Culture of Young Spiny Lobster (*Panulirus argus*): Effects of Density and Feed Type on Growth and Survivorship

M. G. PARDEE[1] and S. M. FOSTER[2]
[1]*Division of Tropical Aquaculture*
HBOI, 5600 Old Dixie Hwy.
Fort Pierce, Florida 34946 USA
[2] *Land Utilization Department*
FPL, P.O. Box 1691
Jensen Beach, Florida 34958 USA

ABSTRACT

Two experiments were conducted to determine the effects of diet and density on growth and survivorship of juvenile post larval spiny lobster, *Panulirus argus*. In experiment I, the effect of diets on growth, development, and survival were evaluated. Four diets were tested: 1) live *Artemia*; 2) live and Murex brand frozen *Artemia*; 3) live *Artemia* and Kyowa brand pellets; and 4) frozen Murex *Artemia* and Kyowa pellets. Two densities were tested, lobsters were held individually or paired in a 20.3 cm diameter ring. After the third molt stage the lobsters were removed from the study. Lobsters held singly and fed live *Artemia*/pellets had greater weight gain than those fed live/frozen *Artemia* ($P<0.03$). Effect of feed type on weight gain for lobsters held in pairs was not significant ($P=0.60$), but cumulative molt interval was effected by the diet for the paired treatment ($P<0.002$). Lobsters fed live *Artemia* progressed through molts faster than the other three diets. Small sample size precluded statistical analysis of mortality, but paired treatments appeared to have higher mortality. Experiment II, further examined the effects of density (17.4 lobsters/m^2 vs 34.8 lobsters/m^2) on growth and survivorship. During the 63 day experiment, neither growth nor survival were significantly different between the two densities.

INTRODUCTION

Spiny lobsters have several characteristics amenable to commercial cultivation. They command high market price, and comprise the most valuable fishery in the Caribbean. They are communal by nature, lack aggressive or cannibalistic behavior, and are generalist feeders (Engle, 1979), thriving on a variety of food sources. Though reliable techniques for culturing lobster larvae have not been established, an alternative suggested by Ingle and Witham (1968), is to capture puerulus stage lobster and rear them through market size. Previous studies have examined several species of Panuliridae in an effort to assess the biological and economic potential for their commercial cultivation. The Australian spiny lobster, *P. cygnus*, has been successfully cultured to market size in four years, although the length of time to reach market size is probably unprofitable (Australian Department of Agriculture, Fisheries Division, 1975). In contrast *P. argus* has been grown from puerulus to market in sixteen months (Lellis, 1991).

The economic viability of an aquaculture enterprise is affected by the cost of feed and facilities (stocking density). This study determined how these factors affect growth and survival of young spiny lobsters.

MATERIALS AND METHODS

Diet/Density Study

P. argus pueruli were collected from floating artificial (Witham *et al;* (1968) habitats from the Florida Power and Light (FPL) St. Lucie Nuclear Plant intake canal, and transferred to the FPL culture facility which consist of two trailers housing 28 fiberglass tanks, measuring 91.4 cm x 152.4 cm x 25.4 cm, (@ 338 l capacity). The rings were provided continuous water flow at a rate of .5 l/minute, ambient temperature was 23.5°C ± 1.9° throughout the experiment.

In order to test the effects of different feed types, the original tank structures were modified by the addition of a manifold water line and a false bottom to accommodate 24 - 20.3 cm diameter PVC screen rings for holding the lobster postlarvae. In experiment I, lobsters were held singly or in pairs in screened rings, that contained one habitat consisting of a 15.2 cm x 20.3 cm sheet of charcoal window screen material (1 mm mesh) folded in half and held in the center by a tie wrap to create a florette. Three tanks (each holding 24 rings) provided nine replicates for each diet/density combination.

A factorial experiment was used to test the effects of the four different diets on growth and survival of individually and communally housed lobsters. The four feed types were: 1) live adult *Artemia*; 2) a combination of live *Artemia* and Murex brand frozen *Artemia*; 3) a combination of live *Artemia* and Kyowa brand larval pellet; and 4) a combination of frozen *Artemia* and pellet. These feed combinations were designed to minimize the use of live *Artemia* by feeding an alternate food source every other day.

Pueruli were held through the first molt to the pigmented first stage, before being randomly selected and assigned to a ring. Food and feces were removed from the tanks and screens daily. The following were measured for all molted lobsters in a 94 day period: wet weight (t=0.01 g), carapace length (t=0.1 mm), and intermolt period (days). After initial weighing, lobsters were weighed five days after molt (to avoid stress), and the carapace length was measured using vernier calipers to the nearest 0.5 mm. The intermolt period was calculated from daily molt records. Mortalities were recorded, and survival rates were determined at the termination of each experiment. The salinity and temperature were monitored daily throughout the experiment.

Over the course of the diet/density study, lobsters were removed when they molted to fourth stage or died. In the single treatments, a handling error resulted in the death of two lobsters fed live *Artemia*. For the paired treatments the number of survivors was represented by the number of remaining pairs. If one individual of the pair died, it was no longer considered a paired replicate and

was removed from the study. Data were analyzed separately for the single and paired treatments and there was an insufficient number of survivors for the paired treatment.

Density Study

In experiment II, the lobsters were held communally at densities of 24 (17.39 lobsters/m^2) and 48 (34.78 lobsters/m^2) lobsters per tank. Each density treatment had 3 replicates (six tanks). Density treatments were randomly assigned to the six tanks and the lobsters randomly allocated amongst the treatments. Eight habitats (mesh florettes) were provided per tank (91.4 cm x 152.4 cm x 25.4 cm) and all lobsters were fed live *Artemia* daily. The tanks were monitored daily and cleaned weekly for a period of nine weeks.

RESULTS

Diet/Density Study

Among lobsters held singly, it appears that those fed diets of live *Artemia*/pellets and live *Artemia* alone had similar growth yet greater weight gain than those fed live/frozen *Artemia* and pellets/frozen *Artemia* (Figure 1). There was no significant difference between replicates in any treatment (MANOVA: Wilk's Lambda $F_{4/42}$=1.21, P=0.32). There was some indication of an effect of diet on weight gain and carapace length, although it was not significant (MANOVA: Wilk's Lambda; $F_{6/46}$=1.98, P<0.09). Increments in weight gain were significantly different (ANOVA; F3/24=3.54, P<0.03) among the four different diets. Lobsters fed live *Artemia*/pellet had significantly greater weight gain than lobsters fed live/frozen *Artemia* at = 0.05 level (Tukey's Multiple Comparison test). In contrast, the weight gain of lobsters fed a diet of live *Artemia* alone was not significantly different from the lobsters fed live/frozen *Artemia*. For lobsters held in pairs, neither tank effect (MANOVA: Wilk's Lambda $F_{4/18}$=1.09, P=0.39), nor the effect of diet on weight gain and carapace length was significant (MANOVA: Wilk's Lambda; $F_{6/22}$=1.44, P=0.25). Weight gain was also not significantly different among the four different diets (ANOVA; $F_{3/12}$=0.65, P=0.60). Paired lobsters fed a diet of frozen *Artemia*/pellet attained the greatest weight gain during the study, although the final sample size was only represented by one remaining pair of lobsters (Figure 1).

Since wet weight and carapace length are clearly correlated, similar results would be expected for the growth measurement of carapace length in lobsters held singly or in pairs. A One-way ANOVA of carapace lengths of lobsters fed the four diets were not significantly different, whether held singly($F_{3/24}$=1.21, P=0.33), or in pairs ($F_{3/12}$=0.50, P=0.69)(Figure 2).

Cumulative molt duration for lobsters held singly and in pairs fed live *Artemia* resulted in faster growth than the other three diets (Figure 3). There was

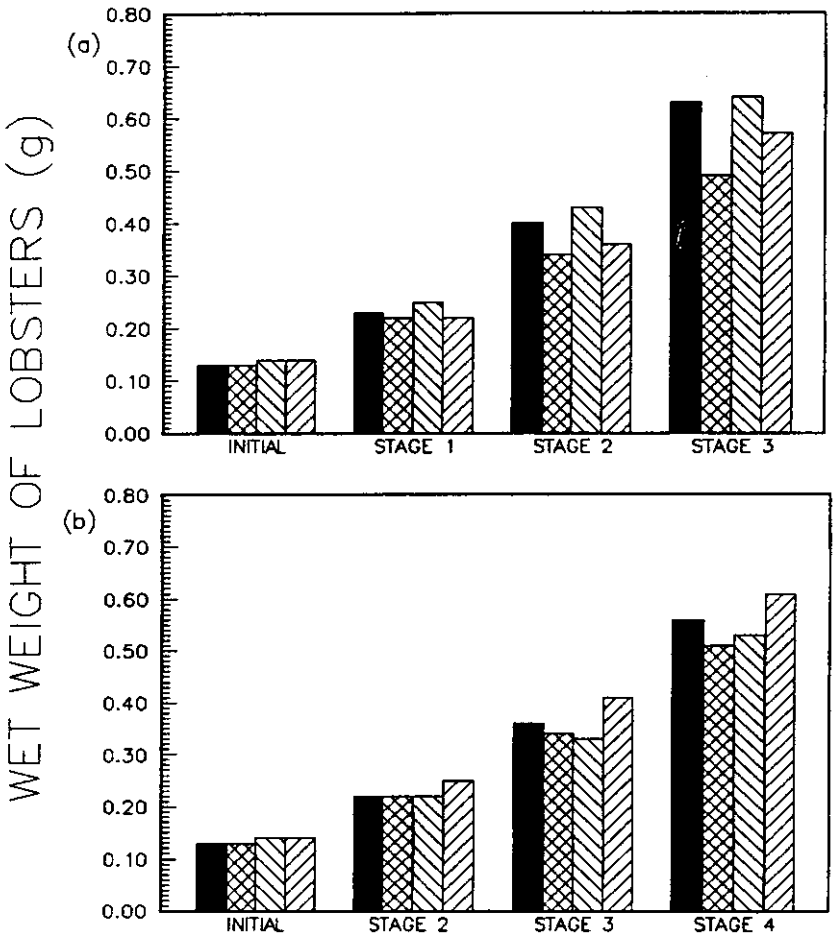

Figure 1. Average wet weight (g) of lobsters held (a) singly or (b) in pairs for different molt stages in relation to feed type:
■ live *Artemia* □ frozen/live *Artemia*
■ pellet/live *Artemia* ▨ pellet/frozen *Artemia*.

no significant difference between replicates (Wilk's Lambda, for singles: $F_{2/23}$=0.76, P=0.48 or pairs: $F_{2/10}$=0.09, P=0.91), so the data were pooled and a One-way ANOVA showed feed type had a significant effect on molt duration ($F_{3/12}$=9.08, P< 0.002) for the paired treatment. Lobsters fed with live *Artemia* progressed through molts faster than lobsters fed the other three diets (Tukey's test=0.05 level). However, the effect of diet on molt duration was not significant (ANOVA; $F_{3/25}$=1.38,P=0.27) for lobsters held singly.

Although sample sizes were too small to statistically analyze, the survival of lobster in relation to feed type, and stocking density had significant effect on mortality for pairs (55.5%) and singles (19.3%). Survival appeared greater for lobsters fed live *Artemia* (70.5%), than those lacking a live food source (frozen *Artemia*/pellets, 33%) (Figure 4).

Density Study

Although lobsters at higher density (48/tank) appeared to have lower weight gain (N=48, x=0.40g + 0.14 vs. N=24, x=0.47g + 0.17; 9 weeks) and higher mortality (28% vs. 22%) than those held at the lower density (24/tank), these differences were not statistically significant (t-Test; for weight gain: t=2.27, df=4, P>0.05 and for mortality: t=1.96, df=2, P>0.05) (Figure 5).

DISCUSSION

In this study, *P. argus* pueruli were successfully reared through fourth stage in a variety of holding conditions and feeding regimes. Lellis and Russell (1990) maintained individualized lobsters at various constant temperatures on a diet of live *Artemia*. They found that lobsters held at a constant 24°C achieved an average of 0.60 g during the 70 day study. Results of this study, in which lobsters were maintained at 23.5°C and fed live *Artemia* was 0.60 g in 48.7-52.0 days were constant with his findings.

Lellis and Russell (1990) reported that lobsters achieve highest weight gain at 29°C, though food conversion rates were better at 27°C. This study emphasizes the need to understand the role temperature and diet play in the growth development and survival of juvenile spiny lobsters.

Lellis (1992) found that puerulus and juvenile *P. argus* maintained on a diet of live *Artemia* had significantly greater increases in weight and carapace length, shorter intermolt periods, and higher survival than lobsters fed a variety of formulated diets. This study suggests a combination of live and artificial diets may be appropriate to culture juvenile and post larval lobsters, at least until fourth stage. For example, weight gain was the same (0.50 g) for lobsters fed live *Artemia*/pellets as for those fed live *Artemia*, and not significantly different for those fed frozen *Artemia*/pellets. Results from Lellis' (1992) study suggest that starvation was the major cause of death among pellet fed lobsters, indicating that growth rates achieved in the live *Artemia*/pellet combination could have

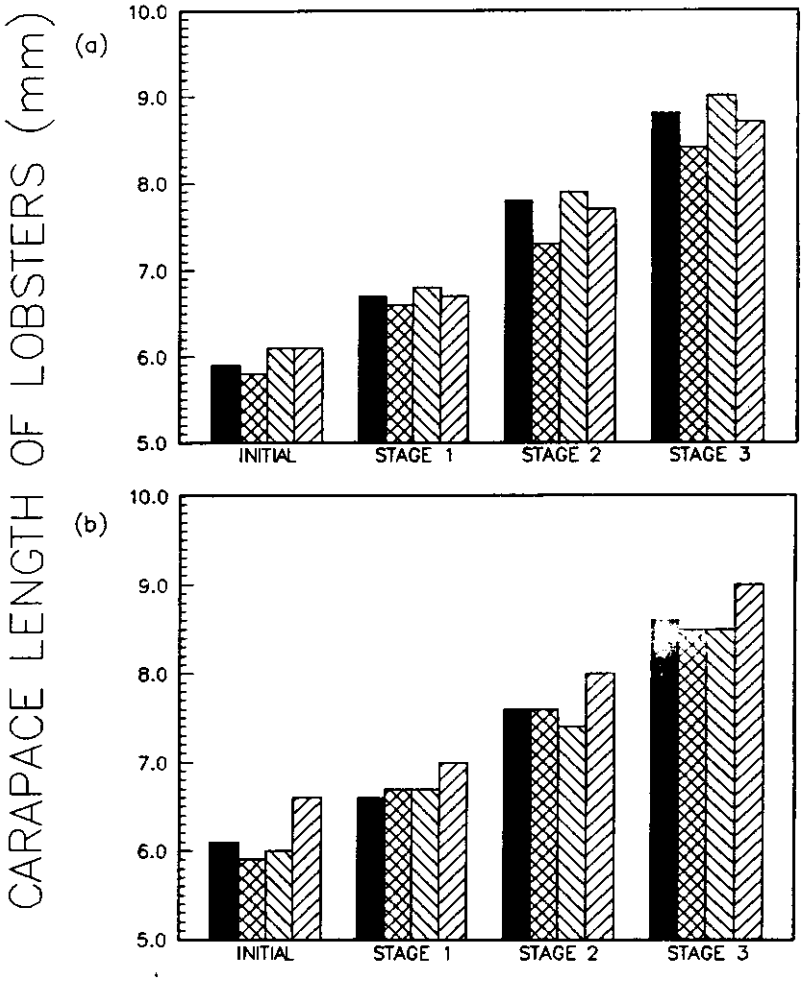

Figure 2. Average carapace length (mm) of lobsters held (a) singly or (b) in pairs for different moit stages in relation to feed type:
■ live *Artemia* □ frozen/live *Artemia*
■ pellet/live *Artemia* ▨ pellet/frozen *Artemia.*

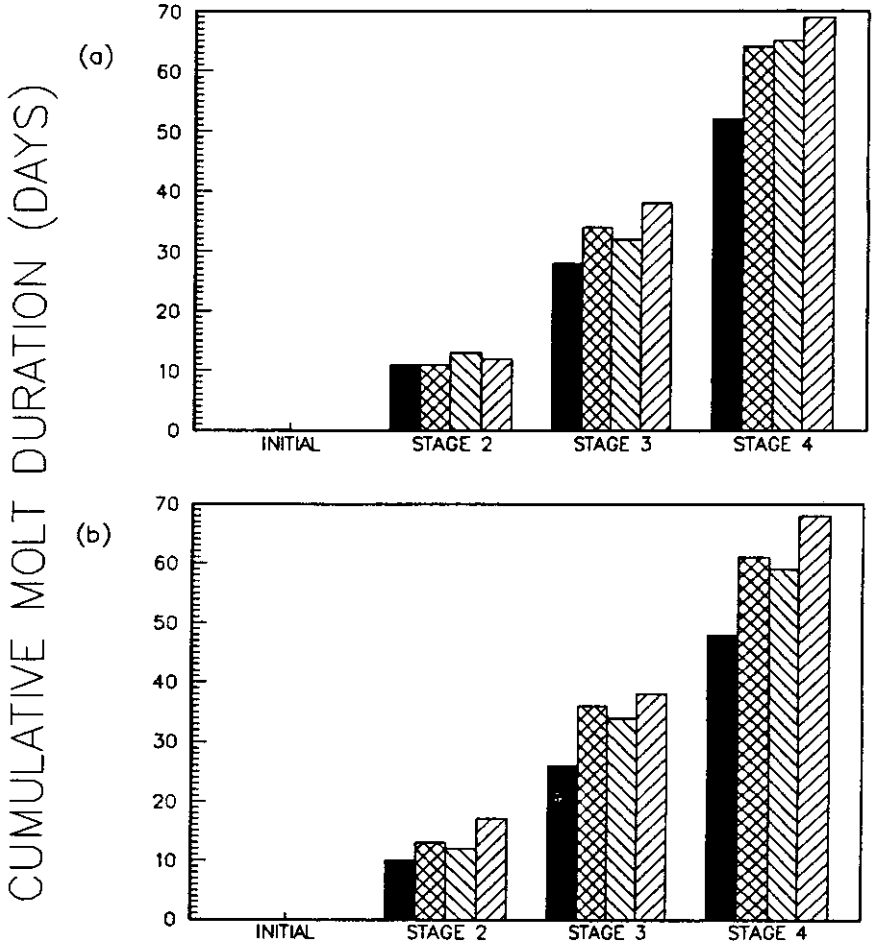

Figure 3. Average molt duration (cumulative number of days) between stages for lobsters held (a) singly or (b) in pairs for different molt stages in relation to feed type:

■ live *Artemia* □ frozen/live *Artemia*

■ pellet/live *Artemia* ▨ pellet/frozen *Artemia*.

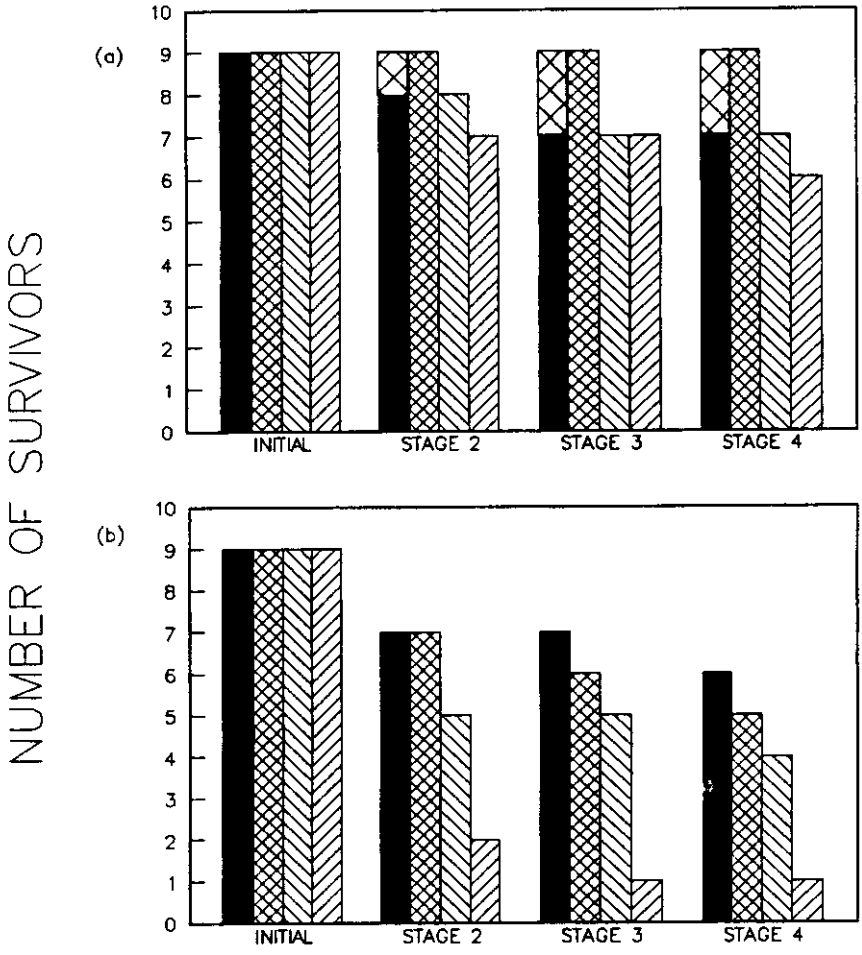

Figure 4. Number of surviving lobsters out of those held (a) singly (initial sample size N=9) and (b) in pairs(initial sample size nine pairs) for different stages in relation to feed type:

live *Artemia* | frozen/live *Artemia*

pellet/live *Artemia* | pellet/frozen *Artemia*.

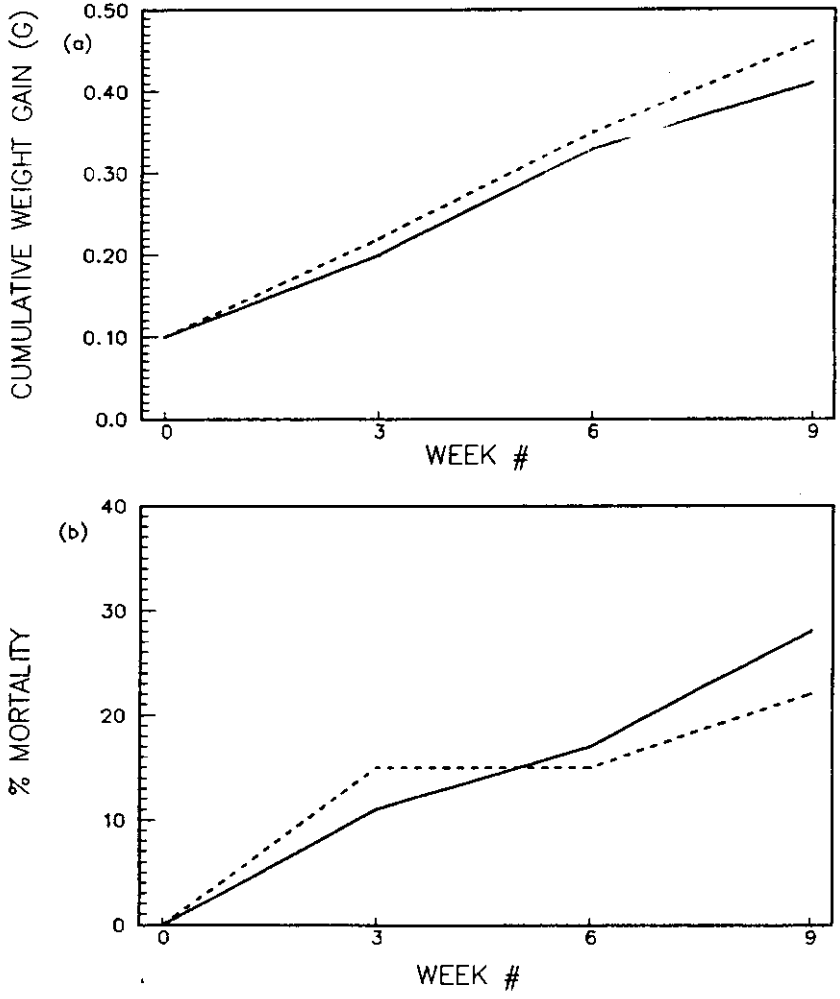

Figure 5. (a) Cumulative weight gain (g/wk) and (b) percent mortality of lobsters held for nine weeks at densities of 48 (-) and 24 (- -) lobsters per tank.

resulted from lobsters feeding solely on the live *Artemia* when available. It does not explain why the frozen *Artemia*/pellet combination did well and not the live/frozen *Artemia* combination. Lellis (1992) found that most mortalities occurred during the first 30 days in culture, suggesting that acceptance of formulated feeds may be a problem during postlarval stages. Similarly, most mortalities occurred between first and second stage (ten to seventeen days) in this study. This phenomenon also occurred with communally held lobsters. Lobsters held in pairs grew faster when supplied a constant diet of live *Artemia*, while survival was low for those deprived of a live food source. Possibly, large individual variation and small sample size compromised detection of differences in growth due to diet, effects that may be more apparent in a larger study.

An important consideration for commercial cultivation of spiny lobsters is the effect of density on growth and survivorship. This study suggests that raising young spiny lobsters communally does not affect growth or survival, when a live food source is available. Behavioral studies have noted that spiny lobsters compete actively for resources such as space and food (Andree, 1982; Berrill, 1975), and perhaps gregariousness is apparently modified by aggressive interactions (Berrill, 1975). Although aggressive displays within communal culture tanks were not observed during this study, social interaction did affect growth and survival. Lobsters are considered nocturnal feeders that forage individually, and although feeding was noted during the day, aggressive encounters may have occurred while foraging at night. This may be reflected in the elevated mortality rates found for lobsters held in pairs versus individually. Although lobsters held in pairs grew faster on live *Artemia* than those on other diets, suggesting that there may be some interaction between density and diet, higher mortalities in the paired treatments may have been the result of higher agonistic behavior. Since food availability was the same for lobsters singly and in pairs, this data suggest that social interaction may affect growth rates, particularly in the absence of a live food source.

Mortality rates were similar for all densities of lobsters (N=1, 22%; N=2, 33%; N=24, 22%; N=48, 28%) fed a diet of live *Artemia* – suggesting diet, not density, is the primary influence on growth, development, and survival of juvenile spiny lobster. In contrast, growth rates were higher for lobsters in experiment I vs experiment II (N=1, 0.63 g in 52.0 days; N=2, 0.56 g in 48.7 days; N=24, 0.41 g in 63 days; N=48, 0.46 g in 63 days). Also, variance of weight gain was much greater in experiment II (0.19 g-0.95 g in 63 days) than for experiment I (0.43 g-0.77 g in 38-57 days). Although the duration ofthese experiments differed it does not explain the greater range of weights found in the higher density treatments. This may be due to detecting a greater variation in lobster growth rates with increasing sample size, differences in recruitment periods, or the influence of social interaction on growth.

This study suggests that when evaluating culture conditions of spiny lobsters, weight gain or carapace length, molt duration, and survival are important variables to be considered. When evaluating the economic potential of a lobster cultivation program they must be examined individually and as an integrated part. For instance, the results of this study have indicated that live *Artemia* can be supplemented with a commercially available pellet (Kyowa brand) without adversely affecting molt increment and weight gain, although in communal culture conditions the intermolt period may be prolonged, and survival lower. Live *Artemia* are expensive (approximately $17.00 US/lb), and laborious to maintain or grow. In contrast, pellets are inexpensive ($5.00 US/lb) and easily stored. In a culture environment where high stocking density is required, the advantages of supplementing with artificial feeds may outweigh the disadvantages of longer intermolt periods and lowered survival. Further studies are suggested to examine the use of live *Artemia* supplemented with formulated feeds in high density culture systems before determining the feasibility of a commercial scale operation.

LITERATURE CITED

Andree, S.W. 1982. Foraging activity patterns and food items of post-puerulus spiny lobsters, *Panulirus argus*. Pages 13-14 in W.G. Lyons, editor. *Proceedings of a Workshop on Florida Spiny Lobster Research and Management.* Florida Department of Natural Resources, St. Petersburg, Florida.

Australian Department of Agriculture, Fisheries Division. 1975. The potential of aquaculture in Australia. *Australian Government Printing Service, Fisheries Paper* No. **21**.

Berrill, M. 1975. Gregarious behavior of juveniles of the spiny lobster, *Panulirus argus* (Crustacean: Decapoda). *Bulletin of Marine Science* **25(4)**: 515-522.

Engle, J.M. 1979. Ecology and growth of juvenile California spiny lobster, *Panulirus interruptus* (Randall). Ph. D. Dissertation. University Southern California, Sea Grant Disseration Service.,USCSG-TD-03-79.

Ingle, R.M. and R. Witham. 1968. Biological considerations in spiny lobster aquaculture. *Proc. Gulf Carib. Fish. Inst.* **21**: 158-162.

Lellis, W.A. and J.A. Russell. 1990. Effect of temperature on survival, growth and feed intake of postlarval spiny lobsters, *Panulirus argus*. *Aquaculture* **90**: 1-9.

Lellis, W.A. 1991. Spiny lobster, a mariculture candidate for the Caribbean? *World Aquaculture* **22(1)**: 60-63.

Lellis, W.A. 1992. A standard reference diet for crustacean nutrition research VI. Response of postlarval stages of the Caribbean king crab *Mithrax spinosissimus* and the spiny lobster *Panulirus argus*. *Journal of the World Aquaculture Society* **23**:1-7.

Witham, R., R. M. Ingle, and Joyce, E.A. 1968. Physiological and ecological Studies of *Panulirus argus*, from the St. Lucie Estuary. *State of Florida, Board of Conservation Technical Series* No. **53**.