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Effects of Stocking Density of All-male *Macrobrachium rosenbergii* (De Man, 1879) in Polyculture Ponds on Production and Economics

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Abstract

A study was conducted to evaluate the effects of stocking density of all-male freshwater prawn *Macrobrachium rosenbergii* (De Man, 1879) on water quality, production and economic return in polyculture ponds. Trials involving three stocking densities of all-male prawn viz., 15,000, 20,000 and 25,000 ha^{-1} were carried out in replicates, combined in polyculture with fixed densities of silver carp, catla and small fish mola at 1,500, 1,000 and 20,000 ha^{-1}, respectively. Commercial prawn feed and fertilisers were applied routinely to all ponds. Blue-clawed males were harvested periodically at 15-day intervals over a 5-month culture cycle before final harvest. Differences in prawn density (treatments) did not significantly (P>0.05) affect any water quality parameters. Mean weight of prawn at harvest decreased significantly (P<0.05) with increasing stocking density. Net production of prawns however, was significantly higher at prawn densities of 25,000 and 20,000 ha^{-1} (661 kg and 640 $kg \cdot ha^{-1}$, respectively) compared with 15,000 ha^{-1}(535 $kg \cdot ha^{-1}$). Silver carp and catla production did not differ significantly among density treatments, while production of mola was higher at 20,000 $prawn \cdot ha^{-1}$. This treatment also resulted in higher net production of all species combined (1,688 $kg \cdot ha^{-1}$) as well as the highest return (US$ 2,597 ha^{-1}).

Introduction

All-male freshwater prawn (*Macrobrachium rosenbergii* (De Man, 1879) culture yields better outcomes than mixed sex or all-female culture (Cohen et al.1988, Nair et al. 2006, Kunda et al. 2009). Male *M. rosenbergii* however, exhibit heterogeneous individual growth (HIG), in some instances producing 50% undersized small males (SM), 40% orange-clawed males (OC) that are larger than SM, and only 10% large blue-clawed males (BC) at harvest (Ra'anan et al. 1991). Thus, HIG is one of the major problems affecting profitability in freshwater prawn culture (Karplus et al. 2000) as demand and market price of prawns depends largely on individual size. Periodic selective harvesting of BC has been proposed as a practical management strategy for enhancing growth-rate of SMs, thereby minimising male size variation and increasing total productivity from ponds (Sagi and Aflalo 2005, Rahman et al. 2010a).

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Polyculture of fish species with freshwater prawns also has potential for increasing total yield and income as well as improving environmental sustainability (Zimmermann and New, 2000). If the stocking densities of fish species are balanced in polyculture with freshwater prawns, synergistic interactions that potentially increase total pond food resources and improve environmental conditions in the pond can develop (Milstein, 1992). This can ultimately increase yields.

Freshwater prawns forage mainly on benthic food organisms that are available in the bottom niche in aquaculture ponds (Coyle et al. 1996) but they do not filter algae directly from the water column. Finfish species selected as co-species with all-male freshwater prawn cohorts for polyculture trial in the current study included: i) silver carp, *Hypophthalmichthys molitrix* (Valenciennes, 1844), a filter feeder that can prevent sudden algal blooms (Hepher and Pruginin, 1981), and also increase food resources for benthophagous fish from production of faecal pellets (Milstein, 1992); ii) catla, *Catla catla* (Hamilton, 1822) the fastest growing species among the three Indian major carps, that is a surface and mid-water feeder (Jhingran, 1991) that shares the upper feeding niche of the pond with silver carp; and iii) a self recruiting small native species, mola, *Amblypharyngodon mola* (Hamilton, 1822), that grazes principally on phytoplankton. Mola has been recommended as a potential species for use in polyculture (Kohinoor et al. 1998) because it has a high content of micronutrients and vitamin-A (Thilsted et al. 1997).

The current study was conducted to evaluate the effects of applying different stocking densities of all-male freshwater prawn cohorts combined with polyculture of selected fish species on water quality, production levels and relative financial returns in Bangladesh. Stocking densities of silver carp, catla and mola were fixed, and were set at frequencies where the fish performed best in a previous study conducted on the same system (Rahman et al. 2010b) while those of prawns were varied. Periodic selective harvesting of BC males were conducted to allow SM individuals left in the pond to grow to larger size and hence to enhance overall biomass (Rahman et al. 2010a).

Materials and Methods

The experiment was conducted at the Fisheries Field Laboratory, Bangladesh Agricultural University (BAU), Mymensingh over 152 days between February and July, 2008. Nine earthen ponds (area 100 m^2 and average depth 1.0 m) were selected for three stocking densities of freshwater prawn: 15,000, 20,000 and 25,000 ha^{-1} (herein called treatments MP_{15000}, MP_{20000}, and MP_{25000}, respectively) with three replications, using a completely randomised design.

Ponds were treated with lime (powdered $CaCO_3$) at the rate of 250 $kg{\cdot}ha^{-1}$ 10 days before stocking, and fertilised with urea and triple super phosphate (TSP) at the rate of 25 $kg{\cdot}ha^{-1}$ each and semi-decomposed cow-dung at the rate of 1,000 $kg{\cdot}ha^{-1}$ three days after liming. Two palm leaves were placed on the bottom of each pond to provide shelter. A fine synthetic net (1.0 mm mesh) was used to make a fence around the ponds to prevent escapes. Seven days after fertilisation, male juveniles (mean individual weight 5.33 g) were stocked into ponds. Males were identified and segregated manually based on the external morphological characters following Nagamine and Knight (1980), and New and Singholka (1985). In addition, silver carp (18.74 g), catla (15.85 g) and mola (1.15 g) were stocked in all treatments at a fixed rate of 1,500, 1,000 and 20,000 ha^{-1} per species, respectively.

Prawns were fed with pellet feed (28% crude protein) at 6% of body weight daily for the first month, 4% in the second month and 3% for the remaining period. Half of the required daily ration was supplied in the morning and half in the evening. Ponds were fertilised at 5-day intervals with urea and TSP at a rate of 6.25 $kg \cdot ha^{-1}$ each and cow-manure at 125 $kg \cdot ha^{-1}$ to maintain a natural abundance of pond food organisms. Periodic selective harvesting of BC individuals from all ponds started on day 90 and was repeated four times at 15-day intervals before final harvest. BC prawns were identified by their blue-coloured and spineous long claws (Karplus et al. 1986; Karplus et al. 1992). Partial harvesting of large mola was started on day 105 and continued at 15-day intervals until final harvest as mola bred in all ponds within 95 to 105 days. Seine netting was repeated twice at each harvesting time and all BC prawns and large mola in the net were harvested.

Water temperature and dissolved oxygen levels (Dissolved Oxygen Meter, YSI Model 58, Yellow Springs, Ohio, USA), and pH (EC 10 portable pH meter) were measured weekly in all ponds at sunrise and sunset. Water transparency (Secchi disc) was measured weekly. Total alkalinity was determined bi-weekly using a titrimetric method (Stirling, 1985). Nitrogen compounds (NH_3-N, NO_2-N, NO_3-N) and orthophosphate (PO_4-P) analyses were performed bi-weekly using a digital HACH kit (model DR 2010, HACH Co., Loveland, USA). Chlorophyll-*a* was determined bi-weekly with a spectrophotometer (Milton Roy Spectronic, Model 1001 plus, Vernon Hills, IL, USA) after acetone extraction (Boyd, 1979). Plankton samples were collected monthly following Stirling (1985) and counted using a Sedgewick-Rafter counting cell (S-R cell) under a binocular microscope (Olympus, M-4000D, Japan). Identification of plankton to genus level was carried out using the keys from Ward and Whipple (1959), Prescott (1962), and Bellinger (1992).

All ponds were harvested separately by repeated netting and complete draining on day 152. All prawns, silver carp and catla were harvested from each pond and counted, measured and weighed individually. Mola from each pond were batch weighed as mola are self recruiting and had reproduced in all ponds during the culture period.

A simple economic analysis was performed to estimate the profit (total benefit –total cost) and benefit cost ratio (BCR = total benefit ÷ total cost) of the different treatments. Cost of inputs, prawns and fish were estimated based on local wholesale market prices in 2008. Prawns were graded and priced according to their weight as large (≥50 g), medium (33.3 g – 49.9 g) or small (≤33.2 g).

One way analysis of variance (ANOVA) was conducted on growth and production data as well as for water quality parameters and plankton data. Percent data were analysed using arcsine-transformed value. If the main effect was found to be significant, a Tukey test was used to compare the treatment means. All statistical tests were carried out using a 5% significance level in Statistical Package for Social Science (SPSS).

Results

Data on mean values of water temperature, transparency, alkalinity, dissolved oxygen (DO), ammonia (NH_3-N), nitrite (NO_2-N), nitrate (NO_3-N) and orthophosphate (PO_4-P), and pH are presented in Table 1. No parameters varied significantly (P>0.05) among treatments.

The plankton community in ponds consisted of four groups of phytoplankton and two groups of zooplankton in all treatments. Varying prawn density among treatments apparently had no significant effect on mean abundance of any specific group of plankton or plankton numbers as a whole. Among phytoplankton (103,000-107,000 cells· or colonies·L^{-1}), Chlorophyceae dominated with 19 genera followed by Bacillariophyceae (9 genera), Cyanophyceae (6 genera) and Euglenophyceae (3 genera). Zooplankton (3,700-4,800 individuals·L^{-1}) consisted of rotifers (5 genera) and crustaceans (6 genera). Phytoplankton biomass in terms of chlorophyll-*a* did not differ significantly among treatments with means of 132, 129, and 134 µg L^{-1}, in the MP_{15000}, MP_{20000}, and MP_{25000} treatments, respectively.

Table 1. Mean±SD of water quality parameters.

Parameters	***N***	**MP_{15000}**	**MP_{20000}**	**MP_{25000}**
Transparency (cm)	69	33.7±4.8	34.5±5.8	33.3±5.3
Temperature at sunrise (°C)	69	26.38±4.34	26.41±4.29	26.41±4.30
Temperature at sunset (°C)	69	30.43±4.28	30.38±4.29	30.45±4.29
pH at sunrise (range)	69	6.8-8.1	6.8-8.1	6.8-8.3
pH at sunset (range)	69	7.4-9.0	7.3-9.1	7.6-9.0
DO at sunrise (mg·L^{-1})	69	2.93±0.65	2.89±0.71	2.68±0.70
DO at sunset (mg·L^{-1})	69	10.83±0.93	10.78±1.19	10.52±0.98
Alkalinity (mg·L^{-1})	36	82.2 ± 42.0	78.6 ± 39.6	78.2 ± 40.7
NH_3-N (mg L^{-1})	36	0.26±0.34	0.20±0.29	0.18±0.22
NO_2-N (mg·L^{-1})	36	0.0023±0.0021	0.0023±0.0028	0.0024±0.0025
NO_3-N (mg·L^{-1})	36	0.029±0.034	0.018±0.017	0.021±0.026
PO_4-P (mg·L^{-1})	36	1.48±0.83	1.75±1.04	1.57±0.99

Growth and production performance results for prawns (selectively harvested periodically and at final harvest), and production performance of silver carp, catla, mola, as well as combined finfish are presented in Table 2. Survival of freshwater prawn did not vary significantly among treatments. Mean individual weight of harvested prawns decreased at higher stocking density and showed a strong negative correlation (R^2 = 0.94). Net production of prawns was significantly higher in the MP_{25000} and MP_{20000} compared with the MP_{15000} treatment. Feed conversion ratio (FCR) was significantly lower in the MP_{15000} treatment compared with MP_{25000}, with the remaining treatment being intermediate and not significantly different from the others.

Table 2. Growth and production parameters of prawn and production performance of silver carp, catla, mola and all species pooled (mean±SD, *N*=3). Mean values with different superscripts indicate significant difference (*P*<0.05) among treatments.

Species	Parameters	MP_{15000}	MP_{20000}	MP_{25000}
Prawn (Selectively harvested plus finally harvested)	Individual stocking weight (g)	5.33±0.02	5.32±0.01	5.33±0.01
	Survival (%)	76.67±3.06	75.67±3.25	72.93±3.00
	Individual weight at harvest (g)	53.48±0.65^a	49.36±1.64^b	43.57±0.96^c
	SGR (% bw·d^{-1})	1.52±0.01^a	1.46±0.02^b	1.38±0.01^c
	Gross production (kg·ha^{-1})	615±20^b	747±23^a	795±47^a
	Net production (kg·ha^{-1})	535±20^b	640±23^a	661±47^a
	Feed conversion ratio (FCR)	2.31±0.08^b	2.41±0.07^{ab}	2.61±0.13^a
Silver carp	Gross production (kg·ha^{-1})	647±32	686±46	631±31
	Net production (kg·ha^{-1})	619±32	658±46	602±30
Catla	Gross production (kg·ha^{-1})	244±11	281±20	249±31
	Net production (kg·ha^{-1})	228±11	265±20	233±31
Mola	Gross production (kg·ha^{-1})	141±3.2^{ab}	148±3.5^a	135±2.8^b
	Net production (kg·ha^{-1})	118±1.8^{ab}	125±5.1^a	112±3.0^b
Finfish combined	Gross production (kg·ha^{-1})	1,033±35	1,114±54	1,014±28
	Net production (kg·ha^{-1})	966±35^{ab}	1,048±53^a	947±30^b
All species combined (Prawn + finfish)	Gross production (kg·ha^{-1})	1,647±54^b	1,861±61^a	1,809±36^a
	Net production (kg·ha^{-1})	1,501±54^b	1,688±60^a	1,608±36^{ab}

Percentage of cumulative selectively harvested BC individuals to total BC by count as well as weight did not differ significantly among treatments. The mean values of percentages of selective harvested BC to total BC ranged from 63.4-66.5% by count and 63.7-67.3% by weight in the different treatments. Percentages of different male morphotypes of prawn by count within treatments are presented in Table 3.The proportion of BC (periodic selectively harvested plus final harvest) decreased significantly with increasing stocking density, representing 33%, 26% and 19% of total harvested male prawn in treatments MP_{15000}, MP_{20000} and MP_{25000}, respectively. The opposite trend was evident for SM: 9% in treatment MP_{15000}, 13% in MP_{20000} and 22% in MP_{25000}. Relative percentages of OC males (59-61%) however, were not significantly different among stocking densities. Despite subjecting male juveniles to careful identification at stocking, a few female prawns (4-5% by count and 3-5% by weight) were identified among freshwater prawns at the final harvest in all treatments. Percentages of female prawns both by count and weight did not however, vary significantly among treatments.

Table 3. Percentages of different male morphotypes of prawn by count (mean±SD, N = 3) within treatments. Mean values with different superscripts indicate significant difference (P<0.05) among treatments.

Morphotypes	$\mathbf{MP_{15000}}$	$\mathbf{MP_{20000}}$	$\mathbf{MP_{25000}}$
Blue-clawed male (BC)	32.6 ± 1.9^{a}	26.1 ± 2.2^{b}	18.9 ± 0.8^{c}
Orange-clawed male (OC)	58.6±1.9	60.9±1.6	58.8±1.7
Small male (SM)	8.8 ± 0.8^{c}	13.0 ± 2.8^{b}	22.3 ± 0.9^{a}

While growth and production parameters for silver carp and catla did not differ significantly among treatments, mola production did vary significantly with the highest net production observed in the MP_{20000} treatment that was significantly different from MP_{25000}, with the remaining treatment being intermediate and not significantly different from the others. Combined net production of all finfish as well as all species (including prawns) differed significantly among treatments. MP_{20000} produced a significantly higher net production of all finfish combined than for MP_{25000}, while production in MP_{15000} was not significantly different from either of the other treatments. MP_{20000} also yielded significantly higher net production of all species combined (finfish and prawn) compared with MP_{15000}, with yield from MP_{25000} not significantly different from the other treatments.

Data on estimated total cost, benefit and profit in US$ (70.00 Bangladesh Taka = 1.00 US$) over a 152-day culture period calculated for a 1 ha pond under the different treatments are presented in Table 4. Cost of prawn juveniles plus feed in treatments MP_{15000}, MP_{20000} and MP_{25000} represented 69%, 74% and 78% of total costs, while prawns contributed 78%, 79% and 81% to the total sale proceeds, respectively. Overall estimated return was significantly higher from the MP_{20000} treatment compared with MP_{25000}, and MP_{15000} was intermediate but not significantly different from the other treatments. The BCR was higher in treatments MP_{15000} (1.89) and MP_{20000} (1.79) than in treatment MP_{25000} (1.53).

Table 4. Comparisons of economics (mean±SD, *N*=3) calculated on the basis of 1 ha pond for 152 days culture period. Mean values with different superscripts indicate significant difference (*P*<0.05) among treatments.

Items	**MP$_{15000}$**	**MP$_{20000}$**	**MP$_{25000}$**
A. Cost in US$			
a) All costs: pond rent, prawn juveniles, fingerlings, feed, fertilisers, labourers, etc.	2545.20±6.29^{c}	3099.29±11.37^{b}	3617.56 ±7.07^{a}
b) Bank interest for 6 months (12% year^{-1})	152.71±0.38^{c}	185.96±0.68^{b}	217.05±0.42^{a}
Total cost in US$ (A)	2697.91±6.67^{c}	3285.24±12.05^{b}	3834.61±7.49^{a}
B. Benefit (sale prices) in US$			
Large prawn (≥50 g) @ US$ 7.14 kg^{-1}	3182.24±87.63	3431.45±133.36	3275.38±233.82
Medium prawn (33.3- 49.9 g) @ US$ 5.00 kg^{-1}	708.80±43.38^{b}	1105.35±129.59^{a}	1238.67±196.27^{a}
Small prawn (≤33.2 g) @ US$ 2.86 kg^{-1}	78.89±6.01^{b}	128.74 ± 5.90^{b}	252.69 ±38.38^{a}
Prawn total in US$	3969.92 ±125.85^{b}	4665.55 ±135.49^{a}	4766.73±316.81^{a}
Silver carp @ US$ 0.79 kg^{-1}	508.59±25.49	538.64±36.10	495.57±24.01
Catla@ US$ 1.29 kg^{-1}	313.96 ±13.63	360.96 ±26.29	320.08±39.36
Mola@ US$ 2.14 kg^{-1}	302.18 ± 6.89^{ab}	316.91 ± 7.49^{a}	288.65±6.06^{b}
Total benefit in US$ (B)	5094.65±151.06^{b}	5882.06±156.32^{a}	5871.04 ±314.31^{a}
C. Profit in US$ (B - A)	2396.74±151.81^{ab}	2596.81±147.26^{a}	2036.43±307.58^{b}
D. BCR (B ÷ A)	1.89±0.06^{a}	1.79±0.04^{a}	1.53±0.08^{b}

1 US$ = 70 Bangladesh Taka

Discussion

Stocking density of prawns did not significantly affect any of the water quality parameters examined in the current study, so any observed differences in productivity related to treatment effects (prawn density) were achieved without any noticeable effect on environmental quality in the ponds.

While survival rates of freshwater prawns in the current study were not affected by stocking density, mean weight at harvest declined significantly at higher densities. Early workers (Cohen et al.1981; Wohlfarth et al. 1985; Karplus et al. 1986; Pillai et al. 2007) have also reported density dependent effects on growth pattern in *M. rosenbergii.* While selective harvesting of BC prawns in each treatment in the present study did minimise HIG effects by reducing the number of SMs (8.8-22.3% in the different treatments), the number of SMs at final harvest reported by Ra'anan et al. (1991) can be up to 50% in some instances. The proportion of SMs present was related to stocking density and the inverse of the effect on BC males as reported by Karplus et al. (1986) in their earlier study. Overall production of prawns in the three treatments here ranged from 615 kg to 795 kg·ha^{-1}over a152-day culture cycle. This production range is promising and almost equivalent to that achieved in farm monoculture (750 kg·ha^{-1}) in Bangladesh as reported by the DoF (2007). In contrast, only 521 kg of freshwater prawn·ha^{-1} at a stocking density of 2.0 prawn·m^{-2} was reported by Karplus et al. (1986) from polyculture ponds. Kunda et al. (2009) recorded a production rate of 697 kg·ha^{-1}for polyculture of all-male prawn with finfish in fallow rice fields where prawns were stocked at 2.0 m^{-2}. Survival rate of freshwater prawn in the different treatments in the present study ranged from 73 to 77% with a survival rate above 50% considered acceptable by New and Singholka (1985). Malecha (1983) reported about 50 to 60% survival rate of freshwater prawn in continuous culture systems while Kunda et al. (2009) recorded a survival rate of prawn of 64% in their all-male freshwater prawn polyculture trials. The relative high survival rate combined with good production performance of prawn in the present study suggest that periodic selective harvesting of BC during the culture phase can improve relative biomass yields (Sagi and Aflalo 2005) in freshwater prawn farming, especially if an all-male prawn-finfish polyculture system is applied (Rahman et al. 2010a).

Carp (silver carp and catla) production in the current study ranged from 880 to 966 $kg^{\cdot} ha^{-1}$over 152 days and this was higher than the average annual finfish production of 660 $kg^{\cdot}ha^{-1}$ in prawn-fish polyculture system in Bangladesh (Asaduzzaman et al. 2006). Additionally productions of 135-148 kg $mola^{\cdot}ha^{-1}$ were comparable with records of 124-152 $kg^{\cdot}ha^{-1}$over 120 days reported by Kunda et al. (2008) in a mixed freshwater prawn and mola culture system in rotational rice fields, and 52-84 $kg^{\cdot}ha^{-1}$ in 138 days in polyculture with major carps in ponds recorded by Kadir et al. (2006).

When net production of all species is combined including prawn and finfish, the yield from the MP_{20000} treatment was better than that for MP_{15000}. When stocking density was highest (MP_{25000}) however, net yield of all species combined in this treatment was not higher than the remaining treatments. The balance achieved at the intermediate density of freshwater prawn with finfish tested here, appeared to provide the best synergistic interaction (Milstein, 2005) resulting in higher overall production levels.

The relative benefits of polyculture of freshwater prawn can vary depending on the yield and size of individuals while costs vary depending on the number and size of prawn juveniles stocked and the quantity of feed supplied (Karplus et al. 1986). Although investment cost will increase with higher prawn density, economic analyses of the current data set reveal that all-male prawn combined with finfish in polyculture was cost-effective at all stocking densities of prawn studied here. While higher gross income was obtained at densities of 20,000 and 25,000 $prawn^{\cdot}$ ha^{-1}, when BCR is considered, prawn densities at 15,000 and 20,000 ha^{-1} provided much better returns. Overall, a stocking density of 20,000 $prawn^{\cdot}ha^{-1}$ achieved the best outcome in terms of overall production level and net profit earned.

Conclusion

While increasing freshwater prawn stocking density had virtually no effect on water quality parameters when periodic selective harvesting of blue-clawed male prawns in polyculture with fish (silver carp, catla, and mola) was tested, the most sustainable production and the best financial returns came from use of the intermediate prawn density at 20,000 ha^{-1}.

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