

Growout of Pacific White Shrimp, *Litopenaeus vannamei*, Stocked into Production Ponds at Three Different Ages

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Abstract

This study was designed to determine the production characteristics of the Pacific white shrimp, *Litopenaeus vannamei*, stocked into grow-out ponds at three different sizes and ages. To meet this goal, three groups of postlarvae (PL) were obtained. The first group was placed in a nursery system for 21 d (N21), the second for 14 d (N14), and the third was stocked directly into ponds (DS). Shrimp from each nursery treatment (three tanks per treatment) were pooled and then subdivided for stocking into four replicate 0.1 ha ponds per treatment, another four ponds were stocked directly (DS) with PL₈. All 12 ponds were stocked on the same day at a density of approximately 35 PL/m², and cultured over a 16-wk period and then drain harvested. After harvest, mean average weights (15.4, 16.9, and 14.9 g), survivals (63, 62, and 64%), FCRs (2.7, 2.5, and 2.7), and average yields (3592, 4005, and 3374 kg/ha) were determined for N21, N14, and DS, respectively. No significant ($P > 0.05$) differences were observed among treatments. Regardless of nursing time, nursed juveniles did not differ significantly in production characteristics from shrimp stocked directly from the hatchery.

In the southern USA, the culture period for shrimp is limited to the warm season, which typically is 6–8 mo under good conditions (Sandifer et al. 1988, Hopkins 1992). Because no areas of the continental USA (between 25° N and 45° N latitude) have adequate temperatures for year-round, outdoor production (i.e., multiple-crop shrimp production) is limited by the growing season. This is particularly true when using direct stocking techniques as the growing season is too short for two crops to be economical (Griffin et al. 1981; Clifford 1985; Sadeh et al. 1986). The inclusion of an early indoor nursery phase has been considered a possible way to extend the growing season (Lawrence et al. 1985; Sturmer and Lawrence 1987; Sandifer et al. 1988). This could add 1 or 2 mo for the first crop and might increase the potential for production of two crops per year. Even if only one crop is targeted, stocking a large shrimp is felt to improve survival and the accuracy of stocking, as larger shrimp are more hardy and easier to quantify. Nursery systems have also been suggested as a critical component of biosecurity systems to minimize the risk

of disease introduction (Samocha et al. 2000; Fegan and Clifford 2001). They are also a critical component of low-salinity culture systems for which postlarvae (PL) need to be acclimate to the low-salinity conditions (McGraw et al. 2002).

Current indoor nursery practices typically involve the use of greenhouse structures and tanks or raceways. PL stocking densities vary between 2/L and 70/L, with survival ranging from 41–100%, depending on age, size, and culture period (Samocha and Lawrence 1992; Stern and Lettelier 1992; Sturmer et al. 1992). Feeding protocols typically start with newly hatched *Artemia nauplii*, followed by high protein (45–50%) prepared diets (Fegan 1992). Specific algal blooms (preferably diatoms) are enhanced by fertilization and inoculation to increase natural productivity for optimal growth and water quality stabilization (Krom et al. 1985; Sturmer et al. 1992). An indoor nursery phase requires a greater initial investment, operational costs, and skilled labor. These additional costs can be justified if the nursery system increases yields or market value of the final product (Samocha and Lawrence 1992).

Although there are many suggested advantages of shrimp nurseries, there is little documented

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information on the effects of various nursery periods on final grow-out performance of shrimp under standardized conditions. Consequently, the objective of this study was to investigate the effects of PL age or nursery duration on final pond production. The hypothesis was that a longer nursery period produces larger older PL that would provide an advantage to shrimp performance during the grow-out phase.

Materials and Methods

This study was designed to determine the production characteristics of the Pacific white shrimp, *Litopenaeus vannamei*, stocked into replicated grow-out ponds at three different sizes and ages. The study was conducted at the Claude Peteet Mariculture Center, in Gulf Shores, Alabama, USA. Three groups of *L. vannamei* PL (8–9 d old) were obtained from GMSB, Inc. (Key West, FL, USA) on April 9, 16, and 29. The PL were in good health and active. The first two groups were stocked at densities of 34 PL/L and 31 PL/L into replicate indoor tanks and nursed for 21 (N21) and 14 (N14) d, respectively. The third group was received, acclimated, and stocked directly into ponds (DS) at the same time the nursery treatments were stocked into ponds. In this way, the three groups (DS, N14, and N21) could be put into growout on the same day to face similar pond conditions to allow evaluation of possible benefits of nursing. Upon receipt of the PL, the three batches used for DS, N14, and N21 treatments had similar initial mean weights (1.23, 0.96, and 1.36 mg), standard deviations (0.72, 0.41, and 0.59 mg), and CV (58.5, 42.7, and 43.4%), respectively.

Nursery

A more complete description of the nursery system and acclimation procedures are given by Zelaya (2005). Upon receipt of the PL, they were visually inspected and acclimated to the culture conditions. The PL were then volumetrically quantified, which allowed verification of quantity supplied and an accurate distribution of PL among nursery treatment tanks and ponds (Hardin et al. 1985; Juarez et al. 1996). The CV

of all counts were below 10% and considered acceptable population estimates for management decisions (Juarez et al. 1996).

The nursery phase was conducted in a semi-closed recirculation system containing six fiberglass culture tanks ($3.0 \times 1.5 \times 0.9$ m), biological filter, rapid-rate sand filter, aeration, and circulation pump located inside a clear, polyethylene plastic, quonset-style greenhouse. A week prior to reception of each PL shipment, tanks were filled with prefiltered ($150 \mu\text{m}$) full strength seawater and then disinfected by chlorination (~ 10 ppm). One day prior to PL stocking, tanks were seeded with the diatom *Thalassiosira weissflogii* (Reed Mariculture Inc., San Jose, CA, USA). A week after inoculation, algal counts were around 50,000–60,000 cells/mL. Four feedings were scheduled each day. During the first 3 d, PL were offered PL Redi-Reserve ($400\text{--}600 \mu\text{m}$) 50% protein diet (Zeigler, Gardners, PA, USA) and brine shrimp (52% protein, $200\text{--}300 \mu\text{m}$) at a rate of 100 *Artemia*/PL/d (INVE Americas, Inc., Salt Lake City, UT, USA). Thereafter, PL were given a combination of diets with increasing particle size as the shrimp grew. The diets were a 45% protein commercial shrimp starter feeds: #0 (<0.6 mm), #1 ($0.6\text{--}1.0$ mm), and #3 ($1.4\text{--}1.7$ mm) (Rangen Inc., Buhl, ID, USA). Random PL-samples ($n > 40$) were taken upon reception of PL and from nursery tanks every 3 d and at the conclusion of the nursery trial. Excess water was eliminated by collecting PL with a strainer, depositing them on an absorbent paper cloth and then weighing individually (0.1 mg) on an analytical scale Model ER-182A (A&D Co., Milpitas, CA, USA). Feeding adjustments were made based on biomass determinations, starting with 50%, of the estimated biomass and gradually reduced to 15% of the estimated biomass for the last offering (Zelaya 2005). Before harvest, juveniles were acclimated from a salinity of 31 to 19 ppt over a 96-h period, then concentrated and quantified gravimetrically. At the conclusion of the nursery phase, data for final average weights, survivals, FCR, biomass loading, and CV for individual weights were determined.

Pond Production Phase

Juveniles from each of the two nursed treatments were pooled, divided, and stocked into four 0.1-ha production ponds for each treatment. PL for the third treatment (DS) were received from the hatchery as PL₈, acclimated, quantified, and stocked directly into production ponds. All 12 ponds were stocked on the same day, at a density of 35 PL/m², cultured for 16 wk, and then harvested. Ponds used for the grow-out phase were approximately 0.1 ha in surface area, rectangular (46 × 20 m), equipped with a 20-cm-diameter standpipe, a concrete catch basin (3.7 × 1.82 × 0.45 m), and lined with 1.52-mm-thick, high-density polyethylene sheeting (Grundle Lining System, Inc., Houston, TX, USA). The sloped pond bottoms were covered with a 25-cm-deep layer of sandy-loam soil. Pond depths averaged 1.0 m. Pond soils were dried for over 2 wk and tilled (10–15 cm) with a rotary tiller prior to filling to allow oxidation and mineralization of organic matter.

Three weeks prior to stocking, the ponds were filled with water from the Intracostal Canal between Mobile and Perdido Bay. Fill water was filtered through a nylon filter sock (Domestic Lace Mfg., Inc., Style 8845230) to prevent the introduction of large predators and minimize the introduction of larval fish and crabs, while allowing the introduction of small plankton. Two weeks before stocking, all ponds were fertilized with liquid inorganic fertilizers (10-34-0 and 32-0-0), applied at a ratio of 1:2 (N : P₂O₅), at 4 kg/ha N (Boyd and Tucker 1998). A mixture of 1.68 L (10-34-0) and 402 mL (32-0-0) and pond water was prepared in a 208-L container, then slowly dripped into the pond, while operating a paddlewheel aerator during a sunny day. Fertilization was used to maintain a minimum Secchi disk reading in the range of 25–40 cm. Depending on individual pond response to fertilization, a second application at half the initial rate was added 2 wk after the first application. Twenty-four hours before stocking, a 1:15 motor oil and diesel fuel mixture at a rate of around 9 L/ha, was applied evenly over each pond surface to reduce the number of air-breathing insects.

Each pond was equipped with a 1-hp spiral paddlewheel aerator (Little John Aerator, Southern Machine Welding Inc., Quinton, AL, USA) representing aeration capacity of 10 hp/ha. In emergency situations, an additional 1-hp propeller aspirator aerator (Aire-O2, Aeration Industries International, Inc. Minneapolis, MN, USA) was utilized to maintain dissolved oxygen (DO) levels. When required, aerators were operated 8 h during the night to maintain oxygen concentrations above 3 mg/L. DO, salinity, and pH were monitored with a YSI 556 meter (Yellow Springs Instrument Co., Yellow Springs, OH, USA) twice a day, at sunrise (~0500 h) and after dark (~1900 h). Weekly water samples were taken in all ponds early in the morning with an 80-cm water column sampler (Boyd and Tucker 1992) and analyzed for total ammonia nitrogen (TAN) using a spectrophotometer (Spectronic 20 Genesys, Spectronic Instrument Inc., Rochester, NY, USA) and the Nesslerization method (APHA 1989). Secchi disk visibility readings were taken once a week. Results of water quality determinations were averaged over time for each pond. Water was added to the ponds only to replace evaporation. During the last 2 wk of culture, water was exchanged for three consecutive days replacing approximately 22% of pond volume.

Shrimp were fed twice daily (~800 and 1600 h) with a 35% protein, pelleted diet (Burris Mill & Feed, Inc., Franklinton, LA, USA). For the first 2 wk of the grow-out phase, ponds were fed at a rate of 8 kg/ha. Beginning

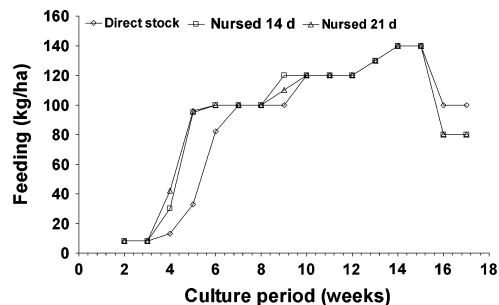


FIGURE 1. Feeding inputs (kg/ha/d) for ponds containing *Litopenaeus vannamei* stocked at 35 PL/m² for 16 wk after either a 21-d nursery period, 14-d nursery period, or directly stocked as PL₈.

the third week, feeding rates were based on 15% of the estimated biomass and then gradually reduced each week as the shrimp biomass increased (Fig. 1). Diet adjustments were made weekly based on estimated shrimp biomass as well as observations from feed trays. Biomass was estimated based on the number of shrimp stocked, weekly sample weight, and an assumed mortality of 30% over 16 wk. Because of warm water temperatures and higher standing crops, diet inputs were reduced during the past 2 wk of culture. Feeding ceased 2 d prior to harvest.

To obtain growth estimates and assess shrimp health, they were sampled on a weekly basis initially using a seine and then a monofilament cast net. Weekly assessments included visual observation of appearance and average weight. Sampling was conducted in the early morning hours to reduce stress. Shrimp were harvested after 16 wk of culture by draining two thirds of the water from each pond the night before harvest. Nightly aeration was provided prior to harvest using paddlewheel aerators. At harvest, ponds were drained with the last portion of the water pumped through a hydraulic fish pump with a 25-cm suction pump (Aqualife-Life Pump, Magic Valley Heli-arc and Mfg., Twin Falls, ID, USA). The pump was placed in the catch basin and shrimp were pumped out of the pond and dewatered as they were moved to the harvest truck. Shrimp were then transported to a wet lab to be washed and weighed. During weighing, a random sample of 100 shrimp was collected from each pond and weighed individually to determine a final mean weight, CV for individual weights, and size distribution. Average number of shrimp per unit weight was also determined for each pond to calculate the number of shrimp harvested from the total yield and estimate survival.

Statistical Analysis

Data was analyzed by a one-way ANOVA using SAS version 8.2 (SAS Institute Inc., Cary, NC, USA). Student-Newman-Keuls multiple comparison test was used to determine significant ($P < 0.05$) differences among treatment means.

Results

Nursery Phase

After 14 and 21 d of nursery phase, mean average weight of juveniles were 10.5 and 16.4 mg/PL, CV were 53.6 and 70.8%, survivals were 94.7 and 91.2%, FCRs were 1.6 and 1.5, and biomass loadings were 0.4 and 0.8 kg/m³, respectively (Table 1). It should be noted that one of the replicate tanks from the N21 treatment was excluded from statistical analyses as it was identified as an outlier. In this tank, the PL ended with an average mean weight of 35.9 mg, the survival was 68.5%, and the CV of the individual weights was 137.61%. All of these results varied by more than 50% from other replicates in the treatment. With the exception of biomass loading, no significant differences among treatments were found for final mean weight, FCR, survival, or CV for individual weight.

The nursery system water temperatures averaged 25.0 ± 2.6 C for early morning and 25.5 ± 2.7 C for late evening hours. Minimum

TABLE 1. Production characteristics of *Litopenaeus vannamei* nursed for 21 and 14 d at 31–34 PL/L as well as the production of nursed and DS PL reared in production ponds over a 16-wk period.^a

	Nursery period (d)			<i>P</i> > <i>F</i>
	21	14	DS ^a	
Nursery phase				
Final average weight (mg)	16.4	10.5	1.23	0.1380
CV (%) of weights	70.8	53.8	58.5	0.0540
Survival (%)	91.2	94.7	–	0.6280
FCR	1.5	1.6	–	0.7190
Final biomass (kg/m ³)	2.67 ^b	1.42 ^a	–	0.0110
Grow-out phase (16 wk)				
Final average weight (g)	15.4	16.9	15.0	0.6800
CV (%) of weights	17.3	16.8	18.2	0.6010
Survival (%)	62.9	63.2	64.0	0.9290
FCR	2.7	2.5	2.7	0.6800
Yields (kg/ha)	3592	4005	3374	0.3550

DS = direct stocked.

^a Means not sharing a common superscript within a row are significantly different ($P < 0.05$).

DO was near saturation (7.0 mg/L) and maximum readings (8.8 mg/L) were likely related to photosynthetic activity of algae, which developed in the tanks. Salinity through most of the nursery period was around 31 ppt, then during the last 3 d through a gradual acclimation, the salinity was reduced to 19 ppt to match that of grow-out ponds. The pH generally fluctuated between 7 and 8. All tanks followed similar TAN dynamics, consistent with the water treatment schedule. Overall TAN concentration means were 1.32 and 1.47 mg/L for N21 and N14, respectively. With the exception of the initial low water temperatures (21–23 C) during the first 7 d of the nursery trial, all DO, salinities, pH, and TAN values were within recommended ranges for *L. vannamei* culture (Hanson and Goodwin 1977; Boyd 1989; Brock and Main 1994).

Grow-Out Phase

Average weights at pond stocking of nursed PL were 1.23 mg for the direct stocked treatment (DS), 10.5 mg for PL that were nursed for 14 d (N14), and 16.4 mg for those that were nursed for 21 d (N21). Weekly averages of shrimp weights are presented in Figure 2. After 16 wk of pond culture, the mean average weights of the shrimp at harvest were 15.4, 16.9, and 14.9 g; survivals were 63, 62, and 64%; FCR were 2.7, 2.5, and 2.7; and average yields were 3592, 4005, and 3374 kg/ha for N21, N14, and DS treatments, respectively

(Table 1). Although no significant differences were found among treatment means, greater observed yields occurred in the N14 treatment than in the other two treatments. Total shrimp production, as distributed across typical shrimp size classes, is presented in Figure 3.

Water quality analysis from the grow-out phase is summarized in Table 2 and is typical for coastal production ponds. Pond water pH, temperature, and DO readings were recorded in the early mornings (AM) and late evenings (PM). Overall, average pH readings for the AM was 7.5, while a pH of 8.0 was recorded in the PM. For the three treatments, overall average AM DO readings were 4.0 mg/L with the lowest readings in the range of 1.9–2.3 mg/L, while PM DO readings were 6 mg/L with the lowest readings in the range of 2–2.6 mg/L. In general, AM readings became lower as the cycle progressed and the standing crop increased. Also, warmer early morning water temperatures (30–31 C) occurred from the 12th wk on, with even higher temperatures in the afternoon hours. Average AM and PM pond temperatures were 28.5 ± 2.5 C and 29.8 ± 2.7 C, respectively (Table 2). In general, the temperature trend through the production cycle started with temperatures around 27.5 C, dropped to 23 C because of a cold front during the third and fourth wk, and then increased to a range of 28–30 C (Fig. 2).

For all three treatments, average TAN values were below 1 mg/L until the eighth wk of the culture period. TAN concentrations fluctuated and reached highest concentrations at different times in different ponds. The typical cycle was a high concentration during an algae die-off, followed by reductions in TAN during the following 3–4 d as new algae blooms developed. The highest TAN concentrations were 6.18, 3.12, and 2.93 mg/L for N21, N14, and DS treatments, respectively. This occurred while pH was in the range of 7.27–7.58 and temperature was 29.1–31.8 C. The decimal fraction of unionized ammonia was 0.020–0.031 or concentrations of 0.16, 0.10, and 0.16 mg/L $\text{NH}_3\text{-N}$ (Boyd and Tucker 1998) with a decreasing trend on the following days. These concentrations were still within a suitable range for shrimp culture according to Chen and Chin (1988),

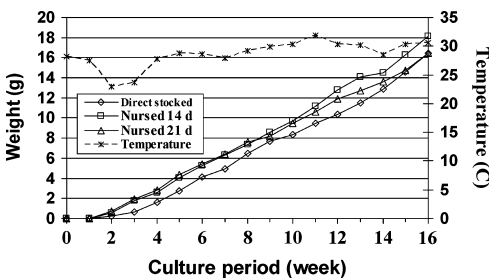


FIGURE 2. Average weekly pond temperatures (dashed line) and mean weight of *Litopenaeus vannamei* obtained from weekly cast net samples from ponds stocked at a density of 35 shrimp/m² for 16 wk after either a 21-d nursery period, a 14-d nursery period, or directly stocked as PLs.

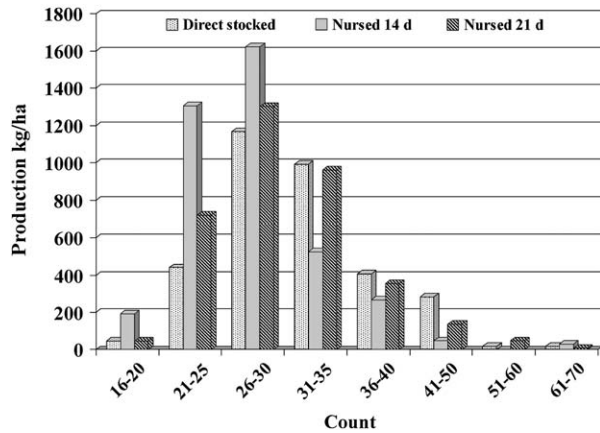


FIGURE 3. Total shrimp production distributed across typical shrimp size classes at the conclusion of 16 wk of pond culture. Grow-out ponds were stocked at 35 shrimp/m² with *Litopenaeus vannamei* juveniles previously nursed for either a 21-d nursery period, 14-d nursery period, or directly stocked as PL₈.

who found toxic levels at 0.81 mg/L of unionized ammonia. Bray and Lawrence (1992) not only considered 1.29 mg/L NH₃-N toxic values (48-h LC₅₀) but also considered concentrations of 0.1 mg/L NH₃-N as maximum acceptable levels for culture.

Discussion

There are a number of suggested advantages of shrimp nurseries; yet, there is little documented information on the effects of various nursery periods on final grow-out performance of shrimp under standardized conditions. For this research, three groups of shrimp were obtained from the same hatchery and either nursed (N21 and N14) or direct stocked into production ponds. Upon receipt of the PL, they had similar

initial mean weights (0.96–1.36 mg) and were all in good health.

When comparing final production numbers for the nursery periods of 14 and 21 d (Table 1), both nursery treatments had good survivals (>90%). These results are better than typical results at this site, which has an average survival of 61.5% (averaged over five different nursery trials) as well as reports from other intensive nurseries studies (Sturmer and Lawrence 1987) and similar to results reported by Sturmer et al. (1992). Feed conversion ratios for shrimp maintained in the nursery were good and similar to values typically obtained at this facility. Observed values for final average weight suggested treatment effects, but differences were not significant. The lack of significance is presumably

TABLE 2. Mean water quality parameters over a 16-wk grow-out period for *Litopenaeus vannamei* stocked at 35 shrimp/m² and nursed for 21 (N21), 14 (N14) d at 31–34 PL/L, or DS.

	N21	N14	DS
Morning pH	7.5 ± 0.09 (8.4, 6.9)	7.4 ± 0.3 (8.2, 7.0)	7.5 ± 0.3 (8.4, 7.0)
Night pH	8.1 ± 0.5 (9.3, 7.1)	8.2 ± 0.5 (9.2, 7.2)	8.2 ± 0.5 (9.1, 7.1)
Salinity (ppt)	21.9 ± 2.5 (24.5, 17.3)	22.1 ± 2.7 (25.4, 17.3)	21.5 ± 2.4 (24.9, 17.2)
TAN (mg/L)	1.05 ± 1.61 (6.18, 0.0)	0.74 ± 0.87 (3.12, 0.0)	0.63 ± 0.88 (2.93, 0.0)
Secchi (cm)	32 ± 12 (56, 20)	28 ± 7 (41, 20)	30 ± 8 (48, 20)
Morning DO (mg/L)	4.6 ± 1.02 (8.4, 2.3)	4.3 ± 1.08 (8.5, 1.9)	4.6 ± 1.08 (7.9, 2.2)
Night DO (mg/L)	6.1 ± 2.41 (13.6, 2.3)	6.4 ± 2.73 (14.4, 2.0)	6.4 ± 2.55 (13.8, 2.6)
Morning temperature (C)	28.5 ± 2.5 (32.6, 19.0)	28.5 ± 2.5 (32.5, 19.0)	28.4 ± 2.5 (32.4, 19.0)
Night temperature (C)	29.8 ± 2.7 (34.5, 21.1)	29.8 ± 2.7 (34.6, 21.1)	29.8 ± 2.7 (34.5, 21.1)

TAN = total ammonia nitrogen; DO = dissolved oxygen; DS = direct stocked. Values represent mean ± SD with minimum and maximum values in parentheses.

because of low temperatures (~ 21.7 C) during the first 6 d of the nursery phase for the N21 treatment. The initial lower temperatures would have reduced metabolism and diet intake of the shrimp (Lester and Pante 1992), consequently slowing growth during the first wk, which would have limited the average weight differences between the two treatments at the end of the nursery phase. Despite less than optimal temperatures during the first wk of the nursery phases, final weights of the PL nursed for 21 d were 156% larger than those nursed for 14 d.

A key aspect of PL quality is the level of variation of the size in the population (Wyban and Sweeney 1991; Fegan 1992; Brock and Main 1994). Contrary to Garza et al. (2004) and Wyban and Sweeney (1991), who reported that the CV of individual weights of a healthy population declined during the nursery phase, results of the present study indicate an increase in the variability of the PL individual weights at the conclusion of the nursery phase. However, after pond growout, the variation decreased for both the nursed and DS treatments. For both nursery treatments, the CV for initial weights prior to the nursery period was high as a CV greater than 30% is considered excessive (Wyban and Sweeney 1991; Brock and Main 1994). Uniformity did not improve in either of the nursery treatments. Similar to the nursery treatments, the DS treatment PL had an initial CV that also was high (CV = 58.5%). Yet, the CV of final weights did not differ significantly between treatments at the conclusion of the pond growout. This suggests that regardless of PL age at stocking, a reduction (and thus an improvement) in size variation takes place during the grow-out phase. The lack of an improved CV during the nursery phase was probably not related to differences in hatchery groups. Initial size variation from the hatchery were similar for all three groups, and there was no significant difference in size variation at the end of the pond growout phase. After the pond grow-out phase, individual weight variation in all treatments fell within normal ranges of 10–20% (Brock and Main 1994). Improvements in the variation of weights during the pond grow-out phase may be related to the abundance and variety of natu-

ral food (Fegan 1992; Moss et al. 1992; Moss 1995). This same trend was observed in previous pond production trials conducted at this facility (Zelaya 2005).

At the conclusion of the pond growout, overall production characteristics of the nursed juveniles did not differ significantly from shrimp stocked directly from the hatchery. Although final production was similar, weights of the DS treatments were lower than those of the other treatment for most of the culture period (Fig. 2). Overall, these results are similar to those reported by Garza et al. (2004) who evaluated a single batch of shrimp that were either directly stocked into ponds or nursed for 10 or 20 d and then transferred into ponds. They reported no statistical differences in survival, yield, or growth between nursed and nonnursed shrimp. In the present study, PL that were provided a head start when pond water temperatures were too cold to stock were larger for most of the production season than those that were directly stocked once the ponds warmed up to an appropriate temperature. Garza et al. (2004), who received one batch of PL (when pond temperatures were adequate), found that the growth rates were higher in the ponds (as would be expected), and hence, these shrimp tended to be larger. Hence, in both cases, the shrimp appeared to perform slightly better under the more favorable environmental conditions.

In addition to growth, size uniformity is a critical issue when marketing shrimp. The CV of individual weights were not significantly different among treatments (Table 1, Fig. 3). It is important to consider the graphical pattern of size distributions (Fig. 3) and the amount of variation in the size of individual shrimp. For all three treatments, the predominant count size was 26–30 (average size of 16 g). However, this count size accounted for 41.5, 36.3, and 34.8% for N14, N21, and DS treatments, respectively. Count sizes that accounted for more than 1% of the population included six for N14 and DS and seven for N21. When considering the percentage of the population within the 26–30 counts and above, 77.75, 49.75, and 55.75% were determined for N14, N21, and DS but no significant differences among treatments were

found. Based on these observed results, the N14 treatment had better uniformity and size distribution at the end of the grow-out period, which was consistent and possibly related to results obtained during the nursery phase; however, statistical evidence is limited.

In temperate regions, implementing nurseries for head starting could be useful if PL availability is limited later in the season or if there is a possibility of two production cycles within the warmer period (Lawrence et al. 1985; Sturmer and Lawrence 1987; Sandifer et al. 1988). Wang and Leiman (2000) suggest using a two-stage production system consisting of a prolonged nursery stage followed by a grow-out stage. One study (Juan et al. 1988) indicated that direct stocking of grow-out ponds with PL and producing one crop per year is more profitable than stocking 1 g juveniles and producing two crops per year. If only one production cycle is available, PL supply is guaranteed from a hatchery, and there are no biosecurity issues; results of this study indicate that a nursery phase may not be justified. Instead it would be convenient to direct stock as pond temperatures reach safe levels and the production cycle could end as autumn temperatures drop. Shrimp (<1 g) grow faster in warm water (Lester and Pante 1992), while medium (12 g) and large shrimp (18 g) are not affected by lower temperatures (23–27 C; Sadeh et al. 1986; Wyban and Sweeney 1991).

If diseases are present, nurseries are justified for biosecurity reasons. Viral diseases have been the greatest cause of losses at commercial shrimp farms in many countries (Lightner 1992, 1996; Flegel 1997; Alday de Graindorge and Flegel 1999). Farms have been advised to minimize the risk of disease impact (Sturmer et al. 1992; Fegan and Clifford 2001) by nursing shrimp in disease-free environments (nurseries) and then stocking grow-out ponds with larger and older juveniles that might have better developed defense systems and therefore are more resistant to biological and abiotic threats (Villalon 1991; Prayinto and Latchford 1995), thus allowing higher survival rates to be more achievable (Samocha et al. 2000).

The decision to utilize or not utilize a nursery system should be based on a wide variety of

factors that are farm specific. The use of a nursery may be justified to help with overall management of the farm and is not necessarily related to improved production during growout (e.g., need to stock a larger PL because of low-salinity conditions). Hence, for a variety of reasons, nurseries may be warranted. However, in terms of effects on pond production, the results of this research demonstrate that there was no advantage to stocking a shrimp that was nursed for 21 d over one that was direct stocked into well-prepared production ponds.

Acknowledgments

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