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The effects of size grading and length of nursery period on growth and population structure of freshwater prawns stocked in temperate zone ponds with added substrates

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Abstract

In temperate regions, the relatively short growing season increases the need for development of technologies to maximize growth and production rates for freshwater prawns. Studies have shown that new technologies, such as adding artificial substrates, increasing feeding rates, using advanced nursed juveniles, and grading of juveniles prior to stocking, can increase production without sacrificing average weights. While these technologies have been evaluated in isolation, it may be possible to further increase production by combining these technologies. This study evaluated the impacts of size grading of nursed juveniles prior to pond stocking and the effects of extending the nursery period (from 61 to 133 days) when combined with added substrate in temperate ponds. Three treatments were evaluated: 61-day ungraded juveniles (current regional technology; controls), 61-day graded juveniles, and 133-day graded juveniles. Individual mean stocking weights for the three treatments were 0.67, 0.72, and 3.1 g, respectively. All ponds were stocked at 59,280 ha^{-1} and were provided with artificial substrate in the form of polyethylene "safety fence" oriented vertically at a rate sufficient to increase available surface area in the ponds by 50%. Compared to control ponds (61-day ungraded), grading of 61-day juveniles significantly increased ($P<0.05$) total production (2549 and 2945 kg ha^{-1}, respectively), production/size index (PSI), and daily yield. Extending the nursery period (and thereby increasing the average stocking weight) did not significantly improve ($P>0.05$) total production or average individual weight. Feed conversion ratios were significantly higher for 133-day juveniles compared to controls (2.8 vs. 2.3). The failure of animals weighing over 350% more at stocking to increase average weights or

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total production at harvest appears to be due to earlier sexual maturation and the resulting cessation of growth.

Keywords: Freshwater prawn; *Macrobrachium rosenbergii*; Size grading; Substrate

1. Introduction

Worldwide production of the freshwater prawn, *Macrobrachium rosenbergii*, increased 636% between 1989 and 1998 while its value increased 957% during the same period (New, 2000). This is at least partially due to several biological characteristics which are positive attributes for their aquaculture production. Freshwater prawns do not appear to be susceptible to most of the viral diseases which have impacted marine (penaeid) shrimp production (Wang et al., 1998). Also, being freshwater, they can be produced in inland locations in closer proximity to large urban markets. Freshwater prawns produce large individual sizes which can command high prices in the market. In addition, prawn production tends to be more environmentally sustainable. This is largely due to their more territorial nature, which limits the biomass densities in growout ponds compared to penaeid species (New, 2000). However, these lower production levels have also been a major constraint on their commercial development compared to several penaeid species. Prawns also tend to have greater size variation at harvest, which can negatively impact marketing. This size variation is largely due to heterogeneous individual growth (HIG) caused by aggressive interactions among different morphotypes, especially males (Karplus et al., 1986a; Daniels et al., 1995). To increase the commercial viability of prawn production, it is important that production rates be increased, large average sizes maintained, and the magnitude of size variability decreased, without sacrificing environmental sustainability.

Several methodologies and technologies can be used to intensify freshwater prawn production. Tidwell et al. (1996) found that temperate water temperatures actually increased production rates due to delayed sexual maturation. Prawn production rates can also be increased by increasing the average stocking size. D'Abramo et al. (1991) reported that when stocked at 40,000 ha^{-1}, production was increased by 29% by stocking animals weighing 0.75 g compared to stocking 0.17 g. Increasing pond stocking rates will also increase production; however, this results in decreases in average individual harvest weights (D'Abramo et al., 1989), negatively impacting marketability. Tidwell et al. (1998) reported that higher stocking densities could be used and higher production rates achieved, while maintaining large average sizes, if artificial substrates were added to ponds. Size grading of juveniles prior to pond stocking has also been shown to significantly increase production without negatively impacting harvest sizes (Daniels and D'Abramo, 1994). Grading appears to disrupt the development of the aggressive interactions within the population, which allows dominant animals (especially males) to suppress the growth of subdominates, decreasing total production and increasing individual size variation (Karplus et al., 1986b). Tidwell and D'Abramo (2000) proposed that combinations of recent management techniques should be evaluated to determine if effects were additive so that best management practices could begin to be developed for freshwater prawn culture. This study was designed to evaluate the potential impacts of using advanced stocker sizes, and the size grading of juveniles, when combined with added substrate and increased stocking densities.

2. Materials and methods

2.1. Pond preparation and stocking

Two weeks prior to the anticipated stocking date, nine ponds located at the Aquaculture Research Center (ARC), Kentucky State University, Frankfort, KY, USA were drained and allowed to dry. Less than 1 week prior to stocking, ponds were filled with water from a reservoir filled by runoff from the surrounding watershed. The water-surface area of each experimental pond was 0.04 ha and average water depth was approximately 1.1 m. A 1/2-hp vertical pump surface aerator (Airolator, Kansas City, MO, USA), modified with a "deep-draw" tube, operated continuously at the surface of the deepest area of each pond to aerate and prevent stratification. Two applications of liquid fertilizer (NPK, 10:34:0) were added to each pond 1 week apart, at a rate of 9.0 kg phosphorous ha^{-1}, to achieve an algal bloom. Water to replace evaporative losses was obtained from the reservoir.

Postlarval prawns (PL) were shipped by air from a commercial hatchery (Aquaculture of Texas, Weatherford, TX, USA), and nursed in a greenhouse at ARC for 61 or 133 days (according to treatment). The PL to be nursed for 133 days were received on January 24, 2000. For the first 57 days, these prawns were stocked in 3420-l tanks at 215, 430, or 865 m^{-2} of substrate (2.9, 5.9, and 11.1 l^{-1}) in a nursery density study. At the completion of that study, juveniles from the treatments were pooled and restocked into 3420-l tanks at a relatively low density (108 m^{-2}; 1.3 l^{-1}) for the remaining 76 days to achieve large juvenile sizes prior to pond stocking. The PL to be nursed for 61 days were received on April 5, 2000. These prawns were stocked into 3420-l tanks at 430 m^{-2} of substrate (5.9 l^{-1}). During the entire nursery period, water temperatures were maintained at 27–28 °C. At the end of the nursery period, there were no sexually mature morphotypes in either the 61- or 133-day populations.

Prior to pond stocking, juveniles from the two populations (61- and 133-day juveniles) were moved into separate holding tanks which were provided with artificial substrate and a constant flow of pond water. Animals that had been nursed for 61 days (currently recommended period) were then separated into two groups. One group was not graded (controls) and retained the original size distribution which had developed during the nursery period. This is the current technology used in the region. The other group of 61-day juveniles was passively graded using a #13 bar grader (0.5 cm spacing). Those which were retained by the grader (the upper grade) were used as the "graded" treatment (approximately 50% of the original population was retained). The 133-day juveniles were passively graded using a #19 bar grader (0.75 cm spacing). The group retained by the #19 grader was then passively graded using a #34 bar grader (1.35 cm spacing) to remove the largest size fraction. Only animals which were retained by a #19 and passed through the

#34 grader were used in stocking. This procedure selected approximately 50% of the original population, removing those animals at the lower and upper end of the original individual size distribution.

The mean stocking weight for each of the three treatments was determined from a sample of 100 prawns from each population. Juveniles were blotted free of surface water and individually weighed. Individual mean stocking weight ($\bar{x} \pm$ S.D.) for each treatment was: (1) controls (61-day ungraded) 0.67 ± 0.23 g; (2) 61-day graded, 0.72 ± 0.41 g; and (3) 133-day graded juveniles, 3.1 ± 1.3 g. Ponds were randomly assigned to receive one of the three treatments with three replicate ponds per treatment. Prawns were hand-counted and stocked into each pond at 59,280 ha^{-1}.

Added substrate consisted of 133-cm wide panels of polyethylene "construction/safety fence" with a mesh opening (length × width) of 7.0 × 3.5 cm. Substrate was hung in vertical orientation and stretched the length of the pond between metal fence posts. The substrate was positioned approximately 30 cm above the pond bottom with a 30-cm separation between layers. The surface area contributed by the artificial substrate was calculated to increase available surface area by 50% compared to the bottom area in ponds without substrate (Tidwell et al., 2000). Surface area of the substrate was calculated based on dimensions of one side of the mesh (length × width), with open area within the mesh subtracted from surface area calculations.

2.2. Samples

A 3.2-mm mesh seine was used to collect a sample of prawns from each pond every 3 weeks. Substrate materials were not removed and only open areas in the pond were seined. The sample was group-weighed (drained weight) to the nearest 0.1 g, counted, and returned to the pond. On the last two sample dates prior to harvest, prawns were also individually weighed and classified into either one of three female morphotypes: berried (egg carrying; BE), open (previously egg carrying; OP), and virgin (VF); or one of three male morphotypes: blue claw (BC), orange claw (OC), and small (< 20 g; SM) as described by Cohen et al. (1981) and modified by D'Abramo et al. (1989). For data presented here, BE and OP females were combined into a composite group of mature females termed reproductive females (RF) (Tidwell et al., 2000).

2.3. Feeds and feeding

For the first 6 weeks, prawns were fed unpelleted distiller's grains with solubles (DDGS) (Tidwell et al., 1997), for weeks 7–12, a 32% prawn diet (as described in Tidwell et al., 1997) was fed, and for weeks 13–16, prawns were fed a 40% protein penaeid diet (Rangen, Buhl, ID, USA). One-half of the daily ration was distributed over the entire surface of each pond twice daily between 0900 and 1000 h and between 1500 and 1600 h. Prawns were initially fed at a set rate of 25 kg ha^{-1} day^{-1} of DDGS until an average individual weight of 5 g was achieved in samples. For weights greater than 5 g, prawns were fed a percentage of body weight based on a feeding schedule modified from D'Abramo et al. (1995) by increasing daily allotments, 20% above table values. Feeding rates were adjusted weekly based on an assumed feed conversion ratio of 2.5 and an assumed survival of 100%. Rates for all ponds within a treatment were based on the treatment average, not on individual pond sample weights.

2.4. Water quality management

Dissolved oxygen (DO) and temperature of all ponds were monitored twice daily (0900 and 1530 h) using a YSI Model 57 oxygen meter (Yellow Springs Instruments, Yellow Springs, OH, USA). Levels of total ammonia–nitrogen (TAN) and nitrite–nitrogen were determined weekly from water samples collected from each pond at approximately 1300 h according to outlined procedures for a HACH DR/2000 spectrophotometer (Hach, Loveland, CO, USA). The pH of each pond was determined daily at approximately 1300 h using an electronic pH meter (Hanna Instruments, Mauritius). Sample data were compiled into monthly pond means for analysis.

2.5. Harvest

Prawns were cultured for 106 days. One day prior to harvest, September 20, 2000, the water levels in each pond were lowered to approximately 0.9 m at the drain end. On the following day, substrates were removed and each pond was seined three times, with a 1.3-cm square mesh seine, and then completely drained. Remaining prawns were manually harvested from the pond bottom and purged in clean water. Total bulk weight and number of prawns from each pond were recorded. A random sample of ≥ 500 prawns from each pond was then individually weighed and classified into one of the six previously described sexual morphotypes. As in sample data, open (OP) and berried (BE) morphotypes were later combined into a composite group of sexually mature reproductive females (RF).

2.6. Statistical analyses

Treatment effects were evaluated using ANOVA (Steel and Torrie, 1980) to compare water quality and harvest data. If significant differences were indicated by ANOVA ($P \leq 0.05$), means were separated using the least significant difference (LSD) test. Production/size index (PSI) was calculated as PSI = production (kg ha^{-1}) × average weight (g)/1000 (Tidwell et al., 2000).

3. Results

3.1. Water quality

There were no significant differences ($P>0.05$) in water quality variables among treatments either monthly or overall. Overall means ± S.E. for water quality variables were: temperature, 25.6 ± 0.1 °C; dissolved oxygen, 7.7 ± 0.1 mg l^{-1}; pH, 9.0 ± 0.0; total ammonia–nitrogen, 0.92 ± 0.04 mg l^{-1}; un-ionized ammonia–nitrogen, 0.35 ± 0.0 mg l^{-1}; and nitrite–nitrogen, 0.05 ± 0.01 mg l^{-1}. These values represent suitable conditions for prawn culture.

Table 1
Mean (± S.E.) harvest weight, production, survival, feed conversion ratio (FCR), production/size index (PSI)[1], daily yield, and marketable percentages of prawns cultured in ponds for 106 days after being stocked with 61-day ungraded juveniles (controls), 61-day graded juveniles, or 133-day graded juveniles

Variable	Treatment		
	Control (61-day ungraded)	61-day graded	133-day graded
Harvest weight (g)	45.0 ± 0.8^a	51.7 ± 3.0^a	50.9 ± 0.9^a
Production (kg ha^{-1})	2548.8 ± 121.9^b	2944.8 ± 155.3^a	2553.5 ± 106.3^b
Survival (%)	96.1 ± 4.6^a	96.3 ± 4.2^a	89.7 ± 1.9^a
FCR	2.3 ± 0.1^b	2.2 ± 0.1^b	2.8 ± 0.1^a
PSI	114.7 ± 6.3^b	152.5 ± 15.3^a	130.1 ± 7.7^b
Daily yield (kg ha^{-1} day^{-1})	23.6 ± 1.1^b	27.3 ± 1.4^a	23.6 ± 0.9^b
% Marketable (>20 g)	87.2 ± 0.7^c	96.2 ± 0.7^a	94.1 ± 0.2^b
% Premium (>30 g)	77.9 ± 2.8^b	91.1 ± 1.7^a	89.5 ± 0.8^a

Treatment means within a row followed by a different letter are significantly different ($P \leq 0.05$) by ANOVA.
[1] PSI = Production (kg ha^{-1}) × average weight (g)/1000.

3.2. Juvenile age and size

At harvest, there were no significant differences ($P>0.05$) in average weight, total production, survival, PSI, or average daily yield between control ponds and those stocked with 133-day graded juveniles (Table 1). Compared to controls, stocking older, larger juveniles significantly increased ($P<0.05$) the percentage of animals which achieved minimum harvest sizes of ≥ 20 g (87% and 94%, respectively) and those achieving premium sizes of ≥ 30 g (78% and 90%, respectively). However, stocking of large (3.1 g) 133-day nursed juveniles rather than smaller 61-day graded juveniles (0.7 g) produced a significant increase ($P>0.05$) in FCR (2.8 vs. 2.3, respectively), indicating less efficient feed utilization.

Use of 133-day juveniles resulted in large shifts in the population structures of prawns at harvest. Compared to controls, stocking 133-day graded juveniles significantly increased ($P<0.05$) the proportion of males which reached BC (31% vs. 8% for controls), significantly decreased ($P<0.05$) the percentage of males which were OC (57% vs. 73%), and significantly decreased ($P<0.05$) the number of stunted SM (12% vs. 19%) (Table 2).

Table 2
The number of prawns classified into five morphotypes at harvest as a percentage of the total number within the respective sex for prawns stocked into ponds as 61-day ungraded juveniles (controls), 61-day graded juveniles, or 133-day graded juveniles

Variable	Treatment		
	Control (61-day ungraded)	61-day graded	133-day graded
Blue claw (BC)	7.7 ± 2.1^b	10.3 ± 1.5^b	31.3 ± 2.1^a
Orange claw (OC)	73.3 ± 2.1^b	83.7 ± 2.1^a	57.0 ± 2.7^c
Small male (SM)	19.0 ± 1.0^a	6.0 ± 1.0^c	12.0 ± 0.0^b
Reproductive female (RF)	53.3 ± 6.0^c	77.0 ± 6.6^b	100.0 ± 0.0^a
Virgin female (VF)	46.7 ± 6.0^a	23.0 ± 6.6^b	0.0 ± 0.0^c

Values are means ± S.E. of three replicate ponds. Treatment means within a row followed by a different letter are significantly different ($P \leq 0.05$) by ANOVA.

Table 3
Average individual weights (g) of prawns classified into five morphotypes at harvest for prawns stocked into ponds as 61-day ungraded juveniles (controls), 61-day graded juveniles, or 133-day graded juveniles

Variable	Treatment		
	Control (61-day ungraded)	61-day graded	133-day graded
Blue claw (BC)	78.2 ± 6.9[a]	70.1 ± 2.8[ab]	67.9 ± 1.5[b]
Orange claw (OC)	53.7 ± 0.9[c]	56.7 ± 2.0[b]	64.4 ± 0.6[a]
Small male (SM)	10.2 ± 0.4[b]	12.2 ± 0.4[a]	10.7 ± 0.5[b]
Reproductive female (RF)	43.6 ± 1.5[a]	41.1 ± 1.2[b]	38.3 ± 0.8[c]
Virgin female (VF)	31.6 ± 1.7[a]	35.9 ± 1.4[a]	27.4 ± 9.9[a]

Values are means ± S.E. of three replicate ponds. Treatment means within a row followed by a different letter are significantly different ($P \leq 0.05$) by ANOVA.

Use of 133-day juveniles significantly decreased ($P<0.05$) the average weight of BC and OC males (Table 3). Stocking of 133-day graded juveniles also had an extremely large impact on female morphotypes. In ponds stocked with 133-day nursed juveniles, 100% of females were sexually mature (RF) at harvest compared to 53% in control ponds. This produced a concomitant shift in virgin females from 47% of total females in control ponds to 0% in those stocked as 133-day juveniles. These differences were statistically significant ($P<0.05$). In prawns stocked as 133-day juveniles, the average weights of RF were significantly lower ($P<0.05$) than in control ponds, while average weights of virgin females were not significantly affected ($P>0.05$).

3.3. Grading

Within 61-day juveniles, grading prior to stocking had no significant impact on survival or FCR which averaged 96% and 2.2, respectively (Table 1). However, grading significantly increased ($P<0.05$) total production, average individual weight, PSI, and daily production (Table 1). Grading of 61-day juveniles significantly increased ($P<0.05$) the percentage of animals achieving a minimum harvestable weight of 20 g (87% and 96%, respectively) and those reaching premium sizes of >30 g (78% and 91%, respectively).

Within male morphotypes, grading significantly decreased ($P<0.05$) the number of SM (from 12% to 6%) and significantly increased ($P<0.05$) the average weights of both OC and SM. Grading of 61-day juveniles significantly increased ($P<0.05$) the number and decreased the average weight of females reaching sexual maturity (RF) and significantly decreased the number and increased the average weight of immature virgin females (VF).

4. Discussion

D'Abramo et al. (1989) reported that increasing the average stocking weight of juvenile prawns ultimately increased total pond production. However, in this study, the stocking of animals weighing 3.1 g provided no production advantage over stocking juveniles weighing less than 25% as much (0.7 g). Examination of the different population structures provides a probable explanation. When prawns become sexually mature, growth rates are drastically reduced as energies are shifted from somatic growth to reproductive activities (Tidwell et al., 1996). In prawns stocked as large 133-day juveniles, 42% of males at harvest were in slow growing morphotypes (BC, SM) and 100% of females were of the sexually mature slow growing morphotype (RF). Average weights of these morphotypes were also lower, indicating they likely transitioned to those morphotypes (with their slower growth rates) earlier than those stocked as 61-day juveniles. This is supported by interim sample data which indicate that at 6 weeks prior to harvest, 0% of the animals in control ponds had reached sexual maturity, while almost 25% of 133-day juveniles had attained reproductive status (Fig. 1). At 3 weeks prior to harvest, 15% of prawns in control ponds were sexually mature, while 64% of those stocked as large 133-day juveniles were slow growing sexually mature morphotypes. During the last 3 weeks of pond culture prior to harvest, prawns in control ponds matured rapidly (mature morphotypes increased from 15% to 40% of the total population). However, prawns stocked as 133-day juveniles only changed from 64% to 66% mature, likely indicating that their population structure had largely stabilized several weeks prior to harvest.

Within 61-day juveniles, grading prior to pond stocking produced a 14% increase in the number of fast growing immature OC males and a 68% decrease in the number of stunted males (SM). Similar changes were observed by D'Abramo et al. (1991) and Daniels et al. (1995). These changes are extremely desirable not only for growth, but also marketability. Among male morphotypes, only OC males maintain rapid growth rates. Also, OC males often represent large average individual weights (>50 g) with better dressout percentages

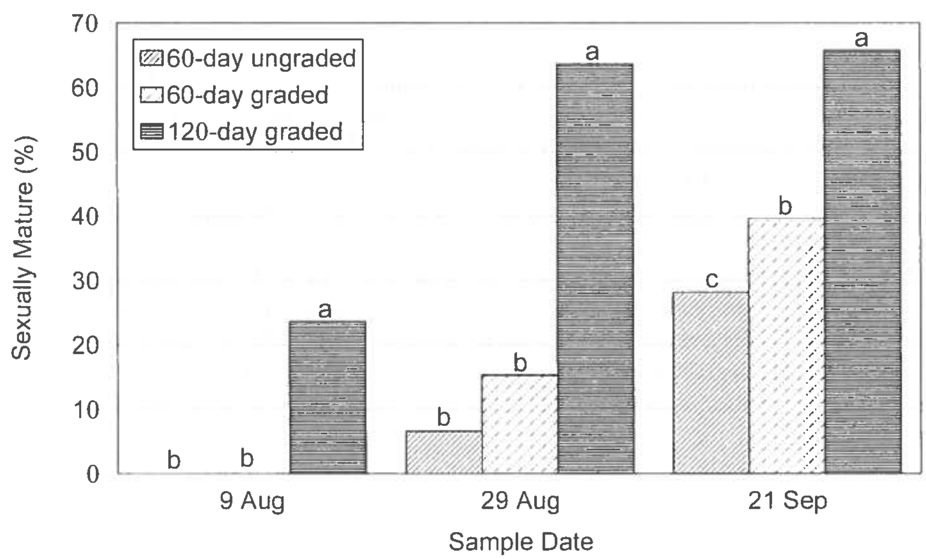

Fig. 1. The percentage of prawns reaching sexually mature morphotypes (BC and RF, respectively) in ponds stocked with 61-day ungraded juveniles (controls), 61-day graded juveniles, and 133-day graded juveniles on sample dates: 6 weeks prior to harvest, 3 weeks prior to harvest, and at final harvest.

than BC males. Decreasing the number of SM increases marketable percentages as SM do not achieve a minimum marketable size of 20 g. It appears that grading allows more males to transition up the developmental pathway from SM to OC (Karplus et al., 2000). However, they "stack-up" at the desirable OC stage as the number progressing on to terminal, slow growing BC stage is not significantly increased. In females, grading also allows a greater number of animals to progress up the developmental pathway as numbers within the sexually mature morphotypes (RF) are increased. However, advancement of females through their developmental pathway is not blocked, while in males, BC males repress the transition of other males below them in the progression.

5. Conclusion

In summary, increasing the stocking weight by extending the nursery period did not increase production due to rapid maturation and early cessation of growth. Within 61-day juveniles, grading increased production by 16%, without decreasing average individual sizes. Grading also increased the number of desirable male morphotypes and decreased the number of stunted males. Production improvements produced by grading appear to be additive with recent management improvements in feeds, feeding, and added substrate. It also appears that production rates in excess of 3000 kg ha^{-1} in less than 133 days at average sizes greater than 35 g are achievable when these management practices are combined. However, future studies must be conducted to evaluate how the use of lower grade animals, not evaluated in this study, will affect production under these conditions. Daniels and D'Abramo (1994) reported that even the lower grade animals could exceed the production of ungraded controls. However, Karplus et al. (2000) indicated that grading is only advantageous where growing seasons exceed 140–150 days, due to the time required for lower grade animals, with lower stocking weights, to catch up in growth. The relative costs and performance of lower grade animals must be evaluated under these management conditions to determine the ultimate feasibility of this procedure in temperate ponds.

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