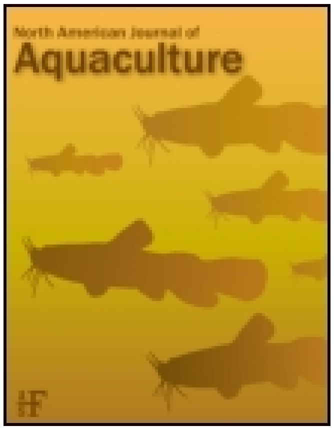

North American Journal of Aquaculture
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/unaj20

Effect of Stocking Size on Growth Performance, Biomass, Production, Yield, and Survival of Caridean Shrimp Cage-Cultured in a Pond System

Jesús T. Ponce-Palafox[a], Fermín López-Uriostegui[a], José L. Arredondo-Figueroa[b], Mario A. Benítez-Mandujano[c], Manuel García-Ulloa Gómez[a], Héctor M. Esparza-Leal[d] & Milton Spanopoulos Hernández[e]

[a] Coastal Bioengineering Laboratory, Escuela Nacional de Ingeniería Pesquera, National School of Fisheries Engineering, Autonomous University of Nayarit, Nayarit 63155, Mexico

[b] Center for Agricultural Sciences, Autonomous University of Aguascalientes, km 3 de la Carretera Jesús María-La Posta, Aguascalientes 20131, Mexico

[c] Multidisciplinary Academic Division of Rivers, Juarez Autonomous University of Tabasco, Av. Universidad s/n, Zona de la Cultura, Col. Magisterial, Centro, Tabasco 86040, Mexico

[d] National Polytechnic Institute, Interdisciplinary Research Centre for Regional Integral Development, Bulevar Juan de Dios Bátiz Paredes 250, Colonia San Joaquin, Guasave, Sinaloa 81101, Mexico

[e] Laboratory of Aquaculture, Mazatlan Institute of Technology, Corsario 1203 Col., Uras Mazatlán, Sinaloa 82070, Mexico

Published online: 15 Sep 2014.

North American Journal of Aquaculture 76:430–435, 2014

ISSN: 1522-2055 print / 1548-8454 online
DOI: 10.1080/15222055.2014.936538

ARTICLE

Effect of Stocking Size on Growth Performance, Biomass, Production, Yield, and Survival of Caridean Shrimp Cage-Cultured in a Pond System

Jesús T. Ponce-Palafox* and Fermín López-Uriostegui
Coastal Bioengineering Laboratory, Escuela Nacional de Ingeniería Pesquera, National School of Fisheries Engineering, Autonomous University of Nayarit, Nayarit 63155, Mexico

José L. Arredondo-Figueroa
Center for Agricultural Sciences, Autonomous University of Aguascalientes, km 3 de la Carretera Jesús María-La Posta, Aguascalientes 20131, Mexico

Mario A. Benítez-Mandujano
Multidisciplinary Academic Division of Rivers, Juarez Autonomous University of Tabasco, Av. Universidad s/n, Zona de la Cultura, Col. Magisterial, Centro, Tabasco 86040, Mexico

Manuel García-Ulloa Gómez
Coastal Bioengineering Laboratory, Escuela Nacional de Ingeniería Pesquera, National School of Fisheries Engineering, Autonomous University of Nayarit, Nayarit 63155, Mexico

Héctor M. Esparza-Leal
National Polytechnic Institute, Interdisciplinary Research Centre for Regional Integral Development, Bulevar Juan de Dios Bátiz Paredes 250, Colonia San Joaquin, Guasave, Sinaloa 81101, Mexico

Milton Spanopoulos Hernández
Laboratory of Aquaculture, Mazatlan Institute of Technology, Corsario 1203 Col., Uras Mazatlán, Sinaloa 82070, Mexico

Abstract
We evaluated the effect of stocking size on growth performance, biomass, production, yield, and survival of the caridean shrimp *Macrobrachium americanum*, a freshwater prawn, cultured in cages held in a pond system. The experiment was conducted using 15 cages of 3 m^3 placed inside an earthen pond of 1,422 m^2 or surface area. Seventy-five prawns were stocked for 180 d at sizes of 5, 15, 25, 35 and 45 g, and the initial stocking density was adjusted to 1.7 individuals/m^3 for all size groups. Growth performance, biomass, production, yield, and survival were significantly affected by stocking size. The mean final weight fluctuated from 21.3 g for the 5-g stocking size to 82.1 g for the 45-g stocking size, whereas prawns initially stocked at 35 g obtained a biomass of 277.8 g and at 45 g obtained a biomass of 246.3 g and a yield >82.0 g/m^3. The specific growth rate decreased with stocking size from 0.78%/d for the 5-g group, to 0.33%/d for the 45-g group. Annual production fluctuated from 28.0 kg/ha for the 5-g group to 88.7 kg/ha for the 45-g group, and yield was from 560.0 kg/ha for the 5-g group to 1,640 kg/ha for the 45-g group. Survival varied from 80.0% for the 5-g group to 60.0% for the 45-g group. The results showed that prawn production in caged-pond systems cultured at lower stocking sizes during the juvenile-adult phase is feasible.

*Corresponding author: jesus.ponce@usa.net
Received December 28, 2013; accepted June 12, 2014

Caridean shrimp *M. americanum*, a freshwater prawn, are distributed in western basin rivers from the Gulf of California, Mexico, to northern Peru and the Galapagos and Cocos islands (Holtschmit 1988). Several native species of the genus *Macrobrachium* such as *M. tenellum* and caridean shrimp have a high potential for aquaculture (Ponce-Palafox et al. 2002). Caridean shrimp is a large species that reaches up to 23.5 cm in total length (Kensler et al. 1974), that ensures a significant commercial value throughout its range. This freshwater prawn can reach a total length of 30 cm and a total weight up to 250 g in natural conditions. In addition, it has a thin shell, good presentation, and acceptable flavor (Ponce-Palafox et al. 2002). Many studies on the technological aspects for caridean shrimp culture have been conducted. For example, there are reports on larvae and postlarvae rearing under laboratory conditions (Monaco 1975; Holtschmit and Pfeiler 1984), its development and reproduction in controlled systems (García-Guerrero 2009; García-Guerrero 2010), the rearing of prawn juveniles under laboratory conditions (Arana-Magallón and Ortega-Salas 2005), and the adaptation of wild juveniles to culture conditions (Smitherman et al. 1974; García-Guerrero and Apun-Molina 2008). Furthermore, the feasibility of polyculture has been tested with red tilapia (Mozambique Tilapia *Oreochromis mossambicus* × Wami Tilapia *O. urolepis*) in recirculating aquaculture systems (Rojo-Cebreros et al. 2013). However, studies on the growth of juvenile *M. americanum* in earthen ponds and cage systems are scarce (Smitherman et al. 1974; Arana-Magallón 1977). The objective of this study was to evaluate the effect of stocking size on growth performance, biomass, production, yield, and survival of caridean shrimp reared in a cages in an earthen pond system.

METHODS

Local and experimental structure.—The experiment was conducted in an earthen pond (1,422 m^2 surface area) located at the San Cayetano Aquaculture Center, Fisheries Department, Nayarit State Government (21°27′24.23″ N; 104°49′29.67″ W), where 15 bottom cages, each with a capacity of 3 m^3 (3 × 1 × 1 m high), were utilized. The cages were built with polyethylene mesh (0.7-mm diameter) and iron frames. Circular trays (50-cm diameter) made of polyethylene screen were used as feeders and fixed inside the cages, as well as synthetic mesh (raffia bags) as refuges. The cages were tied to stakes, placed on the pond bottom at a depth of 1 m, and covered with a polyethylene screen to avoid predators and prawn escape. Water exchange (5% of the pond water) was performed nightly from 1900–2100 hours to assure adequate water circulation.

Water parameters.—Water temperature and dissolved oxygen (Yellow Springs Instruments YSI-85) were measured twice daily (0900 and 1700 hours) inside the cages. Water transparency (Secchi disk) and pH (Bernauer F-1002) were measured daily. Samples of water were collected twice daily (0900 and 1700 hours) for 1 month at the water subsurface and inside the cages to determine alkalinity, ammonia ($N–NH_4^+$), nitrite ($N–NO_2$), nitrate ($N–NO_3$), and total phosphorous (total P). All the analyses were conducted using a YSI 9000 photometer (Yellow Springs Instruments) according to APHA (2005).

Experimental procedures.—We stocked 75 caridean shrimp of different sizes (5, 15, 25, 35, and 45 g) in 15 cages (1.7 shrimp/m^3 or 5 shrimp/cage) using a completely randomized design with three replicates per tested stocking size. Animals were fed twice daily with a commercial diet (Nutripec Camaronina XT, Agribrands, Purina, Mexico; 35% crude protein was 8% lipid and 12% moisture; size was 2–2.5 mm × 6–7 mm). The daily feed ratio was gradually adjusted from 5% at the beginning of the experiment to 2% at the end of the experiment, based on demand and after monitoring the feeding trays. All prawns were weighed and measured monthly to evaluate growth and to adjust the amount of feed supply.

After 180 d of culture, the prawns were individually counted, measured and weighed to determine mean final length (cm), mean final weight (g), weight gain (g/week), biomass (g), production (g/m^3), yield (kg/ha per year), specific growth rate (SGR;%/d), feed conversion ratio (FCR;%) and survival (%), where FCR (%) = total dry feed (g)/ total wet weight gain (g) and SGR (%/d) = $100 \times [(\log_e W_2 - \log_e W_1)/t_2 - t_1)]$, where W_2 and W_1 are mean body weights (g) at times t_2 and t_1 (d).

A regression analysis was applied for each growth rate versus final weight and production versus stocking size relationship of all caridean shrimp (Bhujel 2008). The relationships between final weight versus growth rate and stocking size versus production produced the following quadratic equation:

$$Production = \beta_0 + \beta_1 d + \beta_2 d^2, \quad (1)$$

where β_2 is a quadratic coefficient (other than 0), β1 is the linear coefficient, β_0 is the intercept, and d is density (Bhujel 2008).

The maximum density (d_{max}) is

$$d_{\max} = \beta_1 / 2\beta_2, \quad (2)$$

where $d_{max} =$ maximum density. Maximum production is

$$Production_{max} = \beta_0 + (\beta_1^2/2\beta_2) - (\beta_1/2). \quad (3)$$

Final optimum weight for growth ($W_{opt}GR$) was calculated from the first-order derivative of the parabolic regressions (i.e., when dGR/dW = 0; Bhujel 2008). In addition, optimum stocking size for growth ($SS_{opt}B$) was calculated from the first-order derivative of the parabolic regressions (i.e., when dB/dSS = 0).

Statistical analysis.—Prawn performance data were analyzed using Kolmogorov–Smirnov two-sample and Bartlett's tests to assess normality and homoscedasticity, respectively. Because the requirements of these tests were satisfied by both shrimp performance and water quality data, a paired *t*-test was used to compare the morning and afternoon means of the water

TABLE 1. Mean (±SE) pond-water variables measured in the pond system used to culture caridean shrimp during a 180-d trial period. Within a row, different letters indicate significant differences ($P < 0.05$).

Water variables	Morning	Afternoon
Temperature (°C)	27.0 ± 1.2 z	28.8 ± 1.2 z
pH	8.5 ± 0.2 z	8.6 ± 0.1 z
Secchi disk transparency (cm)	82.5 ± 0.5	
Dissolved oxygen (mg/L)	8.2 ± 1.6 z	8.6 ± 0.6 z
Alkalinity (mg $CaCO_3$/L)	110.0 ± 0.90 z	135 ± 1.3 y
N-NO_3 (mg/L)	1.58 ± 0.15 z	1.32 ± 0.35 z
N-NO_2 (mg/L)	0.55 ± 0.07 z	0.42 ± 0.09 z
N-NH_3 (mg/L)	0.19 ± 0.05 z	0.15 ± 0.08 z
P total (mg/L)	0.56 ± 0.09 z	0.38 ± 0.10 y

variables. All data from all treatments were subjected to one-way analysis ANOVA (Montgomery 2012), where significant main-factor effects were identified; differences among treatments were tested using Tukey's multicomparison test. The results were evaluated at the 5% significance level. Values expressed as percentages were square-root-arcsine transformed prior to analysis but presented as nontransformed for easier review. The analyses were conducted using Statistica package v10 (StatSoft, Tulsa, Oklahoma).

RESULTS

There were no differences in measured water quality metrics among the treatments. During the summer, water temperature remained at approximately 27.9°C. During the cold season, mean temperatures were 26.4°C in November and 25.0°C in December, and a minimum gradient was registered. The dissolved oxygen values were higher during the grow-out phase (9.2–9.6 mg/L). Values for pH oscillated slightly and remained close to 8.5. The remaining water metrics remained stable during morning and afternoon sampling events (Table 1).

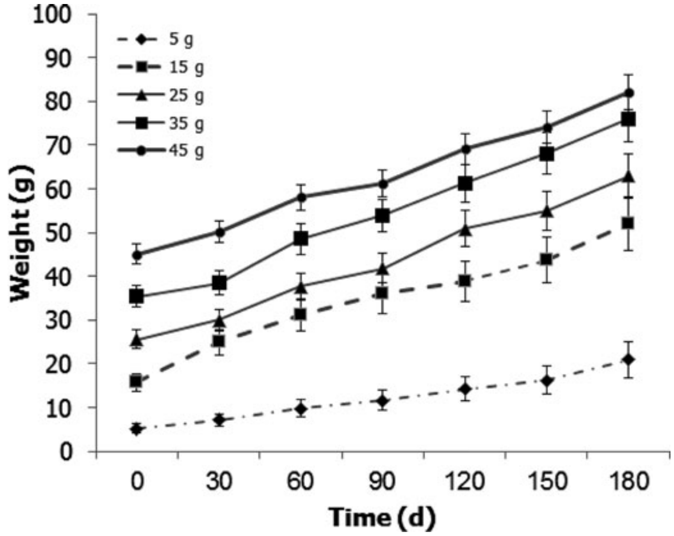

FIGURE 1. Monthly mean weight of caridean shrimp cultured at different stocking sizes in cages held in a pond system during a 180-d trial period.

There were significant differences ($P = 0.02$) in the mean final weight among treatments (Figure 1; Table 2). The 35 g and 45 g groups obtained the highest mean (±SE) values (76.1 ± 7.3 g and 82.1 ± 9.7 g, respectively). A significant increase ($P = 0.03$) in SGR was observed for the 5 g (0.78 ± 0.04%/d) and 15 g (0.66 ± 0.07%/d) groups compared with the other

TABLE 2. Mean (±SE) values of growth performance (GR = growth rate, SGR = specific growth rate, FCR = feed conversion rate), biomass, production, and survival in a pond system where different stocking densities of caridean shrimp were cage-cultured. Within a row, different letters indicate significant differences ($P < 0.05$).

	Stocking size (g)				
Parameters	5	15	25	35	45
Initial length (cm)	6.6 ± 0.2	9.6 ± 0.1	10.7 ± 0.1	11.8 ± 0.1	13.8 ± 0.1
Initial weight (g)	5.0 ± 0.9	15.0 ± 1.8	25.0 ± 2.2	35.0 ± 3.1	45.0 ± 3.3
Final length (cm)	11.9 ± 1.2 x	15.5 ± 2.4 y	15.7 ± 1.9 y	16.8 ± 2.2 zy	18.0 ± 3.5 z
Final weight (g)	21.3 ± 2.6 x	52.1 ± 7.1 y	63.2 ± 8.2 y	76.1 ± 7.3 z	82.1 ± 9.7 z
Biomass (g)	85.2 ± 7.1 w	208.4 ± 6.2 x	230.7 ± 6.0 y	277.8 ± 5.9 z	246.3 ± 5.2 y
Production (g/m^3)	28.0 ± 9.1 x	69.3 ± 6.9 y	73.5 ± 5.1 y	88.7 ± 6.5 z	82.0 ± 4.8 z
Annual yield (kg/ha)	560.0 ± 19.7 x	1,386.0 ± 37.8 y	1,470.0 ± 29.9 y	1,774.0 ± 11.3 z	1,640.0 ± 15.2 z
Daily length gain (mm/d)	0.30 ± 0.02 z	0.33 ± 0.04 z	0.27 ± 0.02 y	0.28 ± 0.01y	0.23 ± 0.03 x
GR (g/week)	0.63 ± 0.10 x	1.45 ± 0.11 y	1.49 ± 0.09 y	1.62 ± 0.05 z	1.48 ± 0.10 y
SGR (% /d)	0.78 ± 0.04 z	0.66 ± 0.07 y	0.50 ± 0.08 x	0.42 ± 0.05 x	0.33 ± 0.06 w
FCR	1.7 ± 0.1 z	1.6 ± 0.2 z	1.8 ± 0.1 z	1.9 ± 0.3 zy	2.2 ± 0.2 y
Survival (%)	80.0 ± 2.5 z	80.0 ± 2.0 z	73.0 ± 1.3 y	73.0 ± 1.6 y	60.0 ± 2.1 x

TABLE 3. Equations and allometric factors (b) obtained in caridean shrimp cultured at different stocking sizes in cages held in a pond system.

Treatment (g)	b (slope)	a (intercept)	r^2
5	2.2559	0.0805	0.9819
15	2.4329	0.0700	0.9617
25	2.4354	0.0788	0.9792
35	2.1841	0.1581	0.9727
45	2.387	0.8660	0.9777

treatments. The same significant trend ($P = 0.04$) was observed for the growth rate, biomass, production, yield and FCR for the 35-g and 45-g groups, which obtained the higher values. The lower FCR and was observed for the 5-g (1.7 ± 0.1) and 15-g (1.6 ± 0.2) groups. The same stocking density groups exhibited higher survival (80.0 ± 2.5%) at the end of the experiment.

Values for fitting the length–weight equation for each stocking size are presented in Table 3, showing a high correlation ($r^2 > 0.96$) for all groups. The resulting parabolic regressions (Figure 2) indicated that the optimum final weight for maximum growth increased with harvest size and was estimated to be 76 g. For the stocking size and production relationship (Figure 3), we found that the optimum for maximum production increased with stocking sizes up to 35 g and was estimated (mean ± SE) to be 88.7 ± 6.5 g/m^3 ($P = 0.01$). Because space did not increase in a cage, growth ceased when the maximum production reached approximately 88.7 ± 6.5 g/m^3 (or 1,774.0 ± 11.3 kg/ha per year, extrapolating), and final density was 1.4 individuals/m^3 (Table 4).

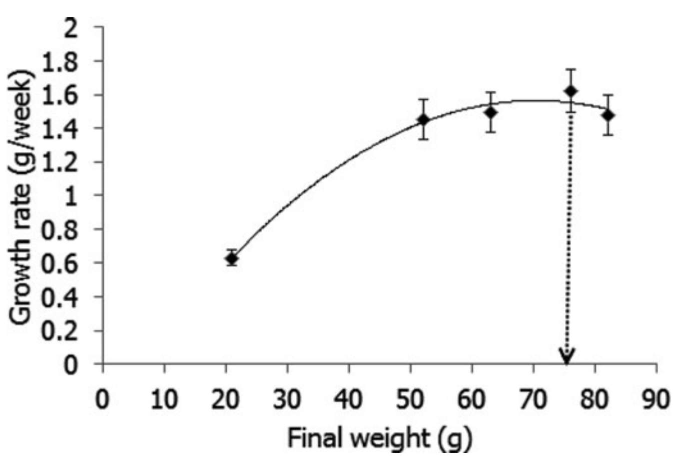

FIGURE 2. Changes in the growth rate (GR) of caridean shrimp cultured cages held within a pond system. The line represents the least-squares second-order polynomial fit to the data: $GR = -0.0004W^2 + 0.0537W - 0.3254$. Error bars = 1 SE; $n = 10$ for each data point.

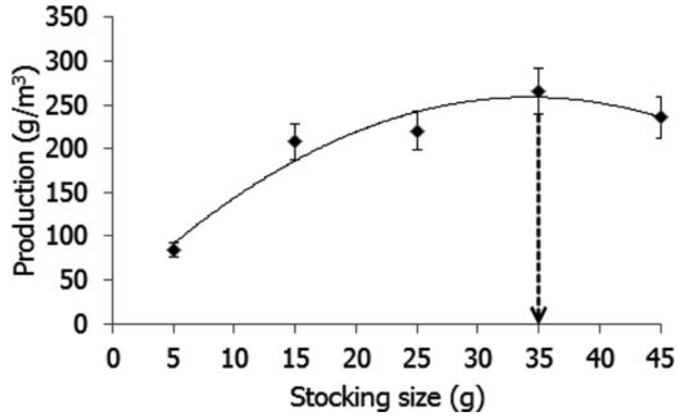

FIGURE 3. Changes in the production (P) due to the different stocking size (SS) of caridean shrimp cultured in a caged-pond system. The line represents the least-squares second-order polynomial fit to the data: $P = -0.1964SS^2 + 13.441SS + 28.918$. Error bars = 1 SE; $n = 10$ for each data point.

DISCUSSION

All the measured variables fell within the recommended range for the cultivation of freshwater prawns (New 2002). The temperature dropped during November December, coinciding with a reduction in the growth rate, probably inducing a decrease in prawn feed intake. Caridean shrimp tolerate a wide range of varying environmental conditions (Ponce-Palafox et al. 2002), but among all the measured environmental variables, only the temperature seemed to have a direct influence on caridian shrimp performance. The water quality was appropriate for the growth rate, biomass, production, yield, and survival achieved in this work.

The results showed that the culture of caridian shrimp in a caged-pond system is a production alternative for this species at the tested stocking size. The daily water exchange was a useful culture tool to improve its growth, even at the limited production surface area, which agrees with several reports for giant river

TABLE 4. Density of caridean shrimp cultured at different stocking sizes in cages held within a pond system. Superscript values were obtained by extrapolating the power equation, adjusting the weight (W) density = 87.992 $W^{-0.998}$; $R^2 = 0.9998$.

Weight (g)	Density (shrimp/m^3)
5	17.7
15	5.9
25	3.5
35	2.5
45	2.0
55	1.6[a]
65	1.4[a]
75	1.2[a]
85	1.0[a]
95	0.9[a]

[a]Densities of <2 shrimp/m^3 were counted as 1 shrimp/m^3, for practical purposes.

prawn *M. rosenbergii* (D'Abramo et al. 2000; Cuvin-Aralar et al. 2007). Most of the studies related to growth for caridian shrimp were performed with postlarvae and early juveniles under laboratory conditions (García-Guerrero and Apun-Molina 2008), adjusting an initial density of 98–196 individuals/m^2 (up to 2.7 g in weight). The mean weight obtained in this work after 120 d of culture (51.0 g) is higher than that obtained by Rojo-Cebreros et al. (2013) for caridian shrimp (41.2 g) in clear-water plastic tanks, with an initial density of 5 individuals/m^2 at 25.3 g stocking size. The growth rate registered for the 5-g group (0.30 mm/d) is similar to that found by Arana-Magallón and Ortega-Salas (2005) for 2-g juveniles (0.36 mm/d) for the same prawn species cultured in laboratory conditions with clear water at 33°C. However, the growth rate is higher than the growth rate of 0.1 mm/d found by Holtschmit (1988). The differences exhibited among these studies can be partially explained by the differences in the culture conditions, such as food, stocking size, and the type of culture system.

Arana-Magallón and Ortega-Salas (2004) found that postlarvae growth of 2–3 g weight was isometric (3.02–3.05); in our study, the allometric growth condition (2.89) was reached with animals from 5 to 85 g, demonstrating that the prawns presented relatively good growth for all stocked sizes. However, when analyzing the relationship per each stocking size, the slope of the length–weight relationship decreased (Table 2), possibly indicating a change in condition caused by a variation in growth rate. The best growth condition was presented in stocking sizes of 15 g and 25 g. By comparing the length growth of caridian shrimp from this work with that reported by Murthy et al. (2013) for giant river prawn, it is possible to conclude that caridean shrimp grow faster (0.33 mm/d) but acquire less weight (0.23 g/d) than the giant river prawn (0.31–0.33 g/d).

The lowest survival (60%) recorded in the 45-g group was due to the smaller space of the cages and greater initial biomass. It is possible that the reduction in survival, growth rate and specific growth rate were attributable to the intensity of competition for food and space, which is a reported characteristic in this species (García-Guerrero and Apun-Molina 2008). It is well known that freshwater prawns of the genus *Macrobrachium* show territorial behavior (New et al. 2000), and at high density storage, even when food is available, growth may be negatively affected due to stress caused by aggressive behavior (Wickins and Lee 2002). The negative effect of crowding on growth rates in crustacean culture systems has been previously reported (D'Abramo et al. 1989, 2000; Ranjeet and Kurup 2002). At high densities, the stress level is higher, causing the prawn to become more sensitive to environmental changes and increasing mortality (Marques et al. 2010). The trend of reduced growth and survival with increasing densities is consistent in this work. Survival generally tends to be high at low densities. We found that the absolute potential growth rate did not increase in direct proportion to the increase in weight of the prawn, rather at a slower rate. This indicates that the relative growth rate, that is, the growth per unit weight, decreases with the increase in the weight of the prawn.

New (1988) reported a FCR of 1.8–3.0 for giant river prawn in pond culture systems. This may be acceptable using dry diets. The FCR of caridian shrimp (1.6–2.2) we found agree with those found by Siddique et al. (1999) in pond culture systems for giant river prawn (1.73–2.12) cultured at low density (1.5 individuals/m^3). The presence of feeders (trays) in cages improved the FCR. In addition, the apparent FCR for prawns was significantly better in the lowest stocking size and had a tendency to increase with increasing stocking size.

Cabrera et al. (1979) found that caridian shrimp showed a growth rate lower than that exhibited by giant river prawn and longarm river prawn *M. tenellum* under laboratory conditions. Arana-Magallón and Ortega-Salas (2005) found that caridian shrimp requires a substrate and a vertical space to increase growth after reaching a weight of 2 g. García-Guerrero and Apun-Molina (2008) suggested that prawn juveniles can be successfully grown in captivity, although lower densities should be used. The density we used was low (1.7 org/m^3); however, the growth rate was influenced by weight, biomass, and production by means of a stocking-size parabolic relationship (Figures 2, 3). The maximum growth rate was obtained at 76 g, and maximum production was found in a stocking size of 35 g; this suggests that culturing can begin with a stocking density of 17.7 org/m^3 of animals weighing 5 g (Table 4) and ultimately reach a density of 1 shrimp/m^3 with individuals weighing 85 g. Nonetheless, according to the market size demand, we recommend an initial stocking size of 25 g for harvesting individuals of 63 g in the culture period of this study (180 d). These results show that caridean shrimp grow best in cages within pond systems rather than indoor synthetic tanks. Most likely, the presence of natural food associated with the periphyton and benthos that developed on the substrate (polyethylene screens), such as the cage wall and bottom, contributed to the improved growth rates (Uddin et al. 2006). Finally, the results suggest that the culture of caridean shrimp caged within pond systems at lower stocking densities during the juvenile–adult phase is feasible.

REFERENCES

APHA (American Public Health Association). 2005. Standard methods for the examination of water and wastewater, 21st edition. APHA, Washington, D.C.

Arana-Magallón, F. 1977. Experiencias sobre el cultivo del langostino *Macrobrachium americanum* Bate, en el noroeste de México. [Experiences on the cultivation of shrimp *Macrobrachium americanum* Bate, in northwest Mexico.]. Pages 139–147 *in* Food and Agriculture Organization of the United Nations (FAO), editor. Actas del simposio sobre acuicultura en America Latina. [Proceedings of the symposium on aquaculture in Latin America.] FAO, FAO-FIR-R159.2, Rome.

Arana-Magallón, F. C., and A. A. Ortega-Salas. 2004. Rearing of the cauque prawn under laboratory conditions. North American Journal of Aquaculture 66:158–161.

Arana-Magallón, F. C., and A. A. Ortega-Salas. 2005. Growth of postlarval *Macrobrachium rosenbergii* at two temperatures. North American Journal of Aquaculture 67:10–12.

Bhujel, R. C. 2008. Statistics for aquaculture. Wiley-Blackwell Scientific Publications, Ames, Iowa.

Cabrera, J. A., C. Chavez, and C. Martınez. 1979. Fecundidad y cultivo de *Macrobrachium tenellum* Smith en el laboratorio. [Fertility and culture *Macrobrachium tenellum* Smith in the laboratory.] Anales del Instituto de Biología de la Universidad Nacional de México 1:127–152.

Cuvin-Aralar, M. L. A., E. V. Aralar, M. Laron, and W. Rosario. 2007. Culture of *Macrobrachium rosenbergii* (De Man 1879) in experimental cages in a freshwater eutrophic lake at different stocking densities. Aquaculture Research 38:288–294.

D'Abramo, L. R., W. H. Daniels, P. D. Gerard, W. H. Jun, and C. G. Summerlim. 2000. Influence of water volume, surface area, and water replacement rate on weight gain of juvenile freshwater prawns, *Macrobrachium rosenbergii*. Aquaculture 182:161–171.

D'Abramo, L. R., J. Heinen, H. Robinette, and J. Collins. 1989. Production of the freshwater prawn *Macrobrachium rosenbergii* stocked as juveniles at different densities in temperature zone ponds. Journal of the World Aquaculture Society 20:81–89.

García-Guerrero, M. 2009. Proximate biochemical variations in eggs of the prawn *Macrobrachium americanum* (Bate 1869) during its embryonic development. Aquaculture Research 40:575–581.

García-Guerrero, M. 2010. Effect of temperature on consumption rate of main yolk components during embryo development of the prawn *Macrobrachium americanum* (Crustacea: Decapoda: Palaemonidae). Journal of the World Aquaculture Society 41:84–92.

García-Guerrero, M., and J. P. Apun-Molina. 2008. Density and shelter influence during adaptation to culture conditions of wild *Macrobrachium americanum* juveniles. North American Journal of Aquaculture 70:343–346.

Holtschmit, K. H. 1988. Manual técnico para el cultivo y engorda del langostino malayo. [Technical manual for Malaysian shrimp growth.] Fideicomiso Fondo Nacional para el Desarrollo Pesquero, Secretaría de Pesca, Talleres Gráficos de la Nación, Mexico City.

Holtschmit, K. H., and E. Pfeiler.1984. Effect of salinity on survival and development of larvae and post-larvae of *Macrobrachium americanum* Bate (Decapoda: Palaemonidae). Crustaceana 46:23–28.

Kensler, C. B., A. Weller De Restori, and J. M. Grande-Vidal. 1974. El desarrollo y cultivo del langostino de río en Michoacán y Guerrero, México. Contribuciones al estudio de las pesquerías de México. [The development and cultivation of giant river prawn in Michoacán and Guerrero, Mexico. Contributions to the study of the fisheries of Mexico.] United Nations Development Programme/Food and Agriculture Organization of the United Nations, Rome.

Marques, H. L. A., J. V. Lombardi, M. Mallasen, H. P. Barros, and M. V. Boock. 2010. Stocking densities in cage rearing of Amazon river prawn (*Macrobrachium amazonicum*) during nursery phases. Aquaculture 307:201–205.

Monaco, G. 1975. Laboratory rearing of larvae of the palaemonid shrimp *Macrobrachium americanum* (Bate). Aquaculture 6:369–375.

Montgomery, D. C. 2012. Design and analysis of experiments, 8th edition. Wiley, New York.

Murthy, H. S., R. Kumarswamy, K. J. Palaksha, H. R. Sujatha, and R. Shankar. 2013. Effect of different types of shelters on survival and growth of giant freshwater prawn, *Macrobrachium rosenbergii*. Journal of Marine Science and Technology 20:153–157.

New, M. B. 1988. Freshwater prawns: status of global aquaculture, 1987. Network of Aquaculture Centers in Asia, Technical Manual 6, Bangkok, Thailand.

New, M. B. 2002. Farming freshwater prawns—a manual for the culture of the giant river prawn (*Macrobrachium rosenbergii*). FAO (Food and Agriculture Organization of the United Nations) Fisheries Technical Paper 428.

New, M. B., L. R. D'Abramo, W. C. Valenti, and S. Singholka. 2000. Sustainability of freshwater prawn culture. Pages 429–434 *in* M. B. New and W. C. Valenti, editors. Freshwater prawn culture: the farming of *Macrobrachium rosenbergii*. Blackwell Scientific Publications, London.

Ponce-Palafox, J. T., F. C. Arana-Magallón, B. H. Cabanillas, and L. H. Esparza. 2002. Bases biológicas y técnicas para el cultivo de los camarones de agua dulce nativos del Pacífico Americano *Macrobrachium tenellum* (Smith 1871) y *M. americanum* (Bate 1968). [Biological and technical bases for cultivating freshwater shrimp native to the American Pacific *Macrobrachium tenellum* (Smith 1871) and *M. americanum* (Bate 1968).] Congreso Iberoamericano Virtual de Acuicultura (CIVA) [online serial] 1:534–546. Available: http://www.revistaaquatic.com/civa2002/coms/pdf/67.pdf. (August 2013).

Ranjeet, K., and B. M. Kurup. 2002. Heterogeneous individual growth of *Macrobrachium rosenbergii* male morpho-types. Naga 25(2): 13–18.

Rojo-Cebreros, Á., M. García-Guerrero, P. Molina, and A. Miranda. 2013. A preliminary assay on the mixed culture of red Florida tilapia and freshwater prawn *Macrobrachium americanum* stocked in outdoor tanks at different tilapia densities. Agricultural Sciences 4:345–352.

Siddique, M. A. L., M. A. Hossain, and M. A. H. Miaje. 1999. Polyculture of giant freshwater prawn, *Macrobrachium rosenbergii* with Indian major carps in ponds with supplemental feed. Bangladesh Journal of Fisheries Research 22:67–74.

Smitherman, R. O., D. D. Moss, and E. L. Diaz. 1974. Observations on the biology of *Macrobrachium americanum* from a pond environment in Panama. Proceedings of the World Mariculture Society 5:29–40.

Uddin, M. S., M. E. Azim, M. A. Wahab, and M. C. J. Verdegem. 2006. The potential of mixed culture of genetically improved farmed tilapia (GIFT, *Oreochromis niloticus*) and freshwater giant prawn (*Macrobrachium rosenbergii*) in periphyton-based systems. Aquaculture Research 37:241–247.

Wickins, J. F., and D. O. Lee. 2002. Crustacean farming: ranching and culture, 2nd edition. Blackwell Scientific Publications, Oxford, UK.