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GROWTH AND SURVIVAL MODELS OF REDTAIL SHRIMP *PENAEUS PENICILLATUS* (ALOCK) ACCORDING TO MANIPULATING STOCKING DENSITY

SHA MIAO

Department of Aquaculture,
National Taiwan Ocean University,
Keelung, Taiwan 20224, Republic of China

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Sha Miao (1992) Growth and survival models of redtail shrimp *Penaeus penicillatus* (Alock) according to manipulating stocking density. *Bull. Inst. Zool., Academia Sinica* **31**(1): 1-8. Four stocking densities of 4, 18, 32 and 46 redtail shrimp per 0.18 m² were studied for the effects of density on growth and survival. Results indicated that the growth rate can be described as a quadratic function of stocking density: $\hat{G}=1.1937228+0.0082454\,D-0.0003487\,D^2$, where $\hat{G}$ is the estimated growth rate, and D is the stocking density. Regarding the maximum growth rate produced, the optimum stocking density is 12 redtail shrimp per 0.18 m². On the other hand, a linear model of $\hat{S}=0.997437-0.0043187\,D$, where $\hat{S}$ is the estimated survival rate, and D is the stocking density, indicated that the survival rate was negatively proportional to the stocking density.

Key words: Redtail shrimp, Stocking density, Optimum, Quadratic function, Linear model.

Liao (1988) indicated that the redtail shrimp, *Penaeus penicillatus* (Alock), is well suited for aquaculture for the following reasons: (1) the redtail shrimp is of the white shrimp species and grows to a comparatively uniform size which is attractive to consumers; (2) it is comparatively resistant to low temperatures, and its migration behavior shows a capability for mariculture; (3) wild spawners are abundant in the natural environment, and induced spawning in captivity is relatively easy; and, (4) it has a low protein requirement (Colvin, 1976; Deshimaru and Kurok, 1974; Lee, 1971; Shigueno *et al.*, 1972; Veronica and Lim, 1983), and shows good growth in its early stages even at high stocking densities of 100-120 shrimp/m².

With regard to proper aquaculture management, stocking density plays a predominant role in influencing growth and survival rates of reared stocks (Smith *et al.*, 1978; Yu and Perlmutter, 1970). The stocking rate of 18 redtail shrimp/0.18 m², equivalent to 100 redtail shrimp/m² (Liao, 1988), is capable of producing good growth. There has been no report, however, quantitatively evaluating the effects of stocking density on the growth and survival rates of the redtail shrimp. The objective of this study was to estimate growth and survival rates under various stocking densities in order to uncover an optimum stocking density.

MATERIALS AND METHODS

Four levels of stocking density (4, 18,

32, and 46 redtail shrimp per aquarium) were selected for this quantitative study. There were five replicates for each treatment. Each aquarium was 60, 30, and 36 cm in length, width, and height, respectively, and had a surface area of 0.18 m^2.

An orthogonal polynomial model (Gill, 1978; Kendall and Stuart, 1969; Petersen, 1985) describes the experimental system as follows:

$$Y=\beta_0+\beta_1 X+\beta_2 X^2+\beta_3 X^3,$$

where

X indicates stocking density;
Y is a variable of either growth rate or survival rate, depending on the system studied;
β_0 is the intercept on Y axis; and,
β_1, β_2, and β_3, are regression coefficients.

Variable Y in the growth model represents a 40-day growth rate equal to $\ln(W_t/W_0)/t$. W_t and W_0 denote the observed body weights of redtail shrimp at both the final and initial stages in a specific aquarium within a duration (t) of forty days; t is a unit of time. On the other hand, variable Y may alternatively represent the survival rate while studying the effects of stocking density on survival rate.

The experimental shrimp were provided by the Tung Kang Marine Laboratory. The experiment started after an acclimatization of seven days, and lasted forty days. The initial weights of the redtail shrimp ranged from 0.23 to 0.45 g, with a mean of 0.32 g and a standard deviation of 0.057 g. A daily diet of 15% of body weight was divided into two equal parts, and given at 0900 and 1300 hours. A commercial shrimp pellet diet (manufactured by President Enterprises Corporation, Taiwan) was the food source and kept refrigerated for this feeding scheme. System illumination included two fluorescent light fixtures using two 40-watt bulbs, each regulated to provide light from 0700 to 1900 hours. In order to prevent the shrimp from escaping, each aquarium was screened. Filtered sea water, came from the National Taiwan Ocean University's supply system originating from the nearby coast, filled the aquaria. The aquaria's cleaning and maintenance were performed on a weekly basis. This cleaning scheme consisted of scrubbing the walls of the aquaria and siphoning metabolic waste and feed residuals. After siphoning, each aquarium was refilled to about one-third its volume with conditioned sea water. In addition, pH, salinity, temperature, and dissolved oxygen measurements were taken every other day.

RESULTS

Experimental observations of growth and survival rates are shown in Table 1. Tables 2 and 3 indicate that the analyses of variance in growth and survival rates, as influenced by stocking density, are significant. Sequential tests on polynomial stocking density effects were then conducted on growth and survival rates (Tables 4 and 5).

Table 4 shows that, by adding a quadratic term, lack of fit loses its significance; this shows that growth rate is a quadratic function of stocking density. Further analysis of density treatments ranging from 4 to 46 shrimp per 0.18 m^2 revealed that the growth rate may be described by the equation:

$$\hat{G}=1.1937228+0.0082454D-0.0003487D^2,$$

where

$\hat{G}$=Expected growth rate; and,
D=Stocking density,

with an optimum stocking density of approximately 12 shrimp per 0.18 m^2 (Fig. 1). However, Table 5 shows that survival is a linear function of stocking density.

Table 1
Observations of growth and survival rates per treatment of stocking density

Treatment of stocking density (No. of shrimp per aquarium)	Aquarium number	Growth rate $(G)^1$	Mean and standard deviation of growth rate	Survival rate $(S)^2$	Mean and standard deviation of survival rate
	1	1.52416	$G_I=1.22088$	1.00000	$S_I=1.00000$
	2	0.89382		1.00000	
I=4	3	1.42534		1.00000	
	4	1.36432	$SD_I=0.30265$	1.00000	$SD_I=0$
	5	0.89675		1.00000	
	1	0.89852	$G_{II}=1.28848$	0.83333	$S_{II}=0.90000$
	2	1.32886		0.94444	
II=18	3	1.47230		1.00000	
	4	1.34742	$SD_{II}=0.22493$	0.94444	$SD_{II}=0.09128$
	5	1.39531		0.77778	
	1	0.91006	$G_{III}=1.00875$	0.90625	$S_{III}=0.84735$
	2	0.96016		0.87500	
III=32	3	1.03971		0.87500	
	4	1.09936	$SD_{III}=0.07404$	0.87500	$SD_{III}=0.08839$
	5	1.03445		0.68750	
	1	1.10698	$G_{IV}=0.86779$	0.86956	$S_{IV}=0.81739$
	2	0.68763		0.80435	
IV=46	3	1.08750		0.91304	
	4	0.67676	$SD_{IV}=0.21338$	0.65217	$SD_{IV}=0.10033$
	5	0.78010		0.84783	

1. $G=\{ln(W_F/W_I)\}/(\text{unit of time})=ln(W_F/W_I)$, where W_F and W_I are, respectively, final and initial weights of shrimp per aquarium for a given treatment of stocking density; the unit of time=40 days.
2. $S=N_F/N_I$, where N_F=number of shrimp surviving on day 40, and N_I=number of shrimp initially stocked in an aquarium.

Table 2
Analysis of variance of growth rates influenced by stocking density

Source of variation	D.F.	Sum of squares	Mean square	F-ratio	$Pr>F$
Total	19	1.33448713			
Stocking density	3	0.56166964	0.18722321	3.88	0.0294
Random error	16	0.77281749	0.04830109		

Table 3
Analysis of variance of survival rates influenced by stocking density

Source of variation	D.F.	Sum of squares	Mean square	F-ratio	$Pr>F$
Total	19	0.20513329			
Stocking density	3	0.09931576	0.03310525	5.01	0.0123
Random error	16	0.10581753	0.00661360		

Table 4

Sequential test of polynomial stocking density effects on growth rates

Source	D.F.	SS	MS	F-ratio	$Pr>F$
Stocking density	3	0.5616696	0.1872232	3.88	$0.025<Pr<0.05$
Linear	1	0.4138682	0.4138682	8.57	$0.005<Pr<0.01$
Deviation from linear	2	0.1478014	0.0739007	1.53	$0.1<Pr<0.25$
Quadratic	1	0.0934293	0.0934293	1.93	$0.1<Pr<0.25$
Deviation from linear and quadratic	1	0.0543721	0.0543721	1.13	$Pr>0.25$

Note: MSE=0.0483011 (with 16 d.f.) is the divisor for F ratios.

Table 5

Sequential test of polynomial stocking density effects on survival rates

Source	D.F.	SS	MS	F-ratio	$Pr>F$
Stocking density	3	0.0993158	0.0331052	5.01	$0.01<Pr<0.025$
Linear	1	0.0913907	0.0913907	13.82	$0.001<Pr<0.0025$
Deviation from linear	2	0.0079251	0.0039625	0.60	$Pr\gg0.25$

Note: MSE=0.0066136 (with 16 d.f.) is the divisor for all F ratios.

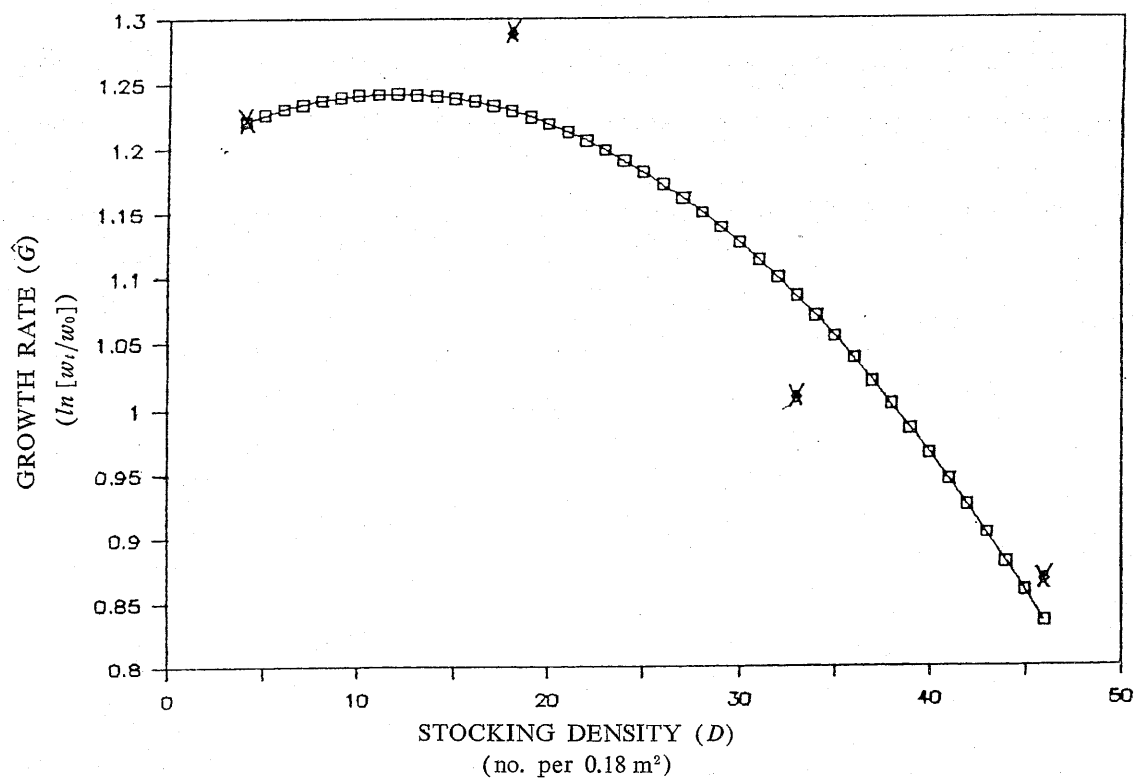

Fig. 1. Estimated growth rate of redtail shrimp at varied stocking densities.

The estimated growth rate ($\hat{G}$) of redtail shrimp at varied stocking densities (D) can be described using a quadratic polynomial functon as $\hat{G}=1.1937228+0.008245\ D-0.0003487\ D^2$. The cross signs indicate average experimental data points.

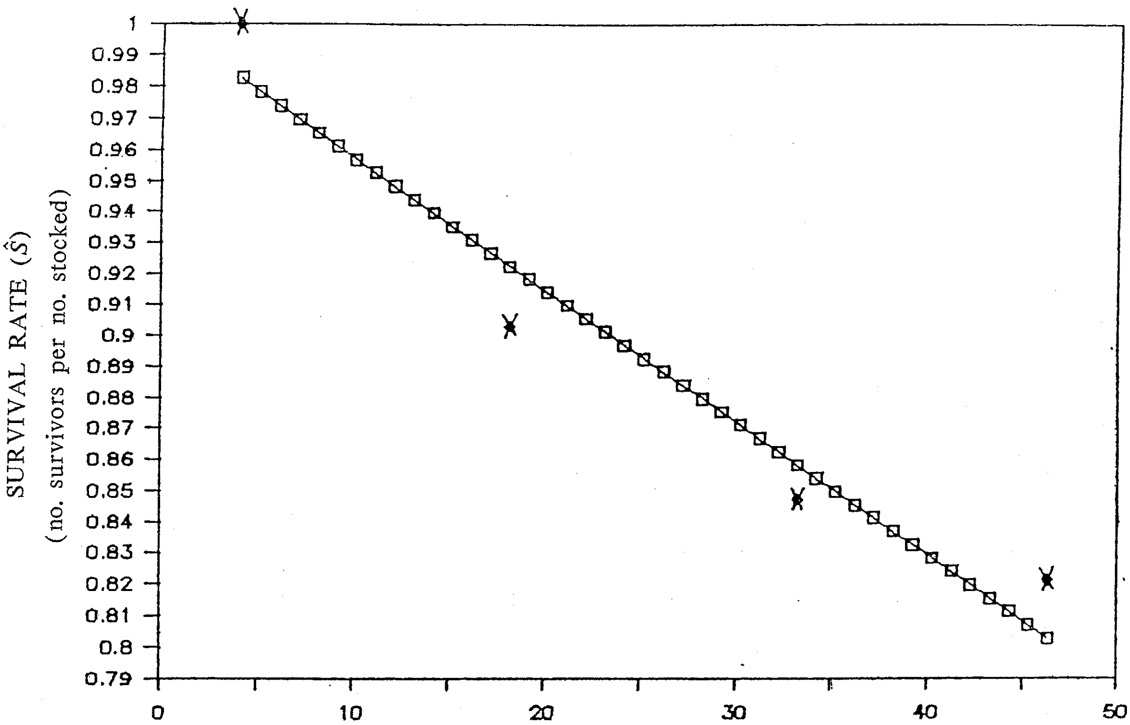

Fig. 2. Estimated survival rate of redtail shrimp at varied stocking densities.
The estimated survival rate ($\hat{S}$) of redtail shrimp at varied stocking densities (D) can be described using a linear polynomial function as $\hat{S}$=0.9974375−0.0043187 D. The cross signs indicate average experimental data points.

Such linearity may be described by the equation

$$\hat{S}=0.997437-0.0043187D,$$

where

$\hat{S}$=Expected survival rate; and,
D=Stocking density.

Fig. 2 shows the linearility between survival rate and shocking density.

Throughout the 40-day study period, the fluctuation of water temperature was 26°±2°C. Water quality, including values of pH and D.O. (dissolved oxygen) was analyzed. Table 6 points out that the

Table 6
Analysis of variance on pH affected by stocking density

Source of variation	D.F.	Sum of squares	Mean square	F-ratio	$Pr>F$
Total	359	3.79096444			
Stocking density	3	1.37583889	0.45861630	19.34	0.0001
Aquarium	16	0.37944444	0.02371528		
Period[1]	17	1.51447000	0.08908647	147.22	0.0001
Stocking density×Period	51	0.52120111	0.01021963	16.89	0.0001
Random error	272	0.16459556	0.00060513		

1. Eighteen pH measurements for each aquarium during the 40-day period.

Table 7
Analysis of variance on D.O.[1] affected by stocking density

Source of variation	D.F.	Sum of squares	Mean square	*F*-ratio	*Pr>F*
Total	359	29.21988889			
Stocking density	3	8.93700000	2.97900000	76.79	0.0001
Aquarium	16	0.62066667	0.03879167		
Period[2]	17	16.78188889	0.98716993	166.23	0.0001
Stocking density×Period	51	1.26500000	0.02480392	4.18	0.0001
Random error	272	1.61533333	0.00593873		

1. Dissolved oxygen.
2. Eighteen repeated D.O. measurements for each aquarium during the 40-day period.

effect of interaction between stocking density and time (18 measurements during the 40-day period) on pH value was highly significant ($p<0.0001$). With an overall mean of 8.08, the pH value varied when the stocking density changed throughout the 40-day period. Finally, throughout the entire experimental period, stocking density had a significant effect on amounts of dissolved oxygen (Table 7), with an overall mean of 5.30.

DISCUSSION

In a polyculture experiment with *Penaeus penicillatus* and *P. monodon* at a mixed stocking density of 15 shrimp/m^2 (7.5 shrimp each), 0.26 g redtail shrimp grew to 16.98 g in 120 days when the water temperature was an average 22°C (Liao, 1977). Another report on a stocking density of 20 shrimp/m^2 indicated that redtail shrimp averaging 0.49 g grew to a marketable size of 21.35 g in 120 days in water with temperatures ranging from 24.8 to 32.1°C (Liao and Chao, 1987). Both results came from single-pond experiments. Liao and Chao (1987) further concluded that warm water seems to favorably affect growth. According to Chen *et al.* (1988), total weights in an extremely intensive culture system increased from 1.44 kg to 4,650 kg during a cold season of 131 days, and from 2.4 kg to 5,160 kg during a warm season of 141 days; these results came from stocking densities of 171 and 286 redtail shrimp/m^2, respectively. The 40-day growth rates, estimated by taking natural logarithms of weight ratios, were 2.467 in cold water and 2.177 in warm water, respectively. These growth rates were obviously much higher than those of the present study, leading to a confusing idea that redtail shrimp grow better in cold water with very high densities.

Liao (1988) reported that redtail shrimp develop good growth in early stages even at high stocking densities of 100-120/m^2. The present study indicates that stocking densities may lead to varied growth and survival rates; the maximum growth rate of redtail shrimp came at a stocking density of 67 shrimp/m^2 (12 shrimp/0.18 m^2), then declined beyond the critical point. Simply stated, growth rate is a quadratic function of stocking density. On the other hand, the survival rate in this study was linear and inversely proportional to stocking density.

Total production in farming systems is described as a summation of individual weights of all reared organisms, or a cross-product of the number of surviving organisms and their mean weight. Accordingly, survival and growth rates have significant effects on production which, in turn, affect total revenue. However, the optimum stocking density defined here focused only on growth rates, not on survival rates. Therefore, the observed optimum stocking density produced maximum growth, but an inferior survival rate. As a result, when considering total production, a modification of the observed optimum density may be necessary. In fact, being part of good farm management, proper stocking density cannot rely merely on biological evidence. Market characteristics—seasonal supply and demand, desired profit, marketable size, etc. —may influence a shift in predetermined stocking densities. For reasons mentioned above, an additional study focusing on goal programming should be conducted to determine appropriate stocking densities according to multiple or conflicting goals.

The effects of stocking density on water quality, including pH value and amount of dissolved oxygen (D.O.), showed that the higher the stocking density, the lower the values of both pH and D.O. This indicates that resultant water quality may play an important role in affecting growth and survival rates. Yu and Perlmutter (1970) reported that metabolic wastes—which are directly proportional to population density—have been implicated as being inhibitive to the growth of fish, as well as being toxic to fish. Water volume also appeared to limit the number of fish which can be supported (tolerance density) (Smith *et al.*, 1978). As a partial explanation for reduced reproduction and growth under crowded conditions, several investigators have suggested the presence of a water-borne, fish-produced reproduction inhibitor (Rose and Rose, 1965; Swingle, 1953) that also reduces growth rates (Francis *et al.*, 1974; Yu and Perlmutter, 1970). Glaser and Kantor (1974) showed that spawning rates in medaka (*Oryzias latipes*) can be inhibited by social factors related to crowding, irrespective of the chemical conditions of the water. Hence, based on experimental results, whether growth and survival rates are purely social functions of crowding, or more complicated biochemical functions of water quality, is not clear; therefore, further study may be required to clarify this issue. To do so, water quality should be maintained at a constant level in a flowing system, within which the effects of stocking density on growth and survival rates may be reexamined.

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紅尾蝦放養密度對成長及活存影響之模式

繆　　峽

本實驗之目的在研究四種放養密度，即 4, 18, 32, 46 隻紅尾蝦/0.18 平方公尺，對紅尾蝦的成長和活存之影響。結果顯示成長速率（$\hat{G}$）可以放養密度（D）的二次方程式表示：

$$\hat{G}=1.1937228+0.0082454\,D-0.0003487\,D^2$$

當放養密度爲 12 隻紅尾蝦/0.18 平方公尺時，成長速率將達最高點。此外，活存率（$\hat{S}$）和放養密度則呈線性反比的關係：

$$\hat{S}=0.9974375-0.0043187\,D$$