1}), survival (98%) and food conversion ratios (FCR = 1.26–1.29) were significantly better ($P < 0.05$), and the protein component of the diet best utilised (protein productive value (PPV) = 18.3–19%) ($P > 0.05$), when the lobsters were fed mussels. There was a significant interaction ($P < 0.05$) between diet and temperature. Growth at 18°C was significantly higher ($P < 0.05$) than at ambient, except when lobsters were fed the prawn diet when there were no significant differences ($P > 0.05$). The high acceptance and good consumption rate of formulated diets is a positive first step in the development of commercial diets for southern rock lobsters. In Experiment 2, lobsters held at ambient (13–18°C) or 18°C were maintained in tanks containing hides, substrates or neither. Hides increased survival (98%, cf. 60–75%) ($P > 0.05$), although they did not increase growth ($P > 0.05$) compared to tanks without hides. The provision of a substrate to aid the lobsters in the moulting process did not prevent cannibalism. Lobsters grew significantly faster ($P < 0.05$) at 18°C (SGR = 1.32% BW day^{-1}) than at ambient (1.21% BW day^{-1}), with the extra growth explained by a significantly higher

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($P < 0.05$) apparent feed intake. Most mortalities were due to cannibalism of soft-shelled lobsters, suggesting that the design and management of systems will be an important component of mass culturing juvenile *J. edwardsii*.

Keywords: Nutrition; Temperature; Hides; *Jasus edwardsii*; Spiny lobsters; Growth; Culture

1. Introduction

There is increasing worldwide interest in the culture of spiny lobsters (Lellis, 1991; Kaleemur Rahman and Srikrishnadhas, 1994; Kittaka and Booth, 1994) due to their high market value and demand. The southern rock lobster, *Jasus edwardsii*, is native to southern Australia and New Zealand, and in both countries there is considerable interest in its aquaculture potential (Booth, 1989; O'Sullivan, 1989; Stevens, 1992). Due to the difficulties with rearing lobsters through their complex larval period, the development of rock lobster aquaculture presently depends on the ongrowing of juveniles captured from the wild. Culture methods for ongrowing need to be developed and optimised.

Researchers in New Zealand have attained reasonable growth and survival of juvenile *J. edwardsii* fed fresh mussels (Tong, 1997). However, due to a restricted access to mussels in Australia, the availability of a suitable formulated diet is recognised as being critical to successful commercial production. Currently little knowledge about the nutritional requirements of rock lobsters is available. The rapid growth of the prawn shrimp farming industry has resulted in the development of many formulated diets for prawns. Prawns and lobsters have similar feeding strategies and rely on chemical cues to locate food (Kanazawa, 1994; Lee and Meyers, 1996). Thus, lobsters can be slow to locate and consume feeds (Jory, 1996), and those characteristics of prawn diets, such as high attractiveness, palatability and water stability, should suit the feeding behaviour of lobsters. An initial trial showed that lobsters detected the presence of food (antennae waving noted) and began a searching pattern immediately after the introduction of prawn pellets to the tank (unpubl. data).

Another important aspect in developing a commercial culture method for *J. edwardsii* is the design of growout tanks. Growout tank design can be complicated for crustaceans. The type of habitat provided needs to accommodate the complex social behaviour of spiny lobsters (Atema and Cobb, 1980). Young juvenile *J. edwardsii* are generally solitary, whereas older juveniles are communal (Edmunds, 1995). Lobsters may grow more slowly when deprived of shelter (Booth and Kittaka, 1994). Cannibalism is common among spiny lobster, especially where there is a shortage of food or shelter. Moulting or just-moulted animals appear to be the most vulnerable (Booth and Kittaka, 1994).

Providing the optimal water quality for growth and survival is an additional aspect to consider for commercial culture to be successful. Temperature is one of the major water quality parameters affecting growth of poikilotherms. It significantly affects growth of *J. edwardsii* juveniles (Manuel, 1991; Bunter and Westaway, 1993) with elevated temperatures having the potential to reduce the culture period. A temperature of 18–20°C has been suggested as optimum for *J. edwardsii* in New Zealand (Booth and

Kittaka, 1994). However, the effect of an elevated temperature on variables such as diet utilisation is unknown.

This study focused on the development of suitable feeds and culture systems to maximise growth and survival during ongrowing. Two experiments were conducted in parallel to assess the effect of diet (mussels, a commercial prawn diet or a formulated moist pellet), tank environment (hides, substrate or neither) and temperature (ambient (13–18°C) and 18°C). The experiments were designed so that the interaction of temperature, either diet or tank environment could be investigated.

2. Materials and methods

2.1. System

The experimental system consisted of 30 black 52-l polyethylene tanks (60 × 36 × 27 cm). Fifteen tanks received recirculating water at 18°C. The remaining 15 tanks received flow-through water (ambient temperature) filtered through a 400 μm Arkell® filter, which prevented the entry of small food items (small mussels, amphipods). Water flow was approximately 175 l h^{-1} (range 150–200 l h^{-1}) to each tank and aeration was supplied via airstones. Water exited via a standpipe with a sleeve to ensure water was drawn from the bottom of the tank.

Temperature was measured daily and in the ambient system ranged from 13.1°C to 18.2°C (mean ± SE = 16.0 ± 0.1°C) over the course of the experiment. Dissolved oxygen concentration (> 90% saturation), total ammonia nitrogen (< 0.25 mg l^{-1}), pH (8.1–8.4) and salinity (33–35‰) were measured fortnightly. Photoperiod was 10 h fluorescent light per day with light intensity (Gossen-Profisix) ranging from 0.36 to 0.6 μmol s^{-1} m^{-2} at the water surface.

2.2. Animals

Lobsters were collected from the wild as pueruli or post-pueruli and held in 4 m^3 tanks supplied with flow-through water until the start of the experiment. They were fed blue mussels (*Mytilus edulis planulatus*) and squid (*Nototodarus gouldii*) three times weekly. Twenty size-graded lobsters (1.7–3.2 g) were stocked into each tank (≈ 90 m^{-2}) and were acclimated to the system and diet for 1 week prior to the initiation of the experiment. Experimental treatments were randomly assigned to each tank.

After the acclimation period, the wet weight of each lobster was recorded after blotting dry on absorbent paper. Any lobsters outside of the experimental weight range were replaced with acclimated lobsters from stock tanks. Average weight of lobsters at the start of the experiment was 2.33 ± 0.02 g (mean ± SE). Mortalities occurring within one week after the start of the experiment were replaced by lobsters of similar size from the stock tanks. The experiment ran for a total of 112 days, after which the lobsters were individually weighed. Lobsters were also weighed on Days 51 and 79 during the course of the experiment.

2.3. Diets

Three diets were tested: fresh blue mussels (control diet), a commercial prawn (*Penaeus monodon*) diet, and a 'home-made' moist diet. The prawn diet was designed for growout of 3–5 g prawns. Each pellet measured 2 mm in diameter and between 3 and 4 mm in length. The basal composition of the moist diet is outlined in Table 1. The moist ingredients, except oil, were passed through a mincer (3 mm dye) and then thoroughly mixed. The vitamin mix, mineral mix and cholesterol were added, and thoroughly mixed in. The mixture was bound together with binders (guar gum and alginic acid) followed by the addition of the oil. The diet was then spread onto a plastic sheet until it was around 1 cm thick, divided into portions of approximately 1 cm × 1 cm, and stored in the freezer (−10°C) for a maximum of 1 month prior to use. The proximate composition of each of the diets is shown in Table 1.

2.4. Tank environment

A mesh floor (black 3 mm oyster mesh) was placed into 24 of the tanks to aid in traction and grip. Six of those tanks (three in recirculating, three in ambient) did not have hides in them, whilst the remaining 18 had hides (nine in recirculating, nine in ambient). Cylindrical hides (approx. 70 mm diameter × 250 mm length) were formed

Table 1
Ingredient composition of the moist diet and the proximate composition of the experimental diets

Ingredients in moist diet	Proportions (g kg^{-1} of diet)
Green prawn	213.3
Mussels	213.3
Squid	213.3
Ox liver	240
Cholesterol powder[a]	10
Vitamin and mineral premix[b]	40
Guar gum[b]	40
Alginic acid[c]	10
Cod liver oil[d]	20

Proximate composition	Mussel	Prawn	Moist
Dry matter (%)	5.3[e]	91.4	38.6
Protein (%DW)	52.0	42.9	32.3
Total lipid (%DW)	9.2	10.2	16.7
Cholesterol (%DW)	0.54	0.85	1.47
Carotenoid (mg/kg)	31	9	14
Ash (%DW)	11.0	14.1	11.8
Gross energy (MJ kg^{-1})	19.7	19.6	20.6

[a] BDH Chemicals (C27H460).
[b] Vitamins added to meet minimum recommended requirements for prawns (Conklin, 1997).
[c] Sigma Chemicals (Sigma A-7003).
[d] Wille Laboratories, Carole Park, Australia.
[e] Includes shell weight.

from black 3 mm oyster mesh and three of these were placed in each tank. The six remaining tanks (three in recirculating, three in ambient) contained neither hides nor mesh substrate.

2.5. Experimental procedure

Each morning, moults and mortalities were recorded and removed, and the amount of feed left uneaten (as a percentage of food fed) was assessed visually. The tanks were siphoned clean before the lobsters were again fed. The feed rate was adjusted so that approximately 90% of the feed was eaten each day. The fresh mussels were split in half before being fed to the lobsters. At each weighing the tanks were thoroughly cleaned.

Two experiments were run in parallel (Fig. 1). Experiment 1 examined the effect of diet and temperature. Experiment 2 examined the effect of tank environment and temperature. A mussel/hides treatment served as the control for both experiments. There were three replicates per treatment.

2.6. Calculations

The growth data fitted an exponential curve. Therefore, growth was examined using Specific Growth Rates (SGR) to overcome problems associated with exponential growth rates (Hopkins, 1992). SGR as %body weight per day (%BW day^{-1}) and percentage weight gain (%WG) were calculated from the weight data:

$$SCR = (\ln \text{Final weight} - \ln \text{Initial weight}) * 100 / \text{Number of days}$$

$$\%WG = (\text{final wgt} - \text{initial wgt}) * 100 / \text{initial wgt}$$

The dry weight of each diet consumed (apparent feed intake) was calculated after taking into account the moisture content of the diets and the proportion of feed lost into the water. To calculate the dry weight of mussel fed, a relationship between the dry weight of mussel tissue and whole mussel wet weight was established. The percentage of the moist diet and the prawn feed lost to the water was calculated by placing samples into a tank with lightly agitated water for 20 h. The feed remaining was collected in a sieve with a 20 μm screen, washed with distilled water to remove salts (Brunson et al., 1997) and dried in an oven at 60°C. To compensate for mortalities, the number of

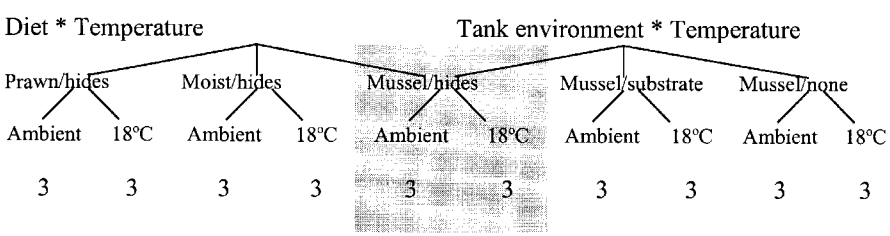

Fig. 1. The experimental design of the experiments. The mussel/hides treatment served as the control for each experiment.

lobster days of feeding was calculated (based on survivors at each weighing) and used to calculate daily weight gain and feed intake for each lobster. The food conversion ratios (FCR), protein efficiency ratios (PER) and the protein productive values (PPV) were calculated as below:

$$\text{FCR} = \text{Estimated dry weight feed consumed per day (g)} : \text{lobster wet weight increase per day (g)}$$

$$\text{PER} = \text{wet weight increase per day (g)} \times 100 / \text{protein intake per day (g)}$$

$$\text{PPV} = \text{dry weight protein gain per day (g)} \times 100 / \text{protein intake per day (g)}$$

2.7. Proximate analyses

Proximate analyses were conducted only on lobsters in the diet × temperature treatments. Lobsters selected for body composition analyses were judged to be in intermoult based on the procedure of Turnbull (1989). Standard methods were used to determine dry matter (freeze-dried to a constant weight), crude protein (Kjeldahl using a selenium catalyst), crude lipid (Bligh and Dyer chloroform methanol (2:1) lipid extraction)(AOAC, 1990), ash (AOAC, 1995), energy (Gallenkamp autobomb, calibrated with benzoic acid), cholesterol (direct saponification of feed sample in KOH in ethanol, followed by sterol analysis with gas chromatography using an HP1 column) (Kovacs et al., 1979), and total carotenoid (extraction with 90% acetone followed by phase separation into hexane and measurement of absorbance at 470 nm using $E(1\%) = 2200$)(Clarke, 1977).

2.8. Statistical analyses

Two-way analysis of variance (ANOVA) was used to test for differences between treatments. The homogeneity of variance was tested and where necessary an appropriate transformation (usually logarithmic) was performed before further analysis. Percentage data was ArcSin transformed prior to analysis. When no significant interactions were present, then multiple comparisons of means (Scheffe's F-test) were conducted on pooled data (Underwood, 1981). Where there were significant interactions, then multiple comparisons of means were conducted on all means (Underwood, 1981). All analyses were conducted on the StatView statistical package.

3. Results

3.1. Diet and temperature

There was a significant interaction ($P < 0.05$) between diet and temperature on growth (Table 2). The SGR and %WG at 18°C was significantly greater ($P < 0.05$) than

Table 2
Growth response (mean ± SE) of juvenile *Jasus edwardsii* grown at ambient temperature (range 13.1–18.2°C, mean 16.0 ± 0.1°C) or at 18°C over a 112-day period. The lobsters were fed one of three dietary treatments. The results of the statistical analyses are included. Values with the same superscripts are not significantly different (%WG = Percentage Weight Gain; SGR = Specific Growth Rate; FI = Apparent Feed Intake; FCR = Food Conversion Ratio). Where no significant interactions were found refer to the superscripts for the results of analyses on pooled data

Treatment		Initial weight (g)	Final weight (g)	%WG	SGR (%BW day^{-1})	FI* (%BW day^{-1})	FCR**	Survival*** (%)
Mussels	Ambient	2.34 ± 0.05^{a}	8.92 ± 0.12^{b}	281 ± 8^{b}	1.20 ± 0.02^{b}	1.33 ± 0.04	1.26 ± 0.04	98 ± 2
	18°C	2.31 ± 0.05^{a}	10.09 ± 0.24^{a}	336 ± 9^{a}	1.32 ± 0.02^{a}	1.45 ± 0.06	1.29 ± 0.04	98 ± 2
Prawn	Ambient	2.29 ± 0.05^{a}	6.66 ± 0.03^{c}	191 ± 3^{c}	0.96 ± 0.01^{c}	1.97 ± 0.05	2.24 ± 0.07	73 ± 7
	18°C	2.36 ± 0.05^{a}	6.80 ± 0.18^{c}	189 ± 9^{c}	0.95 ± 0.03^{c}	2.23 ± 0.14	2.57 ± 0.23	68 ± 2
Moist	Ambient	2.34 ± 0.05^{a}	5.76 ± 0.13^{d}	146 ± 3^{d}	0.81 ± 0.01^{d}	2.87 ± 0.14	3.78 ± 0.23	75 ± 6
	18°C	2.29 ± 0.05^{a}	6.57 ± 0.09^{cd}	188 ± 8^{c}	0.95 ± 0.02^{c}	3.12 ± 0.16	3.57 ± 0.11	60 ± 6
P-values	Diet	0.9836	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
	Temperature	0.8492	< 0.0001	0.0001	0.0001	0.035	0.6948	0.1814
	Interaction	0.1985	0.0130	0.0047	0.003	0.7813	0.2187	0.459

* Significant affect of diet and temperature (Diet — mussels < prawn < moist; Temperature — 18°C > ambient).
** Significant affect of diet (mussels < prawn < moist).
*** Significant affect of diet (mussels > prawn or moist).

Table 3
The effect of diet and temperature on the body composition and protein utilisation of juvenile *Jasus edwardsii* (mean ± SE, $n = 3$). The results of the statistical analyses are included (PER = Protein Efficiency Ratio; PPV = Protein Productivity Value). Where no significant interactions were found refer to the superscripts for the results of analyses on pooled data

Treatment		Protein[a] (%DW)	Ash (% DW)	Lipid[b] (%DW)	Energy[c] (kJ g^{-1})	Dry matter (%)	PER[d] (%)	PPV[e] (%)
Mussels	Ambient	43.4 ± 0.7	34.1 ± 1.7	5.6 ± 0.1	12.6 ± 0.5	31.8 ± 1.3	152.0 ± 5.3	18.3 ± 1.0
	18°C	44.6 ± 0.7	32.2 ± 0.9	6.9 ± 0.4	12.8 ± 0.3	32.3 ± 0.5	150.0 ± 4.9	19.0 ± 0.6
Prawn	Ambient	44.6 ± 0.5	31.7 ± 0.4	6.1 ± 0.5	12.8 ± 0.3	32.9 ± 0.4	104.3 ± 3.3	13.8 ± 0.6
	18°C	45.3 ± 0.3	30.4 ± 0.4	5.4 ± 0.4	13.5 ± 0.2	33.0 ± 0.8	91.3 ± 7.3	12.4 ± 1.4
Moist	Ambient	43.5 ± 0.4	33.9 ± 1.4	5.5 ± 0.3	12.4 ± 0.2	32.7 ± 0.3	82.3 ± 5.0	10.5 ± 0.8
	18°C	42.1 ± 1.1	32.2 ± 1.1	5.0 ± 0.4	12.0 ± 0.2	32.1 ± 0.4	86.7 ± 2.4	10.3 ± 0.5
P-values	Diet	0.0193	0.1385	0.0463	0.0342	0.3492	< 0.0001	< 0.0001
	Temperature	0.7612	0.0973	0.9975	0.4968	0.9713	0.3964	0.6668
	Interaction	0.1512	0.9512	0.0252	0.2275	0.6824	0.2482	0.5144

[a] Significant affect of diet (prawn > moist).
[b] A significant interaction was found however there were no significant differences when the data was tested with multiple comparisons of means.
[c] Significant affect of diet (prawn > moist).
[d] Significant affect of diet (mussel > prawn or moist).
[e] Significant affect of diet (mussel > prawn > moist).

Table 4
Growth response (mean ± SE) of *Jasus edwardsii* grown at ambient temperature (range 13.8–18.2°C, mean 16.0 ± 0.1°C) or at 18°C over a 112-day period. The lobsters were in experimental tanks that contained no substrates or hides (none), or had a mesh substrate glued to the bottom (substrate) or had a mesh substrate and hides (hides) (%WG = Percentage Weight Gain; SGR = Specific Growth Rate; FI = Apparent Feed Intake; FCR = Food Conversion Ratio). Where no significant interactions were found refer to the superscripts for the results of analyses on pooled data

Treatment		Initial weight (g)	Final weight[a] (g)	%WG[a]	SGR[a] (%BW day^{-1})	FI[b] (%BW day^{-1})	FCR[c]	Survival[d] (%)
Hides	Ambient	2.34 ± 0.05	8.92 ± 0.12	281 ± 8	1.20 ± 0.02	1.33 ± 0.04	1.26 ± 0.04	98 ± 2
	18°C	2.31 ± 0.05	10.09 ± 0.24	336 ± 9	1.32 ± 0.02	1.45 ± 0.06	1.29 ± 0.04	98 ± 2
Substrate	Ambient	2.27 ± 0.05	9.07 ± 0.25	300 ± 8	1.25 ± 0.02	1.11 ± 0.06	1.03 ± 0.07	87 ± 6
	18°C	2.34 ± 0.05	10.09 ± 0.26	334 ± 13	1.32 ± 0.03	1.32 ± 0.05	1.18 ± 0.06	85 ± 3
None	Ambient	2.27 ± 0.05	8.46 ± 0.12	270 ± 2	1.18 ± 0.01	1.18 ± 0.04	1.14 ± 0.04	90 ± 3
	18°C	2.33 ± 0.05	10.15 ± 0.55	334 ± 27	1.32 ± 0.06	1.28 ± 0.01	1.14 ± 0.04	83 ± 2
P-values	Tank environment	0.2547	0.6393	0.5825	0.4765	0.0041	0.0103	0.0006
	Temperature	0.3297	0.0002	0.0006	0.0004	0.0021	0.1864	0.3738
	Interaction	0.1641	0.5090	0.5544	0.4495	0.4636	0.3169	0.7071

[a] Significant affect of temperature (18°C > ambient).
[b] Significant affect of environment and temperature (Environment–Hides > substrate or none; Temperature — 18°C > ambient).
[c] Significant affect of environment (Hides > substrate or none).
[d] Significant affect of environment (Hides > substrate or none).

at ambient, except for the lobsters fed the prawn diet, where growth was not significantly different ($P > 0.05$). The final weight, percentage weight gain, and SGR were significantly higher ($P < 0.05$) for lobsters fed mussels. Survival of lobsters fed mussels was significantly higher ($P < 0.05$) than that for either of the formulated diets, but was unaffected by water temperature.

Apparent feed intake was affected by both diet and temperature (Table 2). Feed intake was greatest for lobsters fed the moist diet followed by those fed the prawn diet and then the mussels. Feed intake increased significantly ($P < 0.05$) at 18°C. The FCR was affected by diet (Table 2) and was lowest in lobsters fed the moist diet followed by those fed the prawn diet and then the mussels. The FCRs were not affected ($P > 0.05$) by water temperature.

Diet significantly affected on some components of body composition (protein, energy and lipid)(Table 3). The PER and the PPV (Table 3) followed similar patterns to the growth data, being significantly higher ($P < 0.05$) for lobsters fed mussels than for treatments involving formulated diets.

3.2. Tank environment and temperature

Lobster growth was not affected by tank environment, with no significant differences ($P > 0.05$) in either the final weight, percentage weight gain or SGR of lobsters in the different treatments (Table 4). However, temperature had a significant effect ($P < 0.05$) on growth, with lobsters held at 18°C being 15% heavier than those kept at ambient.

Survival was significantly higher ($P < 0.05$) for lobsters in tanks with hides (Table 4). However, placing substrates in tanks did not improve survival ($P > 0.05$) compared to tanks with neither a hide nor a substrate (none). Mortalities were almost entirely (> 90%) due to cannibalism with most of the cannibalism occurring directly after an animal had moulted. Temperature did not affect survival.

Apparent feed intake was significantly higher ($P < 0.05$) for lobsters in tanks with hides (Table 4). Lobsters kept at 18°C had a higher feed intake ($P < 0.05$) than those kept at ambient temperature. The FCR of lobsters in the tanks with hides was higher ($P < 0.05$), but it was not affected by temperature.

4. Discussion

Mussels have been shown to be a good diet for a broad range of spiny lobsters. The excellent growth of *J. edwardsii* juveniles in this study and others (Rayns, 1991; Hooker et al., 1997) is further indication of the nutritional value of mussels to spiny lobsters. As a result of the large mussel industry, commercial lobster farmers in New Zealand have access to large amounts of waste mussels, and these are seen as a viable food supply for farmed rock lobsters (Tong, 1997). Problems with collection, seasonal variation in quality, storage and handling (Rayns, 1991; Kittaka and Booth, 1994) may make that option unfeasible and/or uneconomical. Very little research has been devoted

to the development of formulated diets for spiny lobsters, even though their availability is seen as an important component for the development of spiny lobster culture (Booth and Kittaka, 1994). In this study, the formulated diets were readily ingested, but they did not support growth rates comparable to that of a 'natural' diet of mussels. Similar results have been seen with formulated diets in studies of other spiny lobsters (Ryther et al., 1988; Lellis, 1992) and with clawed lobsters (Bordner et al., 1986).

Due to the lack of knowledge of the nutritional requirements of *J. edwardsii*, it is not clear why the formulated diets did not support good growth. The physical form of the formulated diets (dry, hard pellet versus moist, soft block) did not appear to influence the feeding response of *J. edwardsii*. The high feed intake, and the fact that juvenile *J. edwardsii* have an apparent protein digestibility of around 80% (Ward, unpubl. data), which is similar to other crustaceans (Lee and Lawrence, 1997), suggest that the reduced growth was due to dietary composition. Excessive dietary lipids are known to have adverse effects upon the growth and survival of crustaceans (Briggs et al., 1994) with best growth and survival generally achieved at a dietary level of between 5% and 8% (D'Abramo, 1997). However, Boghen and Castell (1982) found growth and survival of *Homarus americanus* was best when fed diets containing 10% lipid, similar to the level in mussels (9.2%) which provided good growth for *J. edwardsii*. The high lipid content of the moist diet (16.7%) may have contributed to poor lobster growth in this trial. The high lipid content was not reflected in the carcass composition, suggesting that high lipid diets may have protein sparing value without adversely affecting quality, as noted for the shrimp *Penaeus monodon* (Briggs et al., 1994). The amino acid composition of the formulated diets or their comparatively low protein level, relative to that of mussels, may also have contributed to the low growth. Further research on the protein requirements of juvenile *J. edwardsii* is required.

Micronutrients such as cholesterol, carotenoids, vitamins and minerals are important components of diets. A lack of cholesterol can lead to reduced growth and survival (D'Abramo et al., 1984) and, as crustaceans do not have the ability to synthesise cholesterol, a dietary source is required. The level of cholesterol in the formulated diets in this study would appear to be sufficient given that *Homarus* species require a dietary level of less than 0.5% (Castell et al., 1975; D'Abramo et al., 1984). All diets contained low levels of carotenoids and these levels were reflected in the colour of the lobsters at the completion of the experiment, varying from light red (mussel diet) to almost white (formulated diets). Natural exoskeletal colour is an important characteristic in most markets for lobsters; therefore, its maintenance in cultured juveniles may require the addition of carotenoid pigments such as astaxanthin (Kittaka and Booth, 1994; Konosu and Yamaguchi, 1994). Dietary carotenoid levels of around 100 mg kg^{-1} are required for juvenile *J. edwardsii* to achieve a 'natural' colour (Crear, unpubl. data).

The efficiency of feed utilisation varied with the diet. The mussel diet had a lower FCR, a higher PER and a better PPV than either of the formulated diets. The FCR for the mussel treatment indicated that juvenile *J. edwardsii* were efficient at converting food to growth. Even though the FCR with the prawn diet was considerably higher than that of the mussels, it was equivalent to that of many other crustaceans fed similar formulated diets (Sarac et al., 1993; Baillet et al., 1997). This result indicates that the use of a formulated diet should be feasible in the culture of *J. edwardsii* once a diet is

formulated to meet its nutritional requirements. The efficiency of utilisation of protein in mussels was greater than that in the formulated diets. Overall, the values were similar to those found in other crustacean studies (Colvin, 1976; Baillet et al., 1997; Mu et al., 1998).

The dietary treatments had little effect on the gross body composition of lobsters. The significant differences in growth, therefore, suggest that gross body composition may not be a sensitive indicator of nutritional status. The digestive gland and its composition have been used as indicators of nutritional status in other crustaceans (Glencross and Smith, 1997). Cockcroft (1997) found that the lipid content of the digestive gland appeared to be a good indicator of growth in male *J. lalandii*. Further research will be required to determine whether the digestive gland composition can also be used as an indicator of nutritional status for *J. edwardsii*.

Growth of lobsters improved at 18°C, while survival was unaffected, compared to ambient temperature. The increased growth was the result of a higher feed intake, with the FCR, PER and PPV not being affected at the higher temperature. Recent research has shown that *J. edwardsii* can be grown at temperatures up to 22°C without adversely affecting growth or survival (Thomas et al., 2000). The temperature for optimum FCR was 19.3°C (Thomas et al., 2000) suggesting that the efficiency of utilisation of diets decreases at higher temperatures. The FCR of the Caribbean spiny lobster, *Panulirus argus*, was also constant over a wide temperature range and only decreased at a high culture temperature (Lellis and Russell, 1990).

Under the optimal conditions, juvenile *J. edwardsii* survived well in culture, as has been observed in other studies (Hooker et al., 1997; James and Tong, 1997) and in other species of spiny lobsters (Phillips et al., 1977; Lellis and Russell, 1990). Cannibalism occurs in spiny lobsters, especially when there is a shortage of food or shelter (Booth and Kittaka, 1994), and it was observed in this study even though sufficient feed was available. Provision of a nutritionally inadequate diet may also lead to an increase in cannibalism. Cannibalism occurred almost exclusively during the post-moult period, at a time when the lobsters were soft and vulnerable to predation. When lobsters were fed an adequate diet (mussels), cannibalism was almost completely eliminated through the provision of hides. Phillips et al. (1977) found that animals held in smooth PVC tanks often had difficulty moulting, meaning they could be susceptible to cannibalism during the process. However, the provision of a substrate to assist traction and improve the ease and speed of moulting did not reduce cannibalism of lobsters in this study. Very rarely were cannibalised lobsters still within their exuvia, suggesting that predation does not occur during the difficult process of moulting, but some time after.

Lobsters will likely be grown at high density in indoor tank systems. Productivity must be maximised in such a system to ensure that production costs are kept to a minimum. Of the parameters investigated in this study, mussels, 18°C and hides provided the best growth and survival. The ready acceptance and consumption of formulated diets offers potential for the further development of diets for *J. edwardsii*. The communal nature of spiny lobsters is regarded as one of their positive culture attributes (Booth and Kittaka, 1994). However, the results of this study show that the design and management of systems which prevent cannibalism will be an important component in achieving successful mass culture of juvenile *J. edwardsii*.

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