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Density-Dependent Growth and Survival of *Penaeus setiferus* and *Penaeus vannamei* in a Semi-Closed Recirculating System

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Abstract.—Two growth trials utilizing *Penaeus vannamei* and *Penaeus setiferus* were conducted at densities of 28.4, 56.8, 85.2, 113.6, 170.4, 227.3 and 284.1/m^2 in an indoor recirculating system. There was an inverse linear relationship between stocking density and growth among both species. The relationship between final weight and stocking density is described by the following linear equation: *P. setiferus*, $Y = -0.00619X + 4.46$, adj. $r^2 = 0.8572$; *P. vannamei*, $Y = -0.00717X + 7.39$, adj. $r^2 = 0.6230$. Although the responses in terms of growth depressions were similar, *P. setiferus* growth was lower than that of *P. vannamei*. There was an inverse relationship between stocking density and survival for *P. setiferus*. Survival of *P. vannamei* was highly variable but was negatively correlated with density. Based on the results of the present study, *P. setiferus* has a similar tolerance of high density as that of *P. vannamei* and hence may be suitable for intensive culture systems. However, depressed growth rates of *P. setiferus*, which do not appear to be due to effects of water quality or density, must be solved if growth rates similar to *P. vannamei* are to be realized.

Penaeus vannamei is the most widely cultured shrimp in the western hemisphere (Wedner and Rosenberry 1992). Rapid growth, good survival in high density culture, and disease tolerance make it a good choice for the semi-intensive and intensive grow-out strategies employed in U.S. production. *Penaeus setiferus* has recently garnered interest from U.S. growers for several reasons. As a native species, no exotic permit is needed, accidental release would not pose an ecological threat to the Gulf of Mexico and south Atlantic, and high profit markets like live bait could be explored. In addition, it has been reported that sub-adults have been overwintered in ponds in South Carolina (Sandifer et al. 1990). *P. setiferus* have been stocked at 40/m^2 with 97.5% survival yielding 5,258 kg/ha at an average weight of 13.5 g, and are an alternative if *P. vannamei* post-larvae supplies are scarce or IHHN infected (Sandifer et al. 1990; Browdy et al. 1991). Recently, experimental evidence demonstrated that the potential growth of *P. setiferus* approached that of *P. vannamei* (Robertson et. al. 1993) but commercial growth comparisons have demonstrated that *P. setiferus* significantly lagged that of *P. vannamei* (Browdy et al. 1991). This study sought to investigate the effects of density on the growth rate and survival of these two species under controlled laboratory conditions.

Methods

Two experiments were carried out in succession, one with *P. setiferus* and one with *P. vannamei*. *P. setiferus* were stocked in tanks having a 0.176 m^2 footprint at densities of 5, 10, 15, 20, 30, 40 and 50 per tank (28.4, 56.8, 85.2, 113.6, 170.4, 227.3 and 284.1/m^2) with initial mean weight ± standard deviation of 0.24 ± 0.017 g. Four replicates were utilized per treatment with an additional four tanks stocked with 50 shrimp and put on continuous automatic feeding. The experiment ran for 50 d and weights were taken on day 28 and day 50.

The same stocking was repeated for *P. vannamei* the following year with the following modifications. Initial mean weight ± standard deviation was 0.12 ± 0.020 g. The experiment ran for 49 d, and only day 49 weights were taken. An additional four tanks were stocked with five shrimp each and weighed each week to estimate weekly growth. Feed amount was adjusted in all tanks based on the weekly growth data with feed being offered in excess four times daily.

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Each tank was a component of a semi-closed recirculating system containing a common biological filter, a rapid rate sand filter and a circulation pump. Shrimp were fed a 40% protein water stable pellet containing 10% squid (Rangen Inc., Buhl, Idaho, USA) in the absence of natural foods. All shrimp were fed in excess during the entire study. With the exception of the treatment with automatic feeders, shrimp were fed four times per day at approximately 0800, 1100, 1300 and 1600 h. Water quality was maintained by biofiltration, removing uneaten feed in the morning before first feeding, and by adjusting incoming water input into the semi-closed system. Water temperature, dissolved oxygen and salinity were measured daily. Total ammonia-nitrogen, total nitrite-nitrogen and pH were measured three times per week by the methods of Spotte (1979). Water circulation into the tanks varied from 2 L/min (turnover 2.4 times/h) to 3 L/min (turnover 3.6 times/h) by the end of the experiment. Daily exchange (water replacement) varied from 5%/d to 25%/d by the end of the experiments.

Data were analyzed using a one-way analysis of variance to determine significant ($P < 0.05$) differences among treatment means. Student-Newman-Keuls' multiple range test (Steel and Torrie 1980) was used to evaluate significant differences among treatment means. To describe the effects of density on the dependent variables, linear regression analyses were utilized. All statistical analyses were conducted using the Statistical Analysis System (SAS Institute Inc. 1988).

Results and Discussion

During the growth trial with *P. vannamei* salinity, temperature and dissolved oxygen were maintained at (mean ± standard deviations) 27.4 ± 2.4 ppt, 27.9 ± 1.1 C and 5.9 ± 0.3 mg/L. Mean ± standard deviations values for total ammonia-nitrogen, total nitrite-nitrogen, and pH were 0.10 ± 0.07 mg/L, 0.07 ± 0.05 mg/L and 7.7 ± 0.1. During the growth trial with *P. setiferus*, salinity, temperature and dissolved oxygen were maintained at 31.8 ± 2.4 ppt, 27.1 ± 1.0 C and 5.8 ± 0.3 mg/L. Values for total ammonia-nitrogen, total nitrite-nitrogen, and pH were 0.12 ± 0.11 mg/L, 0.05 ± 0.07 mg/L and 7.9 ± 0.2. In both growth trials, intermittent evaluations of dissolved oxygen and total ammonia-nitrogen levels between treatments were utilized to adjust aeration, water flow and water exchanges to maintain equivalent water quality parameters between treatments.

Using Student-Newman-Keuls' test, significant differences among stocking densities existed in growth for both species (Table 1). The effects of the use of a continuous automatic feeding vs feeding 4 times daily at the highest density is unclear. Data utilizing final weights indicate a significant effect whereas data for percent weight gain and total biomass (as well as instantaneous growth rates which were not reported) indicate no significant effect. The observed weight gain for *P. vannamei* and *P. setiferus* (7.2–5.3 g and 4.2–2.8 g, respectively) over the 7-wk growth trials is consistent with other populations which have been followed in our laboratory under similar conditions. This growth would be expected to be adequate to result in differential responses to treatment effects. Differences in final weight were directly related to stocking density for both species and could be described by the following linear equations: *P. vannamei*, $Y = -0.00717X + 7.39$, adj. $r^2 = 0.6230$; *P. setiferus*, $Y = -0.00619X + 4.46$, adj. $r^2 = 0.8572$ (Fig. 1). The effects of stocking density on final biomass are presented in Fig. 2 and followed a curvilinear pattern which is described by the following equations: *P. vannamei*, $Y = 1.22X - 0.00163X^2 + 2.20$, adj. $r^2 = 0.8984$; *P. setiferus*, $Y = 0.670X - 0.00117X^2 + 2.25$, adj. $r^2 = 0.8776$. Although survival of *P. vannamei* appears to decrease with density, a significant response, as determined by analysis of variance, was not demonstrated for *P. vannamei* (Table 1). Linear regression demonstrates a significant negative effect of density on sur-

TABLE 1. *Response of* P. vannamei *and* P. setiferus *juveniles (mean initial weight 0.12 and 0.24 g) to stocking density at the conclusion of two successive 49- and 50-day growth trials, respectively*[a].

	P. vannamei				*P. setiferus*			
Density/m^2	Final weight (g)	Weight gain (%)	Biomass (g)	Survival (%)	Final weight (g)	Weight gain (%)	Biomass (g)	Survival (%)
28.4	7.28[z]	5,968.5[z]	34.8[v]	95.0[z]	4.47[z]	1,630.3[z]	21.2[w]	95.0[z]
56.8	6.97[yz]	5,710.5[yz]	64.4[vw]	92.5[z]	4.15[y]	1,635.4[z]	38.4[x]	92.5[yz]
85.2	6.57[xyz]	5,372.5[xyz]	93.9[w]	95.0[z]	3.73[x]	1,397.8[y]	50.3[x]	90.0[yz]
113.6	6.75[xyz]	5,524.8[xyz]	127.9[x]	95.0[z]	3.58[x]	1,478.9[yz]	57.4[x]	80.0[yz]
170.4	6.09[wxy]	4,974.3[wxy]	163.2[y]	89.0[z]	3.50[x]	1,302.4[xy]	84.8[y]	80.0[yz]
227.3	5.78[wx]	4,717.8[wx]	188.5[y]	81.3[z]	3.19[w]	1,271.8[xy]	97.8[yz]	77.3[xy]
284.1	5.38[w]	4,382.8[w]	222.0[z]	82.5[z]	2.65[w]	1,066.8[w]	95.9[yz]	72.0[xy]
284.1 autofeeder					3.05[v]	1,172.9[wx]	110.6[z]	72.0[x]
Pooled standard error	0.262	218.6	11.37	4.79	0.106	54.0	6.25	4.44

[a] Data represent the mean of four replicates. Mean values in any column with the same letter are not significantly different ($P < 0.05$).

vival. However, variability of the data results in a poor fit ($Y = -0.0581X + 98.07$: Adj. $r^2 = 0.2253$). The use of an automatic feeder did not significantly affect survival of *P. setiferus*. However, survival was affected by density (Table 1) and could be described by the following linear equation $Y = -0.0885X + 95.98$, Adj. $r^2 = 0.4266$.

Increasing grow-out densities in pond production systems, as well as increased interest in raceway production systems, have been the trend in U.S. aquaculture. Inten-

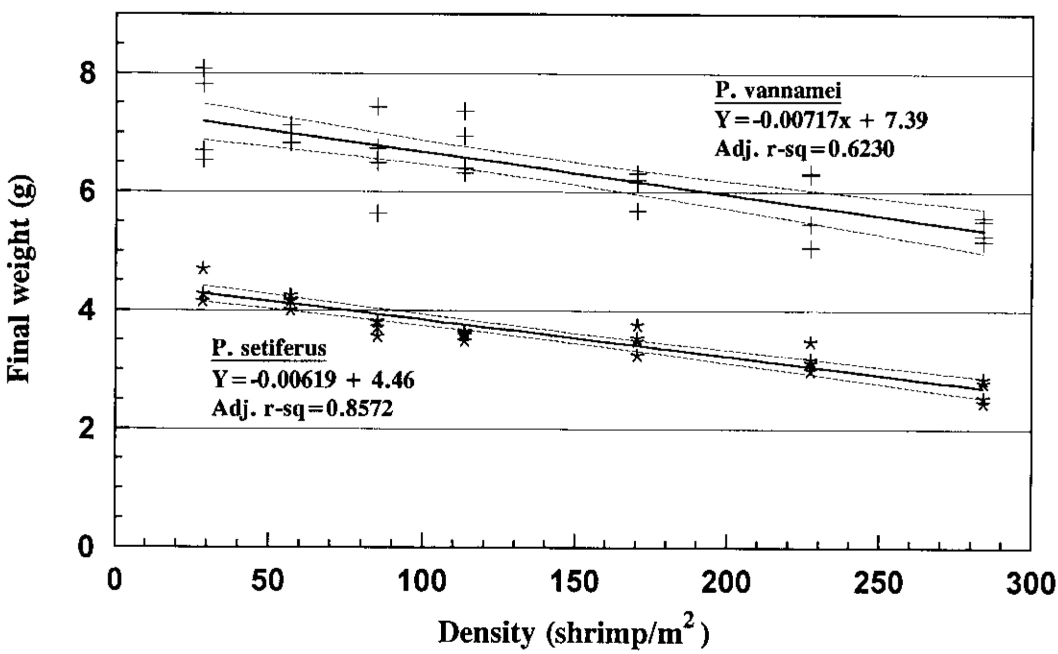

FIGURE 1. *Relationship (predicted value ± 95% confidence interval for the expected value of the dependent variable) of final weights for* Penaeus vannamei *and* P. setiferus *in response to stocking density under controlled laboratory conditions.*

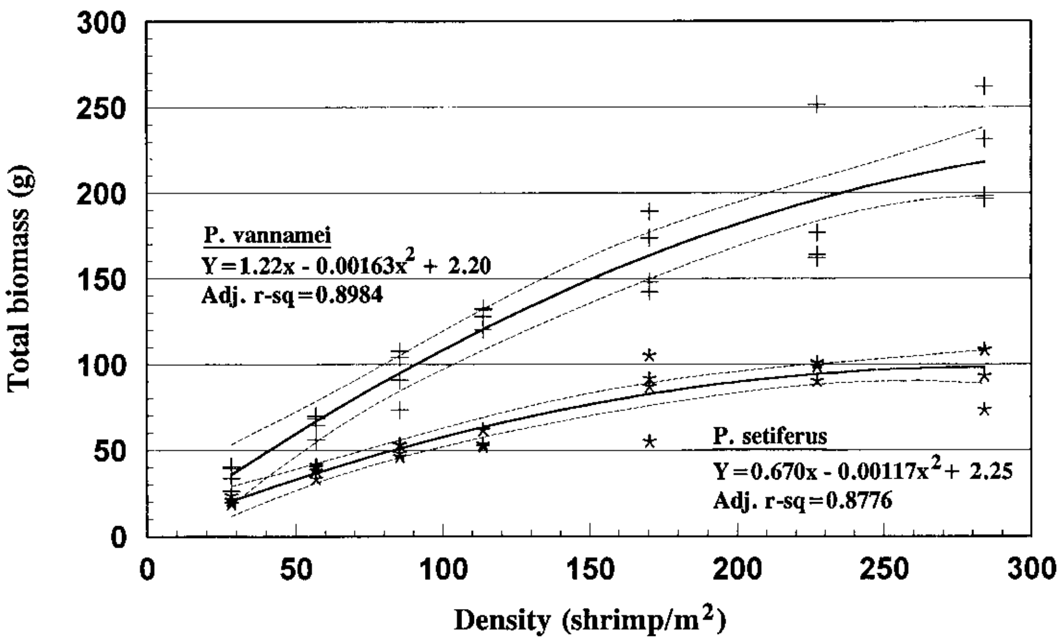

FIGURE 2. *Relationship (predicted value ± 95% confidence interval for the expected value of the dependent variable) of final biomass of* Penaeus vannamei *and* P. setiferus *to stocking density under controlled laboratory conditions.*

sification has been suggested as a primary means to improve economic performance of shrimp culture systems (Wyban and Sweeney 1989). The intensification of pond production systems is exemplified by the work of Sandifer et al. (1988). They found little difference in growth rates of *P. vannamei* maintained in ponds at densities from 20–100/m^2. More recently, Sandifer et al. (1991) demonstrated that acceptable growth rates (1 g/wk) could be obtained for *P. vannamei* maintained in production ponds stocked at densities as high as 200/m^2. Although considerable advances have been made in intensive culture techniques, little is understood about the response of the culture animal to increasing density under standardized conditions.

Under the reported conditions, juvenile shrimp were maintained in the laboratory in a semi-closed recirculation system in which water quality parameters and food availability were standardized between treatments. Based on the presented data, growth response of *P. vannamei* and *P. setiferus* can be described as a linear function of stocking density (Fig. 1), which is different from the quadratic function of redtail shrimp, *P. penicillatus,* determined by Miao (1992). The observed weight gain for *P. vannamei* and *P. setiferus* (7.2–5.3 g and 4.2–2.8 g, respectively) over the 7-wk growth trials is consistent with other populations which have been followed in our laboratory under similar conditions. Reid and Arnold (1992) stocked *P. vannamei* as high as 970/m^3 (1,121/m^2) and 2,132/m^3 (1,815/m^2) in two recirculation raceway systems, each having a footprint of 32.88 m^2, and also found a reduction in growth and survival at the higher density. These results indicate that reduced growth and survival rates of *P. vannamei* and *P. setiferus* which can occur at high densities, are partially due to the social function of crowding.

The growth response to increasing densities followed the same trend line for both species with values for *P. vannamei* significantly higher than for *P. setiferus* at all densities (Fig. 1). These experiments were not specifically designed to compare the growth of these two species. However, the reported results exemplify growth disparities occurring under intensive culture conditions. Cultured growth rates of *P. setiferus* have significantly lagged that of *P. vannamei* (Parker and Holcomb 1973; Sandifer et al. 1990). In a comparison of commercial grow-out of *P. setiferus* and *P. vannamei*, Browdy et al. (1991) stocked both at 40 and 75 PL/m^2. Growth of *P. setiferus* was reduced at the higher density (0.64 vs 0.73 g/wk). This growth rate was also considerably lower than that of *P. vannamei* which grew at 0.9 g/wk at both densities. The slower growth of *P. setiferus* may be due to inadequacies of the feed. Robertson et al. (1993) reported that growth of *P. setiferus* was dependent on feed quality and found that naturally occurring food organisms found in the culture pond were responsible for $\leq$ 52% of shrimp growth, which agrees with the results obtained with *P. vannamei* by Parker et al. (1989). Robertson et al. (1993) also found close to a 50% increase in growth rate of *P. setiferus* when stocked at low densities with natural forage as the primary food source (1.56 g/wk vs. 1.04 g/wk). This suggests that commercial feeds may not be properly formulated for the nutritional and/or palatability requirements of *P. setiferus.* It has been determined that artificial feeds, such as the water stable pellets offered to both species, need to be offered over an extended period. Since the shrimp in this study were fed in excess, it is likely that the reduced growth was not a result of feed availability. Results from the comparison of four feedings vs automatic feeding at a density of 284.1 shrimp/m^2 are unclear. Analyses of final weights would indicate an effect whereas analyses of weight gain, instantaneous growth rates and final biomass indicated no significant effect. Consequently, additional research on the effects of the number of feedings in relation to density is warranted.

Survival in both experiments was reasonable and is consistent with typical results found within our laboratory. In both experiments survival decreased with increasing density with some shrimp lost due to jumping. The high variability in survival of *P. vannamei* was thought to be primarily related to disturbance-induced jumping from tanks. The combined effects of density, weight gain and survival (final biomass) are presented in Fig. 2. For both species increasing the density resulted in increases in final biomass production. The curvilinear pattern of these curves for both species may indicate a plateau at extremely high densities.

Based on the results of the present study, *P. setiferus* has a similar tolerance of high density as that of *P. vannamei* and hence may be suitable for intensive culture systems. However, depressed growth rates of *P. setiferus,* which do not appear to be due to effects of water quality, feed availability or density, must be solved if growth rates similar to *P. vannamei* are to be realized.

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