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Impact of Different Management Technologies on the Production, Population Structure, and Economics of Freshwater Prawn *Macrobrachium rosenbergii* Culture in Temperate Climates

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Abstract

In temperate zone ponds, maximization of total production without decreasing average harvest weight is of increased importance due to the relatively short growing season. Recent research on the freshwater prawn *Macrobrachium rosenbergii* has shown that techniques such as size grading juveniles and adding artificial substrate to the ponds can accomplish these goals, and their impacts appear to be cumulative. However, due to the greater investments required, private producers have been reluctant to adopt these practices. The studies involved in developing these independent technologies have been conducted over a number of growing seasons with their different environmental conditions. It is important that different production technologies being utilized by commercial producers be directly compared under standardized conditions. The objective of this study was to compare the previously recommended and widely used technology (39,200/ha; ungraded juveniles; no substrate) (Low Input) with an intensified version of that technology used by some producers (54,340/ha; ungraded juveniles; no substrate) (Medium Input) with a technology package developed through a series of research trials to maximize production (69,160/ha; graded juveniles; with substrate; phase feeding) (High Input) under standardized conditions. Each of the seven 0.04-ha ponds were randomly assigned to either the Low Input, Medium Input, or High Input treatment with two, three, and two replicate ponds per treatment, respectively. Juvenile prawns (ungraded 0.6 ± 0.3 g; graded 0.9 ± 0.3 g) were stocked at one of the three densities according to its randomly assigned treatment. Low and Medium Input ponds received no added substrate while artificial substrate was added to the High Input ponds a rate sufficient to increase available surface area by 50%. Low and Medium Input Treatments were fed a 32% protein sinking pellet according to a feeding table. High Input ponds were fed at rates 20% above the feed table recommendations. After 104 d, survival was significantly higher ($P \leq 0.05$) in the High Input treatment (92%) than in the Medium Input treatment (83%), with Low Input ponds being intermediate (88%). Compared to the Low Input technology, the Medium Input technology significantly increased ($P \leq 0.05$) total production but significantly reduced average weight, so that Production Stock Index (PSI) and production of marketable size animals (> 20 g) or premium size animals (> 30 g) was not significantly increased ($P > 0.05$). Compared to the original Low Input technology, the High Input treatment significantly increased ($P < 0.05$) production (92%), average weight (6%), Production Stock Index (PSI) (102%), marketable production (> 20 g) (140%), production of premium size animals (> 30 g) (130%), and feed efficiency (32%). The move from the Low Input technology to the High Input technology reduced breakeven costs by 13% based on operating costs and 22% based on total cost figures. In summary, adoption of the High Input technology appears to be biologically and economically justified if similar results can be obtained in commercial scale ponds.

Freshwater prawns are considered more territorial than penaeid shrimp. Because of this, lower stocking rates are normally used and average production levels achieved by prawns are usually lower than those reported for penaeid shrimps. Over the past 10 yr several new technologies (substrate) (Tidwell et al. 2000) and management techniques (grading) (Karplus et al. 1986; Daniels and D'Abramo 1994) have been developed that appear to be additive and have greatly increased prawn production densities. However, many of these techniques and technologies have not been readily adopted by commercial producers. Some of

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these technologies do require additional labor and investment, and producers are not yet convinced that they are economically justified. Since these technologies have been developed independently over a series of years with different weather conditions and in different geographic regions, direct comparisons of their impacts on production, and their relative costs and returns, under standardized conditions have not yet been made.

This study was conducted to directly compare a widely used previously recommended technology (39,520/ha; ungraded juveniles; no substrate) (Low Input), a commonly utilized producer modification of that technology (54,340/ha; ungraded juveniles; no substrate) (Medium Input) and a High Input technology which combines recent advancements (69,160/ha; added substrate; graded juveniles; phase feeding). This will allow not only relative impacts on production to be compared, but also impacts on water quality, economics, and population structures.

Materials and Methods

Pond preparation and stocking

Two weeks prior to the anticipated stocking date, seven ponds located at the Aquaculture Research Center (ARC), Kentucky State University, Frankfort, Kentucky, USA were drained and allowed to dry. Less than 1 wk 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 ½-hp vertical pump surface aerator (Airolator, Kansas City, Missouri, USA) modified with a "deep-draw" tube was operated continuously at the surface of the deepest area of each pond to aerate and prevent thermal stratification. Two applications of liquid fertilizer (NPK, 10:34:0) were added to each pond 1 wk apart, at a rate of 9.0-kg phosphorous/ha, to achieve an algal bloom. Water to replace evaporative losses was obtained from the reservoir.

Post-larval prawns were shipped by air from a commercial hatchery (Aquaculture of Texas, Weatherford, Texas, USA) and stocked into 11 1,900-L tanks housed in a temperature-controlled greenhouse at the (ARC). Artificial substrate, in the form of horizontally layered sheets of black plastic mesh (0.625 cm openings) supported by a PVC frame, was added to each tank to provide 20.5 m^2 of total surface area. Prawn post-larvae were fed a #2 crumble (42% protein and 8% lipid) commercial trout diet (Silver Cup, Murray, Utah, USA) according to rates and schedules recommended by D'Abramo et al. (1989). The daily ration was divided into two equal feedings (0900 and 1500 h). All tanks received approximately 8 L/min of tempered water from an outside reservoir pond. Water temperatures in all tanks were maintained at 28 C by flowing water through a common heat pump unit. Each tank was aerated by an air stone supplied with air from a regenerative blower. Total length of the nursery period was 60 d.

Prior to pond stocking, juveniles were moved into holding tanks which were provided with artificial substrate and a constant flow of reservoir water. Animals were then separated into three groups. One group was not graded (ungraded) and retained the original size distribution that had developed during the nursery period. Ungraded juveniles are the most common form used in the region. These juveniles were used to stock the Low Input (two replicate ponds) and Medium Input (three replicate ponds) treatments. The other group of 60-d juveniles was passively graded into two approximately equal groups using a #13 bar grader (0.5-cm spacing). Those that were retained by the grader (upper grade) were used as graded juveniles for the High Input treatment (two replicate ponds).

The mean stocking weight for each of the juvenile groups was determined from a sample of 100 prawns from each group. Juveniles were blotted free of surface water and individually weighed. Individual mean stocking weight ($\bar{x}$±SD) for ungraded juveniles was 0.58 ± 0.32 g, and for graded juveniles, 0.89 ± 0.31 g. Ponds were randomly assigned to receive juveniles from either the ungraded or graded groups (according to treatment). Juveniles were hand-counted and stocked on 4 June 2002 into each pond at a density of 39,520, 54,340, or 69,160/ha per assigned treatment.

In ponds assigned to the High Input treatment, artificial substrate was added. It consisted of 120-cm wide panels of polyethylene "construction/safety fence" with a mesh opening (length x width) of 7.0 cm x 3.5 cm. Substrate was hung in vertical orientation and stretched the length of the pond between metal fence posts. 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 x width), with open area within the mesh subtracted from surface area calculations.

Samples

A 3.2-mm mesh seine was used to collect a sample of ≥ 50 prawns from each pond every 3 wk. 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).

Feeds and feeding

In the Low Input and Medium Input treatments, prawns were fed a 32% protein steam pelleted sinking diet throughout the study. In the High Input treatment, prawns were "Phase Fed." For the first 4 wk prawns were fed unpelleted distiller's grains with solubles (DDGS) (Tidwell et al. 1997), for weeks 5–12 a 32% prawn diet (as described in Tidwell et al. 1997) was fed, and for weeks 12-15 prawns were fed a 40% protein penaeid diet (Rangen Inc., Buhl, Idaho, USA). For all treatments, 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 per d 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 from D'Abramo et al. (1995). In the High Input treatment, daily allotments were increased 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.

Water quality management

Dissolved oxygen (DO) and temperature of all ponds were monitored twice daily (0900 h and 1530 h) using a YSI Model 57 oxygen meter (Yellow Springs Instruments, Yellow Springs, Ohio, 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 Co., Loveland, Colorado, USA). The pH of each pond was determined daily at 1300 h using an electronic pH meter (Hanna Instruments, Ltd., Mauritius). Un-ionized ammonia concentrations were calculated from TAN, pH, and temperature according to Boyd (1979). Sample data were compiled into monthly pond means for analysis.

Benthos

Baseline benthic samples were taken from each pond 3 d prior to stocking of prawns according to Lind (1979). After stocking, benthic macroinvertebrate samples were taken at 3-wk intervals. One sample per pond was taken with a 0.09-m^2 Ekman dredge (Wildco, Saginaw, Michigan, USA). The dredge sample was taken 2 m from the perimeter of the deepest (1.5 m) end of each pond. At each sample date the dredge site was moved 1 m further out to prevent re-sample. The sediment sample was sieved through a 20-L capacity U.S. Standard 35 mesh (0.5-mm mesh) sieving bucket and the contents preserved in 70% ethanol until identification and enumeration. If possible, benthic macroinvertebrates were identified to phylum, class, and order, and insects were identified to family and/or genus, using taxonomic keys of Needham and Needham (1966), Pennak (1978), Lehmkuhl (1979), and Merrit and Cummins (1984).

TABLE 1. *Overall means of twice weekly determinations of total ammonia-nitrogen (TAN), un-ionized ammonia-nitrogen, nitrite-nitrogen, afternoon pH, morning temperature, afternoon temperature, morning dissolved oxygen (DO), and afternoon DO.*

Variable	Treatment		
	Low Input	Medium Input	High Input
TAN (mg/l)	0.51 ± 0.02b	0.47 ± 0.01b	0.69 ± 0.05a
Un-ionized ammonia-N (mg/l)	0.08 ± 0.01a	0.07 ± 0.02a	0.06 ± 0.00a
Nitrite-N (mg/l)	0.01 ± 0.00b	0.01 ± 0.01b	0.04 ± 0.01a
pH	8.4 ± 0.03a	8.3 ± 0.12a	8.2 ± 0.03a
AM Temp (C)	25.9 ± 0.5a	26.1 ± 0.2a	26.1 ± 0.3a
PM Temp (C)	27.7 ± 0.4a	27.9 ± 0.3a	27.9 ± 0.3a
AM DO (mg/L)	6.8 ± 0.5a	6.5 ± 0.2a	6.7 ± 0.1a
PM DO (mg/L)	9.9 ± 0.3a	9.9 ± 0.1a	9.2 ± 0.1b

Harvest

Prawns were cultured for 104 d. One day prior to harvest, 15 September 2002, the water levels in each pond were lowered to approximately 0.9 m at the drain end. On the following day, substrates (if present) were removed and each pond was seined 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).

Statistical analyses

Treatment effects were evaluated using ANOVA (Steele 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. Feed conversion ratio (FCR) was calculated as FCR = total weight of feed fed (kg ÷ total live weight gain (kg) during the study. Production/Size Index (PSI) was calculated as PSI = production (kg/ha) x average weight (g) ÷ 1,000 (Tidwell et al. 2000). Effect of treatment on individual size variation was evaluated using a one-factor ANOVA of the coefficient of variation (CV) against treatment type, followed by multiple comparison tests. Percent and ratio data were arc-sin transformed prior to analyses. These data are presented in their untransformed state to facilitate comparisons.

Economics

Production data from this experiment were used to develop economic measures for the three technologies (Low Input, Medium Input, and High Input). Breakeven prices (US$/kg) of whole prawn were computed for each technology based on covering either operating costs only or total costs, according to procedures presented in Dasgupta and Tidwell (2003). The operating cost for a technology was based on the sum of the cost of stocking, feeding, electricity, fuel, chemicals, labor and management, legal fees (propagation permit), telephone use, and harvesting and marketing costs. Total costs were calculated by adding the fixed costs, which include the depreciation on pond and equipment, interest charged on the value of land, pond and equipment, and property tax. A detailed breakdown of the fixed costs associated with a small-scale prawn farm is provided in Dasgupta and Tidwell (2003).

Results

Water Quality

There were no significant differences between the Low or Medium Input treatments in any of the measured water quality variables (Table 1). With the High Input treatment there was a significant increase ($P \leq 0.05$) in total ammonia-nitrogen but no increase ($P \geq 0.05$) in toxic un-ionized ammonia concentrations. Nitrite-nitrogen concentra-

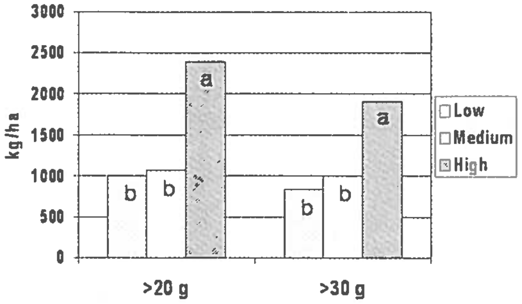

FIGURE 1. *Biomass (g/m²) of macroinvertebrates in ponds in which prawns were stocked with ungraded juveniles at 39,520/ha (Low Input), 54,340/ha (Medium Input) in ponds without substrate, or with high graded juveniles at 69,160/ha in ponds with added substrate (High Input). Values are means of two, three, and two replicate ponds, respectively.*

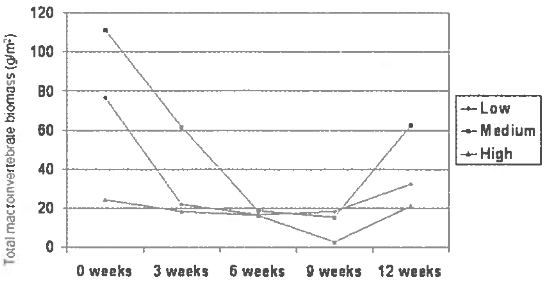

FIGURE 2. *Marketable production (kg/ha), based on minimum sizes of 20 g or 30 g, of prawns cultured in ponds for 104 d after being stocked with ungraded juveniles at 39,520/ha (Low Input), 54,340/ha (Medium Input) in ponds without substrate, or with high graded juveniles at 69,160/ha in ponds with added substrate (High Input). Values are means of two, three, and two replicate ponds, respectively. Bars with different letters indicate significant differences (P ≤ 0.05) by ANOVA.*

tions were also significantly higher ($P \leq 0.05$) in the High Input treatment and afternoon DO was significantly lower ($P \leq 0.05$) in the High Input treatment. However, these differences were not of magnitude to be biologically significant (Boyd and Zimmerman 2000).

Benthos

There was no significant difference ($P > 0.05$) in the density (no./m²) or biomass (g/m²) of gastropods, oligochaetes, total non-insects, chironomids, total dipterans, total insects, or total macroinvertebrates among the three treatments at any of the five sampling dates or based on overall means. Fig. 1 shows the combined biomass of all macro-invertebrate taxa by treatment for each of the five sample dates.

Production

Increasing stocking density between the Low Input and Medium Input treatments had no significant impact ($P > 0.05$) on survival (Table 2). However, the shift from the Low Input to Medium Input technologies significantly increased ($\underline{P} \leq 0.05$) total production (1,310 vs 1,547 kg/ha, respectively) but significantly decreased ($P \leq 0.05$) average harvest weight (38 g vs 35 g, respectively). Because of this "give and take" relationship in production and average size, the shift from Low Input to Medium Input resulted in no significant change ($P > 0.05$) in the Production Stock Index (PSI), which combines these variables.

Specific growth rates, both absolute (g) and relative (%), were both significantly decreased ($\underline{P} \leq 0.05$) by the shift from the Low Input to Medium Input culture densities. These are reflected in the lower harvest weights of animals in the Medium Input treatment. Due to this, the shift from Low Input to the Medium Input technologies did not result in significant increases ($P > 0.05$) in marketable production, whether based on a 20-g minimum weight or a 30-g minimum weight (Fig. 2). Moving from the Low Input to the Medium Input technology significantly improved ($P \leq 0.05$) the feed conversion ratio (FCR), decreasing FCR from 3.6 to 3.1.

The shift from the Medium Input technology to the High Input technology resulted in statistically significant increases in survival ($P \leq 0.05$) and highly significant increases ($P \leq 0.01$) in average harvest weight and PSI. There was a highly significant improvement ($P < 0.01$) in feed conversion ratio, which decreased from 3.1 to 2.5. Absolute Specific Growth Rate (g/d) was significantly increased ($P \leq 0.05$) by the shift from Medium Input to High Input; while Relative Specific Growth Rate (%) was significantly decreased ($P \leq 0.05$). These differences largely reflect the larger stocking size of the graded animals used in the High Input treatment. Since total production and average in-

TABLE 2. *Mean (± SE) harvest weight, production, survival, feed conversion ratio (FCR), production size index (PSI)*[a]*, specific growth rates (g/d and percent) of prawns cultured in ponds for 104 d after being stocked with ungraded juveniles at 39,520/ha (Low Input), 54,340/ha (Medium Input) in ponds without substrate, or with high graded juveniles at 69,160/ha in ponds with added substrate (High Input). Values are means ± SE of two, three, and two replicate ponds, respectively. Treatments means within a row followed by a different letter are significantly different (P ≤ 0.05) by ANOVA.*

Variable	Treatment		
	Low Input	Medium Input	High Input
Harvest weight (g)	37.9 ± 0.4b	34.5 ± 0.5c	40.0 ± 0.7a
Production (kg/ha)	1,310 ± 62c	1,547 ± 43b	2,514 ± 88a
Survival (%)	87.9 ± 3.2ab	83.1 ± 1.9b	91.9 ± 1.6a
FCR	3.6 ± 0.2a	3.1 ± 0.1b	2.5 ± 0.1c
PSI	49.7 ± 2.9b	53.4 ± 1.9b	100.7 ± 5.2a
Absolute SGR (g/d)	0.35 ± 0.00b	0.32 ± 0.00c	0.37 ± 0.01a
Relative SGR (%/d)	3.98 ± 0.01a	3.89 ± 0.01b	3.63 ± 0.02c

[a] *PSI = Production (kg/ha) X average weight (g) ÷ 1,000.*

TABLE 3. *The number of prawns classified into five morphotypes at harvest as a percentage of the total number within the respective sex for prawns in ponds for 104 d after being stocked with ungraded juveniles at 39,520/ha (Low Input), 54,340/ha (Medium Input), or with high graded juveniles at 69,160/ha in ponds with added substrate (High Input). Values are means ± SE of two, three, and two replicate ponds, respectively. Treatment means within a row followed by a different letter are significantly different (P ≤ 0.05) by ANOVA.*

Variable	Treatment		
	Low Input	Medium Input	High Input
Blue claw (BC)	5.9 ± 2.3a	6.9 ± 2.9a	8.6 ± 1.9a
Orange claw (OC)	68.2 ± 1.2ab	62.3 ± 7.4b	82.9 ± 3.7a
Small male (SM)	25.9 ± 1.1a	30.8 ± 8.4a	8.6 ± 1.9b
Reproductive female (RF)	44.9 ± 6.7b	55.1 ± 3.1b	83.5 ± 6.3a
Virgin female (VF)	55.1 ± 6.7a	44.9 ± 3.1a	16.5 ± 6.1b

dividual weight were both increased by the shift from Medium Input to High Input, this resulted in highly significant increases ($P \leq 0.01$) in production of marketable animals (> 20 g) and premium size animals (> 30 g) (Fig. 2).

Population Structure

Intensification from the Low to Medium Input produced no significant ($P > 0.05$) changes in the numbers of the five morphotypes (as % of sex) (Table 3). Further intensification to the High Input technology did not affect the number of BC males, but did produce a large shift within the other male morphotypes with a significant decrease ($P \leq 0.05$) in the number of small males and a significant increase ($P \leq 0.05$) in the number of orange claw males (the opposite of what is normally seen as stocking rates are increased). Intensification produced a large shift in females with a highly significant decrease ($P \leq 0.01$) between the number of immature VF and a highly significant ($P \leq 0.01$) increase in the number of sexually mature RF. This occurred relatively early as by the fourth sample date (18 d before harvest) there was already a highly significant difference ($P \leq 0.01$) in the number of RF in the High Input (45%), Low Input (2%), and Medium Input (15%) treatments, which were not significantly different ($P > 0.05$). At this sample date there was no significant difference between treatments ($P > 0.05$) in the numbers of males achieving sexual maturity (BC).

Intensification from Low Input to Medium Input significantly decreased ($P < 0.05$) the average weight of BC and OC males (Table 4). However, further intensification from Medium Input to High Input did not produce a significant change ($P >$

TABLE 4. *Average individual weights (g) of prawns classified into five morphotypes at harvest for prawns stocked into ponds as 60-d ungraded juveniles at 39,520/ha (Low Input), 54,340/ha (Medium Input), or with high graded juveniles at 69,160/ha in ponds with added substrate (High Input). Values are means ± SE of two, three, and two replicate ponds, respectively. Treatment means within a row followed by a different letter are significantly different ($P \leq 0.05$) by ANOVA.*

Variable	Treatment		
	Low Input	Medium Input	High Input
Blue claw (BC)	78.3 ± 2.8 a	61.6 ± 3.6 b	54.6 ± 4.7b
Orange claw (OC)	51.1 ± 0.7a	45.4 ± 1.1b	47.3 ± 1.8b
Small male (SM)	9.2 ± 1.3a	8.0 ± 0.6a	9.2 ± 1.0a
Reproductive female (RF)	40.9 ± 0.6a	36.3 ± 1.7b	32.7 ± 0.8c
Virgin Female (VF)	24.0 ± 2.8b	22.8 ± 1.5b	30.1 ± 1.7a

TABLE 5. *Calculated breakeven costs based on covering only operating costs, or total costs, for prawns cultured in ponds for 104 d after being stocked with ungraded juveniles at 39,520/ha (Low Input), 54,340/ha (Medium Input), or with high graded juveniles at 69,160/ha in ponds with added substrate (High Input).*

Variable	Treatment		
	Low Input	Medium Input	High Input
Covering Operating Costs ($/kg)[a]	6.62	6.75	5.74
Covering Total Costs ($/kg)[a]	10.45	9.99	8.12

[a] *All monetary figures are in years 2003 U.S.$.*

0.05) in male morphotype weights. In females, the intensification from the Low Input treatment to Medium Input did not significantly impact ($P >$ 0.05) the average weight of VR, but decreased the average weight of RF. However, further intensification from Medium Input to High Input produced a significant ($P \leq 0.05$) decrease in average weights of RF but actually increased the weights of VF.

Economics

Based on only covering operating costs, the Medium Input technology breakeven price ($6.75/kg) was slightly higher than the breakeven price for the Low Input technology ($6.62/kg) (Table 5). The High-Input technology had the lowest breakeven price ($5.74/kg), which was 13% lower than the Low Input scenario and 15% lower than the Medium Input. When calculated on a total cost basis, the breakeven cost for the Medium Input technology ($9.99/kg) was under these conditions lower than for the Low Input technology ($10.45/kg). However, the High Input technology again resulted in the lowest breakeven price ($8.12/kg) which was 22% lower than the Low Input technology and 19% lower than the Medium Input technology.

Discussion

Increased stocking rates and higher feed rates which are part of the High Input technology resulted in some changes in measured water quality variables. Total ammonia-nitrogen was increased compared to Low and Medium Input treatments. However, the concentration of the toxic un-ionized portion was not increased in the High Input treatment, probably due to lower overall pH levels. While nitrite concentrations were significantly higher in the High Input treatment than in the other treatments, differences were likely not of sufficient magnitude to be biologically significant. This is supported by the High Input treatment having the highest survival rate (92%).

Using the older Low Input technology (39,520/ha with no substrate), production and average weights were near expected values (1,310 kg/ha; 38 g, respectively). Increasing the stocking rate by 38% to 54,340/ha increased production by 18%, but reduced average harvest weight 9% (1,547 kg/ha, 35 g, respectively). This increased the PSI (which concomitantly measures production and average weight) by only 8%. However, shifting from the Low Input technology to the High Input technology increased production 92% (2,414 kg/ha) and average weight 6% (40 g) resulting in a 102% increase in PSI (101). Compared to the previous Low Input technology the High Input technology also improved feed efficiency by 32% and increased the per unit production (kg/ha) of marketable animals (> 20 g) by 140% and premium size animals (> 30 g) by 130%, without seriously impacting water quality. Compared to the Low Input technology, High Input ponds resulted in a 67% reduction in the number of males in the stunted SM morphotype. However, the number of berried females, which may not be well accepted by some markets, was increased 71%. Despite increased investments required for the High Input technology, results indicate that they are more than compensated for by increased production and decreases in breakeven costs (13–22%).

Many producers have resisted adoption of the technologies that formed the High Input treatment citing the greater investments required for additional seedstock and purchase of substrates. However, it appears that adoption of the more intensive technology actually reduces breakeven prices. In summary, adoption of the High Input technology appears to be biologically and economically justified if similar results can be obtained in commercial scale ponds.

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