Aquacult Int (2018) 26:523–541
https://doi.org/10.1007/s10499-017-0229-8

Effects of stocking densities of tilapia *Oreochromis niloticus* (Linnaeus, 1758) with the inclusion of silver carp *Hypophthalmichthys molitrix* (Valenciennes, 1844) in C/N-CP prawn *Macrobrachium rosenbergii* (De Man, 1879) culture pond

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Received: 10 July 2017 / Accepted: 12 December 2017 / Published online: 7 January 2018

Abstract The effects of stocking density of tilapia *Oreochromis niloticus* with the inclusion of silver carp *Hypophthalmichthys molitrix* were evaluated in the C/N-CP prawn *Macrobrachium rosenbergii* farming system in triplicate. Management practices were same for all treatments. Bamboo side shoots were posted vertically into the pond bottoms as a periphyton substrate. A locally formulated and prepared feed containing 15.44% crude protein with a C/N ratio 15 were applied twice daily in all ponds. Maize flour was supplied in water for raising the C/N ratio 20 in all treatments. Water quality parameters, except transparency and chlorophyll *a*, did not differ significantly ($P > 0.05$) among the treatments. The periphytic abundance and biomass differed significantly ($P < 0.05$) among the treatments and even among different months. Although the individual harvesting weight, individual weight gain, and SGR were significantly higher ($P < 0.05$) in the T_{10000} treatment compared to T_{15000} and T_{20000} treatments, respectively, the gross and net yields of tilapia were significantly higher ($P < 0.05$) in the treatment T_{20000} followed by T_{15000} and T_{10000} treatments resulting in higher combined gross and net yield of both prawn and tilapia (16.05 and 16.92%, 32 and 33.59% from the later two treatments, respectively) with a higher economic return (BCR 0.53) during a 122-day culture period. As a whole, the study revealed that prawn, tilapia, and silver carp with a stocking density at 30,000,

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20,000, and 1250 ha^{-1}, respectively, was found to provide an optimum and sustainable production as well as economic benefit in the C/N-CP-based culture system.

Keywords Stocking density · Tilapia · Silver carp · Freshwater prawn · C/N ratio · Periphyton

Introduction

The giant freshwater prawn (*Macrobrachium rosenbergii*) is a major aquaculture species found mostly in the south-southeast Asia and Asia pacific region (Akand and Hasan 1992). Bangladesh is recognized as one of the most suitable countries in the world for giant freshwater prawn farming due to its favorable vast area of resources and sub-tropical agro-climatic conditions (Hassanuzzaman et al. 2011; Ahmed et al. 2010). At present, the freshwater prawn farming is one of the most emerging sectors in the national economy of Bangladesh and its development has attracted considerable attention over the last two decades because of its export potential over the world (Yasmin et al. 2010). Nearly all freshwater prawns have enormous demand and high price in international markets (DoF 2013), particularly in the USA, Europe, and Japan (Ahmed et al. 2009), and high price in local market (Asaduzzaman et al. 2009a, b). It is a very popular species for its high growth rate, omnivorous feeding habits, allow variety of feeds, good flavor and taste, and high nutritive value (Shafi 2003). Therefore, freshwater prawn is a suitable species for aquaculture and its farming is contributing significantly in the national economy of Bangladesh. On the contrary, the total production of shrimp and prawn was 186,892 mt, of which 51,599 mt was exported earning a US$412.17 million in 2009–2010, where, the shrimp (*Penaeus monodon*) alone contributed about 75% of the total exported volume (DoF 2011). Hence, shrimp farming is more vulnerable than prawn due to coastal environmental degradation and disease outbreak like white spot disease which is not found in prawn. However, shrimp is still contributing the major part of the total export earning in the fisheries sector (Haque et al. 2015).

Several research efforts have been made to improve productivity and sustainability of pond aquaculture production and seem to be promising: (1) control of C/N ratio (Avnimelech 2007; Hari et al. 2004); (2) development of periphyton using substrates (Tidwell and Bratvold 2005; Milstein et al. 2009); (3) fish driven re-suspension (Milstein et al. 2002; Ritvo et al. 2004); and (4) combination of the C/N ratio, periphyton substrates, and fish driven approaches in freshwater ponds that is known as the C/N controlled periphyton-based (C/N-CP) system (Asaduzzaman et al. 2008, 2010; Haque et al. 2015). These approaches are simple, cheap, socially, and economically sustainable for small-scale farmers.

In the earlier research, it has been found that addition of tilapia, *Oreochromis niloticus* (1 individual m^{-2}), in the C/N-CP-based freshwater prawn culture system improved pond ecology, growth, and production of prawn (Haque et al. 2015). The periphyton community can easily take TAN and nitrate formed by this culture technology and enhances their edible biomass. It has been found that tilapia can efficiently scrape on periphyton (Dempster et al. 1993; Milstein et al. 2009) as well as the phytoplankton community (Perschbacher and Lorio 1993). Therefore, this technique efficiently improves the overall conversion of the feed. Jiménez-Montealegre et al. (2002) claimed that tilapia re-suspends bottom sediments by their stirring activity and increases the availability of dissolved oxygen there leading to better mineralization and stimulating the natural food. In addition, monosex male tilapia (*Oreochromis niloticus*) has been found to be compatible with freshwater prawn, leading to a promising production due to its faster growth rate, more efficient utilization of natural feed, and bioturbation effect (Asaduzzaman et al. 2009a, b, 2010).

The silver carp, *Hypophthalmichthys molitrix* (Val.), is an appropriate candidate species for polyculture in south Asian aquaculture (Wahab et al. 1995) with freshwater prawn and other carps (Rahman 2010). This species is a phytoplanktivorous filter feeder, which feeds on algae of various sizes (Smith 1989), can prevent sudden algal bloom efficiently (Hepher and Pruginin 1981), and can raise benthophagous fish food resources through its fecal pellets in a polyculture system (Milstein 1992). Besides, it has a greater acceptance in the local market (Rahman et al. 2010b) and fetches low market price which is affordable to the poorer section of the people to meet their protein demand. In our previous experiment of the C/N controlled periphyton-based polyculture system, it was assumed that all the natural foods were not used entirely by stocking tilapia with prawn. Therefore, considering the importance of silver carp as an indispensable species in the polyculture of Bangladesh having phytoplanktivorous filter-feeding food habit, it was necessary to evaluate the effects of stocking densities of tilapia with the inclusion of silver carp on the production and economics in C/N-CP-based tilapia-freshwater prawn farming ponds. Special attention was given on the effect of different treatments on water quality, natural food availability, production, and economic performances of such system.

Materials and methods

Experimental design

The trial was conducted using the randomized complete block design into three treatments namely, T_{10000}, T_{15000}, and T_{20000} with three replications. Treatments were named according to stocking densities of monosex male tilapia (*Oreochromis niloticus*) per hectare. The stocking density of prawn (*Macrobrachium rosenbergii*) and silver carp (*Hypophthalmichthys molitrix*) was same in all treatments as prawn 30,000 ha^{-1} and silver carp 1250 ha^{-1}. Feed with maize flour for prawn and bamboo *kanchi* were provided in all treatments for maintaining the C/N ratio 1:20 and developing periphyton, respectively.

Experimental site and pond preparation

The experiment was carried out at the Fisheries Field Laboratory of the Faculty of Fisheries, Bangladesh Agricultural University (BAU), Mymensingh, for a period of 122 days during 15 April to 15 August, 2010. Nine rectangular earthen ponds with an area of 130 m^2 and an average depth of 1.5 m each were used for this research. The ponds were rain fed and fully exposed to prevailing sunlight and being used for research over last 15 years. The pond banks were well protected and covered with grasses. Aquatic vegetation was manually cleaned before commencing the experiment. All unwanted fish were eradicated by the application of rotenone at the rate of 380 g pond^{-1}. Lime ($CaCO_3$) was applied to all ponds at 250 kg ha^{-1} on day 1. On day 4, 15 bamboo side shoots (locally called *kanchi*) per square meter (mean diameter of 2.8 cm) were posted vertically into the bottom mud, excluding a 0.5-m wide perimeter. This resulted in an additional area of 171 m^2 for periphyton development equaling 131% of the pond surface area. On day 7, ponds were fertilized with urea and triple super phosphate (TSP) each at 50 kg ha^{-1}. Ponds were left 10 days to allow plankton development in the water column and periphyton growth on substrates and subsequently stocked with prawn and fishes.

Stocking and pond management

The juvenile of prawn (individual weight 5.27 ± 0.00), fry of tilapia (individual weight 0.42 ± 0.00), and fingerlings of silver carps (individual weight 9.21 ± 0.00) were procured from a government hatchery at Katiadi Upazila of Kishoreganj District, nearby commercial private hatchery, and fish traders of Mymensingh district, respectively. All prawn and fishes were stocked in the ponds following the experimental design. After, stocking ponds were also fertilized fortnightly following the same rate as applied before stocking to continue steady natural food abundance. A locally formulated and prepared pellet feed (2 mm size) containing about 15% protein (dry matter basis) with a C/N ratio 15:1 was used. The feed was applied considering the body weight of prawn only after each sampling at a daily feeding rate of 10% body weight at the beginning the experiment (up to 30 days) and assuming 80% survival feed application was gradually reduced reaching 4% body weight at the end of the culture period. Feed was distributed uniformly over the pond surface twice daily at 07:00 and 18:00 h. Individual weights of minimum 10% of the initially stocked prawn in numbers were taken at monthly interval to estimate the biomass and adjust the feeding rate. The prawns were sampled using a cast net after eliminating some bamboo side shoots, which were re-positioned after each sampling.

A locally purchased maize flour was used as the carbohydrate source for manipulating the C/N ratio. The analyzed proximate composition of feed and maize flour is given in Table 1. In the pond, 0.78 kg maize flour was applied for each kilogram of formulated feed to raise the C/N ratio to 20:1. The pre-weighed maize flour was mixed with pond water in a beaker and evenly distributed over the pond surface directly after the application of feed at 07:00 and 18:00 h.

Harvesting of prawn, tilapia, and silver carps

Freshwater prawn, tilapia, and silver carps were harvested after draining the ponds using a shallow pump. The individual length (wooden measuring board; precision 0.1 cm) and individual weight (Denver-xp-3000, Denver Instrument Company, Arvada, CO, USA; precision = 0.1 g) were recorded. Specific growth rate (SGR), feed conversion ratio (FCR), and net yields were calculated as follows:

$$\mathrm{SGR}\left(\%\mathrm{bw\,day}^{-1}\right) = [(\mathrm{Ln}\,final\quad weight - \mathrm{Ln}\,initial\quad weight) \times 100]/culture\quad periods(days)$$
$$\mathrm{FCR}(prawn\quad only) = feed\quad applied(\mathrm{dry}\,weight)/live\quad weight\quad gain$$
$$\mathrm{Net}\,yield = total\quad biomass\,\mathrm{at}\,harvest - total\quad biomass\,\mathrm{at}\,stocking.$$

Determination of water quality parameters

All water quality parameters viz. temperature, dissolved oxygen, pH, transparency, total alkalinity, nutrients, and NO_2-N, NO_3-N, NH_3-N, and PO_4-P concentrations were determined according to Haque et al. (2015).

Table 1 Proximate composition of the prepared feed and maize flour (dry weight basis)

Component	Moisture (%)	Protein (%)	Lipid (%)	Fiber (%)	Ash (%)	NFE (%)
Prepared feed	16.35	15.44	10.31	6.35	15.21	36.34
Maize flour	11.08	7.72	4.64	5.40	1.14	70.02

NFE = nitrogen free extract = (100 − (moisture + protein + lipid + crude fiber + ash)

Estimation of plankton and benthic macroinvertebrates

Plankton and benthic macroinvertebrates were estimated and calculated as described by Haque et al. (2015).

Taxonomic composition and biomass of periphyton

Taxonomic composition and biomass of periphyton were estimated and calculated as described by Haque et al. (2016).

Economic analysis

An economical analysis was performed to estimate the net return and benefit-cost ratio in two treatments. The following equation was used:

$$R = I - (\mathrm{FC} + \mathrm{VC} + \mathrm{Ii})$$

Where, R = net return, I = income from prawn and tilapia sale, FC = fixed/common costs, VC = variable costs, and Ii = interest on inputs. The benefit cost ratio was determined by following equation:

Benefit cost ratio (BCR) = total net return / total input cost.

The wholesale price per kilogram of prawn, tilapia, and silver carp were 400, 95, and 60 taka, respectively. The prices of inputs, prawn, and fish correspond to the local (Mymensingh) wholesale market prices in April to August, 2010, and are expressed in Bangladeshi taka (US$1 = 70 BDT).

Statistical analysis

One-way analysis of variance (ANOVA) was performed to compare growth and production of prawn and tilapias among the treatments. Survival and per cent data were analyzed using arcsine transformed data, but per cent values were reported. Water quality parameters including plankton, periphyton, and benthic macroinvertebrates data were compared in a repeated measure ANOVA where treatments were the main factors and time was the sub-factors (Gomez and Gomez 1984). If the main effect was found significant, the ANOVA was followed using Tukey's test. The assumptions of normal distribution and homogeneity of variances were checked before analysis. All statistical tests were carried out at a 5% level of significance using SPSS version 16.0.

Results

Water quality parameters

Water quality parameters (Table 2) did not vary significantly ($P > 0.05$) among the treatments, except transparency and chlorophyll *a*. Nonetheless, a significant variation on different sampling dates (temporal effects) was observed on water quality parameters. The highest mean temperature was recorded on the last week of July (32.25 °C) in all treatments, and the lowest mean temperature was recorded on the last week of June (26 °C) in the T_{15000} treatment. The highest mean transparency (63 cm) was found in the second week of August in treatment T_{20000}, and the lowest mean transparency (33 cm) was recorded in the second week of April during the first sampling in treatment T_{10000}. A more or less increasing trend of water transparency was observed in all treatments during the experimental period (Fig. 1). The water pH ranged from 6.9 to 8.9 throughout the study. The highest mean dissolved oxygen concentration (9.0 mg L^{-1}) was recorded in the last week of May in treatment T_{20000}, and the lowest mean DO concentration (3.0 mg L^{-1}) was recorded in the third week of July, second week of May, and third week of April in treatments T_{10000}, T_{15000}, and T_{20000}, respectively.

The highest total alkalinity (190 mg L^{-1}) was observed in the second week of August in treatment T_{15000}, and the lowest total alkalinity (50 mg L^{-1}) was observed in the second week of April (during the first sampling) and May in treatment T_{10000} and second week of May in treatment T_{20000}. The inorganic nitrogenous compounds (NH_3-N, NO_3-N, and NO_2-N) were affected by the treatment, but the phosphate phosphorus was not also affected ($P > 0.05$) by the treatments. A temporal effect as well as an increasing trend of water transparency, total alkalinity and phosphate phosphorus, and a decreasing trend of chlorophyll *a* was observed among different sampling dates throughout the study period (Fig. 1).

Abundance of plankton and benthos

The abundance of plankton population (phytoplankton and zooplankton) and their different groups did not vary significantly ($P > 0.05$) among the treatments (Table 3), but they varied significantly ($P < 0.05$) among different sampling dates (temporal effects). Phytoplankton was 81% in number of the total plankton in all treatments. The plankton communities in pond water composed of four major groups of phytoplankton and two groups of zooplankton in all treatments. Thirty-five genera of phytoplankton belonging to Chlorophyceae (14), Bacillariophyceae (11), Cyanophyceae (8), and Euglenophyceae (2) were found. Chlorophyceae followed by the Bacillariophyceae was the most dominant group in terms of number of genera among phytoplankton in each treatment. The dominant genera were *Pediastrum*, *Chlorella*, *Tetraedron*,

Table 2 Mean (± SD) values of water quality parameters

Variables	Treatments			Level of significance (P) at 5%
	T_{10000}	T_{15000}	T_{20000}	
Temperature (°C)	29.49 ± 1.64	29.31 ± 1.54	29.44 ± 1.55	0.827
Transparency (cm)	38.7 ± 7.13b	40.22 ± 7.46ab	42.19 ± 8.20a	0.049
pH range	7.1–8.7	7–8.9	6.9–8.8	0.129
Dissolved oxygen (mg L^{-1})	5.31 ± 1.37	5.75 ± 1.36	5.53 ± 1.39	0.250
Total alkalinity (mg L^{-1})	109 ± 45.13	119 ± 47.52	109 ± 42.52	0.783
Total NH_3-N (mg L^{-1})	0.17 ± 0.06	0.16 ± 0.05	0.17 ± 0.06	0.741
NO_3-N (mg L^{-1})	0.11 ± 0.13	0.08 ± 0.05	0.09 ± 0.07	0.692
NO_2-N (mg L^{-1})	0.02 ± 0.01	0.03 ± 0.04	0.04 ± 0.03	0.175
PO_4-P (mg L^{-1})	0.70 ± 0.30	0.76 ± 0.39	0.82 ± 0.42	0.646
Chlorophyll *a* (μg L^{-1})	144.31 ± 45.70a	118.60 ± 40.15ab	102.10 ± 50.10b	0.048

NS values are not significantly different ($P > 0.05$) based on Tukey's test

*Values with different lowercase letters in the same row indicate a significant difference (P<0.05) based on one-way ANOVA followed by Tukey's test

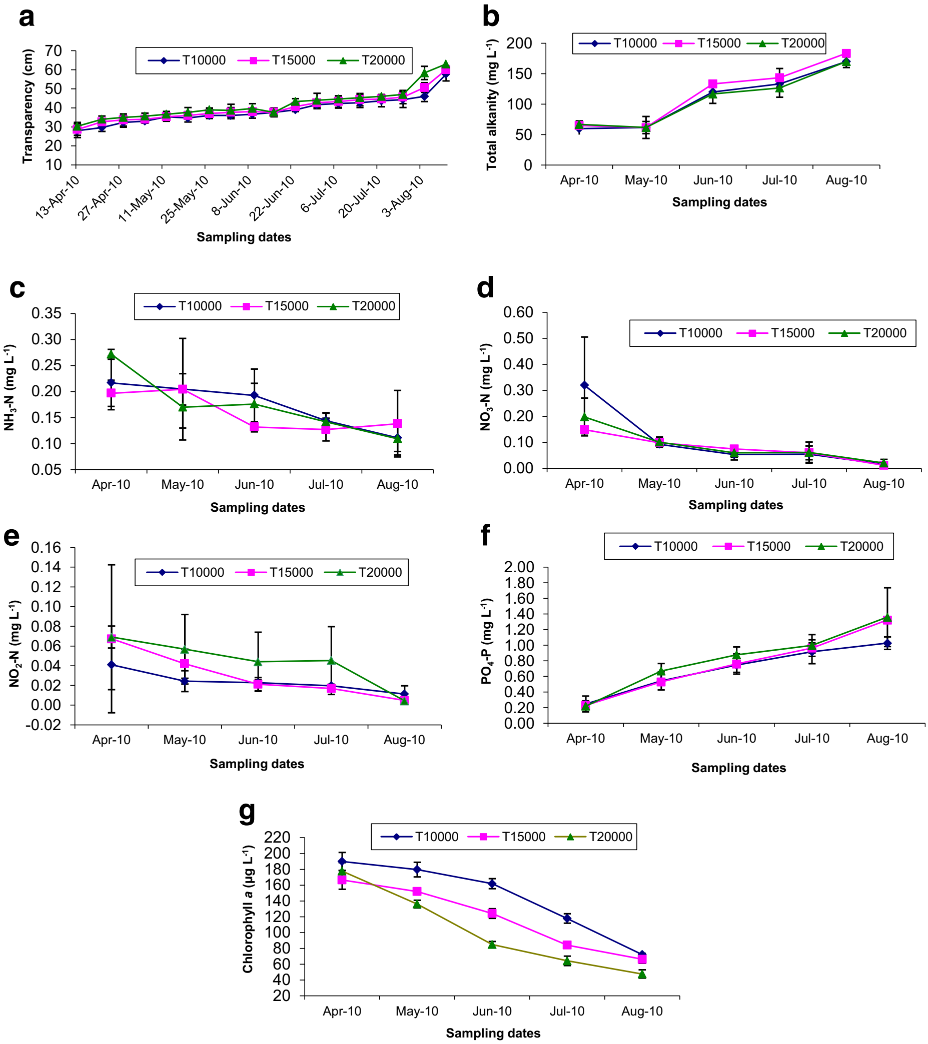

Fig. 1 Mean (± SD) concentration of **a** transparency, **b** total alkalinity, **c** ammonia, **d** nitrate, **e** nitrite, **f** phosphate, and **g** chlorophyll *a* in three treatment ponds over the sampling period

Scenedesmus, *Actinastrum*, and *Ulothrix* (Chlorophyceae); *Navicula*, *Tabellaria*, *Cyclotella*, *Coscinodiscus*, *Fragillaria*, and *Nitzchia* (Bacillariophyceae); *Anabaena*, *Gomphosphaeria*, *Microcystis*, and *Gleocapsa* (Cyanophyceae); and *Euglena* and *Phacus* (Euglenophyceae). A total 12 genera of zooplankton of which five genera of Rotifera and seven genera of Crustacea were identified. The abundance of total phytoplankton, and zooplankton (except in June of treatment T_{15000}) decreased gradually throughout the study period (Fig. 2).

The benthic macroinvertebrates consisted of Chironomidae, Oligochaeta, Mollusca, and unidentified species. Chironomidae followed by Oligochaeta was the most dominant group among benthos in all treatments. There were no significant ($P > 0.05$) effects on the mean abundance of any major group of benthic macroinvertebrates and total benthos in the pond bottom among the treatments (Table 3) but a significant ($P < 0.05$) temporal effect of mean abundance of total benthic macroinvertebrates with their different groups among different sampling dates was observed. The major groups of total benthos did not show any definite trend, except Oligochaeta with a lower trend excluding last month in treatments T_{10000} and T_{15000}, but the total number of benthos decreased gradually in all treatments (Fig. 2).

Periphyton composition and biomass

Thirty-seven genera of phyto-periphyton belonging to Chlorophyceae (15), Bacillariophyceae (12), Cyanophyceae (8), and Euglenophyceae (2), and six genera of zoo-periphyton belonging to Rotifera (5) and Crustacea (1) were identified as periphytic communities in three treatments during the experiment. Chlorophyceae was the most abundant and dominant in species number, and Euglenophyceae was the least abundant groups of periphytic algae in three treatments. In contrast, Rotifera was found to be higher zoo-periphytonic group in species number than Crustacea in three treatments. *Botriococcus*, *Chlorella*, *Pediastrum*, *Scenedesmus*, *Ceratium*, and *Actinastrum* (Chlorophyceae); *Melosira*, *Cyclotella*, *Diatoma*, *Coscinodiscus*, *Nitzchia*, *Navicula*, *Fragillaria*, and *Actinella* (Bacillariophyceae); *Microcystis*, *Gomphosphaeria*, and *Gleocapsa* (Cyanophyceae); and *Euglena* and *Phacus* (Euglenophyceae), while *Brachionus*, *Asplanchna* and *Karatella* (Rotifera), and larval Nauplius (Crustacea) were the dominant genera of zooplankton in three treatments. The total abundance of phyto-periphyton, zoo-periphyton, and periphyton population with Chlorophyceae, Cyanophyceae, and Euglenophyceae groups varied significantly ($P < 0.05$) among the treatments (Table 4). Hence, a temporal effect ($P < 0.05$) was observed on the total abundance of them among different sampling dates during the experimental period. The major groups of total periphyton did not show any definite trend, except Euglenophyceae with a lower trend in all treatments, but the total number of phyto-periphyton, zoo-periphyton as well

Table 3 Abundance of plankton and benthos (mean ± SD; $N = 15$) with different groups identified in different treatments

Variables	Treatments			Level of significance at 5%
	T_{10000}	T_{15000}	T_{20000}	
Plankton (× 10^3 cells or colonies L^{-1})				
Chlorophyceae	22.30 ± 4.84	19.47 ± 5.46	21.20 ± 4.30	NS
Bacillariophyceae	16.30 ± 4.63	17.37 ± 5.27	13.90 ± 6.19	NS
Cyanophyceae	13.23 ± 5.27	11.40 ± 8.08	10.07 ± 5.33	NS
Euglenophyceae	5.10 ± 2.84	5.60 ± 4.40	4.60 ± 2.82	NS
Total phytoplankton	57 ± 7.57	54 ± 11.74	50 ± 8.95	NS
Rotifera	6.30 ± 3.08	4.97 ± 1.93	5.93 ± 2.40	NS
Crustacea	7.73 ± 3.86	7.97 ± 3.92	7.23 ± 3.49	NS
Total zooplankton	14 ± 5.88	13 ± 5.12	13 ± 5.73	NS
Total plankton	71 ± 12.60	67 ± 15.44	63 ± 12.91	NS
Benthos (individual m^{-2})				
Chironomidae	435 ± 356	494 ± 278	350.62 ± 255	NS
Oligochaeta	410 ± 250	405 ± 209	386.17 ± 238	NS
Mollusca	352 ± 216	337 ± 147	303.21 ± 108	NS
Unidentified	63.21 ± 33.35	75 ± 36	56.30 ± 19	NS
Total benthos	1261 ± 540	1310 ± 430	1096 ± 458	NS

NS values are not significantly different ($P > 0.05$) at the 5% level of significance based on one-way ANOVA followed by Tukey's test

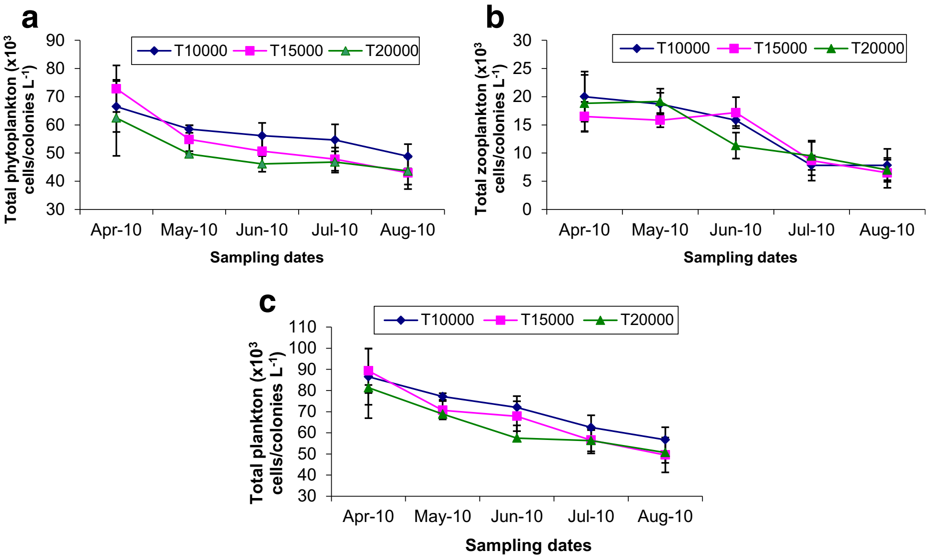

Fig. 2 Abundance of **a** total phytoplankton, **b** total zooplankton, and **c** total plankton in three treatment ponds over the sampling periods (mean ± SD, $N = 3$)

as periphyton decreased gradually in all treatments (Table 4). The periphytic compositions differed with plankton. *Melosira* and *Botryococcus* were the different periphytic genera which were not common in the phytoplankton communities. On the contrary, *Daphnia*, *Diaphanosoma*, *Sida*, *Moina*, *Cyclops*, and *Diaptomus* were the different zooplankton communities which were not found in periphytic communities.

The DM, ash, AFDM, and chlorophyll *a* contents varied significantly ($P < 0.05$) among the treatments (Table 4) as well as among different sampling months during the experimental period. A more or less decreasing trend was observed for the DM, AFDM with a few exception and chlorophyll *a* content over the culture period. The autotrophic index (AI) values were found to be ranged from 75.18 to 221.24, 60.68 to 220.23, and 79.49 to 198.51 in T_{10000}, T_{15000}, and T_{20000} treatments, respectively.

Growth and yield parameters of prawn, tilapia, and silver carp

Growth and yield parameters including individual harvesting weight, individual weight gain, specific growth rate, FCR (for prawn only), gross, and net yields of prawn and silver carp did not vary significantly ($P > 0.05$) among the treatments. On the contrary, individual harvesting weight, individual weight gain, and specific growth rate (% body weight per day) of tilapia were significantly ($P > 0.05$) higher in the T_{10000} treatment compared to T_{15000} and T_{20000} treatments, respectively. The overall gross and net yields of tilapia were significantly higher ($P > 0.05$) in treatment T_{20000} followed by T_{15000} and T_{10000} treatments. In addition, a significantly ($P < 0.05$) higher combined gross and net yield of prawn, tilapia, and silver carp were also observed in treatment T_{20000} (32 and 33.59%, respectively) followed by treatments T_{15000} (16.05 and 16.92%, respectively) and T_{10000} (Table 5).

Table 4 Abundance and biomass of periphyton (mean ± SD, $N = 15$) assessed in different treatments

Variables	Treatments			Level of significance (P) at 5%
	T_{10000}	T_{15000}	T_{20000}	
Periphyton (× 10^3 cells or colonies cm^{-2})				
Bacillariophyceae	6.83 ± 0.94	6.23 ± 1.73	5.75 ± 1.68	0.154
Chlorophyceae	8.86 ± 0.65a	7.78 ± 2.17a	6.44 ± 2.10b	0.002
Cyanophyceae	3.85 ± 0.51a	3.12 ± 0.68b	2.05 ± 0.64c	0.000
Euglenophyceae	1.97 ± 0.60a	1.43 ± 0.80b	1.19 ± 0.75b	0.015
Total phyto-periphyton	21.52 ± 1.56a	18.56 ± 4.03b	15.43 ± 4.73c	0.000
Rotifera	1.72 ± 0.33	1.68 ± 0.41	1.63 ± 0.43	0.813
Crustacea	0.57 ± 0.32	0.42 ± 0.36	0.37 ± 0.31	0.220
Total zoo-periphyton	2.30 ± 0.49	2.09 ± 0.56	2.00 ± 0.67	0.362
Total periphyton	23.82 ± 1.93a	20.66 ± 4.47b	17.43 ± 5.25c	0.001
Quantitative biomass				
Dry matter (mg cm^{-2})	3.04 ± 0.68a	2.26 ± 0.88b	1.48 ± 0.90c	0.000
Ash (mg cm^{-2})	1.20 ± 0.29a	0.91 ± 0.39b	0.63 ± 0.43c	0.001
Ash free dry matter (mg cm^{-2})	1.83 ± 0.69a	1.35 ± 0.65b	0.85 ± 0.62c	0.001
Chlorophyll *a* (μg cm^{-2})	13.78 ± 3.97a	10.25 ± 3.88b	6.88 ± 5.36c	0.001
Autotrophic index	134 ± 44	132 ± 52	132 ± 40	0.995

*Values with different lowercase letters in the same row indicate a significant difference ($P < 0.05$) based on one-way ANOVA followed by Tukey's test

Economics

Although the extrapolated costs of all variable inputs were significantly higher ($P < 0.05$) in the T_{20000} treatment followed by treatments T_{15000} and T_{10000}, a significantly higher ($P < 0.05$) gross earning as well as net profit with a BCR of 0.53 was obtained in treatment T_{20000} followed by treatments T_{15000} (BCR 0.48) and T_{10000} (BCR = 0.42) (Table 6). Substrates were the most expensive inputs (about 42–45% of the total costs) in all treatments followed by prawn juveniles (34–36%). A significantly ($P < 0.05$) higher earning was obtained from a tilapia sale in treatment T_{20000} followed by treatments T_{15000} and T_{10000}. However, about 59–65% of the total income obtained from prawn sale while the remainders came from tilapia and silver carp sale.

Discussion

Water quality parameters

Most of the water quality parameters were within the satisfactory range for prawn and finfish culture throughout the experiment (Boyd and Zimmermann 2000; New 2002). Water transparencies were found to vary from 33 to 63 cm in different treatments, exceeded the upper limit of the recommended range (15–40 cm) suggested by Boyd (1992). The transparency was lower at the beginning of the experiment, but it increased gradually over time in all treatments. These might be attributed to the higher grazing pressure of the cultured herbivorous/omnivorous organisms with the increasing biomass over time, which might be also an evidence of the decreasing trends of chlorophyll *a* as well as plankton abundance. The

Table 5 Growth and production performance (mean ± SD) of prawn, tilapia, and silver carp in different treatments during a122-day culture period

Variables	Treatments		
	T_{10000}	T_{15000}	T_{20000}
Prawn			
Individual stocking weight (g)	5.27 ± 0	5.27 ± 0	5.27 ± 0
Individual harvesting weight (g)	34.0 ± 1.05	34.40 ± 0.80	34.80 ± 1.31
Individual weight gain (g)	28.73 ± 1.05	29.13 ± 0.80	29.53 ± 1.31
Specific growth rate (% bw day^{-1})	1.53 ± 0.03	1.54 ± 0.02	1.55 ± 0.03
Food conversion ratio	3.0 ± 0.09	2.97 ± 0.05	2.92 ± 0.09
Survival (%)	75.56 ± 2.07	74.10 ± 1.18	74.27 ± 1.55
Gross yield (kg ha^{-1} 122 day^{-1})	757 ± 20.53	764 ± 13.47	787 ± 27.83
Net yield (kg ha^{-1} 122 day^{-1})	640 ± 20.26	647 ± 13.55	668 ± 27
Tilapia			
Individual stocking weight (g)	0.42 ± 0.00	0.42 ± 0.00	0.42 ± 0.00
Individual harvesting weight (g)	235 ± 2.63a	199 ± 6.52b	179 ± 5.71c
Individual weight gain (g)	235 ± 2.63a	199 ± 6.52b	178 ± 5.71c
Specific growth rate (% bw day^{-1})	5.19 ± 0.01a	5.05 ± 0.03b	4.96 ± .03c
Survival (%)	60.51 ± 1.18	59.66 ± 1.07	59.36 ± 0.80
Gross yield (kg ha^{-1} 122 day^{-1})	1425 ± 35c	1782 ± 73.44b	2122 ± 43a
Net yield (kg ha^{-1} 122 day^{-1})	1422 ± 35c	1778 ± 73b	2117.53 ± 44a
Silver carp			
Individual stocking weight (g)	9.21 ± 0	9.21 ± 0	9.21 ± 0
Individual harvesting weight (g)	267.49 ± 34.43	312.60 ± 54.92	330.46 ± 59.91
Individual weight gain (g)	258.28 ± 34.43	303.39 ± 54.92	321.25 ± 59.91
Specific growth rate (% bw day^{-1})	2.76 ± 0.10	2.88 ± 0.15	2.93 ± 0.15
Survival (%)	98 ± 3.40	94 ± 6	98 ± 3.4
Gross yield (kg ha^{-1} 122 day^{-1})	342 ± 31.5	382 ± 51.3	422 ± 63.0
Net yield (kg ha^{-1} 122 day^{-1})	330 ± 32.0	371 ± 52.0	410 ± 63.2
Combined			
Gross yield (kg ha^{-1} 122 day^{-1})	2524 ± 16.64c	2929 ± 75.86b	3332 ± 70a
Net yield (kg ha^{-1} 122 day^{-1})	2392 ± 17.97c	2797 ± 78.35b	3196 ± 73.15a
Contribution to total yield (%)			
Prawn gross yield	30 ± 0.64a	26 ± 0.92b	23 ± 1.25c
Prawn net yield	26.75 ± 0.67a	23.16 ± .0.86b	20.93 ± .1.21c
Tilapia gross yield	56.46 ± 1.74b	60.85 ± 1.86a	63.70 ± 0.56a
Tilapia net yield	59.46 ± 1.86b	63.59 ± 1.96a	66.26 ± 0.61a
Silver carp gross yield	13.54 ± 1.15	13.04 ± 1.60	12.65 ± 1.69
Silver carp net yield	13.79 ± 1.23	13.65 ± 1.68	12.82 ± 1.77

Values with different lowercase letters in the same row indicate a significant difference ($P < 0.05$) based on one-way ANOVA followed by Tukey's test

bw body weight

significantly higher transparency in the T_{20000} treatment might be higher grazing pressure of the cultured herbivorous/omnivorous species followed by T_{15000} and T_{10000} treatments. It is reported that the transparency of water was affected by many factors such as silt, microscopic organisms, suspended organic matter, season of the year, latitude and intensity of light, application of manure, grazing pressure of fishes or prawns, and rainfall (Boyd 1990). The range of water pH (6.9–8.9) in different treatments was suitable for pond aquaculture (Boyd 1998), although pH values of 7–8.5 have been found to be ideal for grow out phase of freshwater prawn (Boyd and Zimmermann 2000). The observed dissolved oxygen

Table 6 Comparison of economics (mean ± SD, $N = 3$) among three treatments during the 122-day culture period calculated on the basis of 1 ha pond

Variables	Amount	Price rate (BDT)	Treatments		
			T_1	T_2	T_3
Fixed/common cost					
Land rental cost	1 ha	20,000 $ha^{-1}year^{-1}$	10,000 ± 0	10,000 ± 0	10,000 ± 0
Rotenone	12.5 kg	250 kg^{-1}	3000 ± 0	3000 ± 0	3000 ± 0
Lime	250 kg	10 kg^{-1}	2500 ± 0	2500 ± 0	2500 ± 0
Urea	50 kg	10 kg^{-1}	500 ± 0	500 ± 0	500 ± 0
TSP	50 kg	25 kg^{-1}	1250 ± 0	1250 ± 0	1250 ± 0
Substrates (reuse—five times)	150,000 P	1 $piece^{-1}$	150,000 ± 0	150,000 ± 0	150,000 ± 0
Fuel cost	500 units	4 $unit^{-1}$	2000 ± 0	2000 ± 0	2000 ± 0
Fencing (reuse—five times)			5000 ± 0	5000 ± 0	5000 ± 0
Labor	50 man day^{-1}	120 man day^{-1}	6000 ± 0	6000 ± 0	6000 ± 0
Prawn juveniles	30,000 ha^{-1}	4 $juvenile^{-1}$	120,000 ± 0	120,000 ± 0	120,000 ± 0
Tilapia fry		2 $juvenile^{-1}$	20,000 ± 0	30,000 ± 0	40,000 ± 0
Silver carp fingerlings	1250 ha^{-1}	2 $juvenile^{-1}$	2500 ± 0	2500 ± 0	2500 ± 0
Subtotal			315,250.00 ± 0	325,250.00 ± 0	335,250.00 ± 0
Variable cost					
Feed		25 kg^{-1}	756.35 ± 10.39	747.69 ± 19.08	743.90 ± 17.29
Maize		15 kg^{-1}	353.97 ± 4.86	349.92 ± 8.93	348.14 ± 8.09
Subtotal			1110.32 ± 15.25	1097.61 ± 28.01	1092.04 ± 25.38
Total			316,360.32 ± 15.25c	326,347.61 ± 25.72b	336,342.04 ± 25.38a
Bank interest on costs (5 months)		12% annually	15,818.02 ± 0.76c	16,317.38 ± 1.40b	16,817.10 ± 1.27a
Total inputs			332,178.33 ± 16.01c	342,664.99 ± 29.41b	353,159.14 ± 26.65a
Financial returns					
Prawn sale		400 kg^{-1}	302,969 ± 8214	305,846 ± 5388	315,066 ± 11,132
Tilapia sale		100, 95, and 90 kg^{-1}	142,490 ± 3499.60c	169,334 ± 6977.21b	191,026 ± 3873.87a
Silver carp sale		60 kg^{-1}	20,515 ± 1889	22,941 ± 3078	25,323 ± 3772
Total returns			465,975 ± 6486.71c	498,122 ± 5444.64b	531,416 ± 7413.49a
Total net returns			133,796 ± 6486c	155,457 ± 5421b	178,257 ± 7387a
Benefit cost ratio (BCR)			0.42 ± 0.02c	0.48 ± 0.02b	0.53 ± 0.02a

Mean values with different lowercase letters in the same row indicates a significant difference ($P < 0.05$) based on one-way ANOVA followed by Tukey's test

BDT Bangladesh Taka (70 BDT = US$1), *TSP* triple super phosphate concentration was found to fluctuate 3 to 9 mg L^{-1} in different treatments, which exceeded the upper limit of the ideal range (3–7 mg L^{-1}) for the grow out phase of freshwater prawn culture (Boyd and Zimmermann 2000) and lower limit of desired concentration (5–15 mg L^{-1}) for pond aquaculture (Boyd 1998). The recorded lowest mean DO concentration (3.0 mg L^{-1}) in the third week of July, second week of May, and third week of April in treatments T_{10000}, T_{15000}, and T_{20000}, respectively, was not at a stress level for freshwater prawn, tilapia as well as silver carp, because freshwater prawn becomes stressed at a dissolved oxygen level below 2 mg L^{-1} (Roger and Fast 1988), and when it declines below 1 mg L^{-1}, prawn becomes exhausted with serious physiological effects leading to suffocation (Boyd and Zimmermann 2000). The observed higher DO concentration (9 mg L^{-1}) recorded in the last week of May in treatment T_{20000} might be due to the re-suspension of bottom sediment by the stirring activity of tilapia resulting release of trapped nutrient which phytoplankton utilize for growth and produce oxygen through photosynthesis (Asaduzzaman et al. 2009a).

The observed mean values of total alkalinity with the ranges in all treatments were approximately identical suggested by Boyd (1990). He showed that an alkalinity below 30 mg L^{-1} as $CaCO_3$ limits primary production in well-fertilized ponds, while in unfertilized ponds, an alkalinity below 120 mg L^{-1} can reduce primary production. It is also reported that 40–100 mg L^{-1} $CaCO_3$ is optimum for growth of *M. rosenbergii* (New and Singholka 1985), while others claimed that 20 to 200 mg L^{-1} is optimal (Vasquez et al. 1989). The temporal effects as well as the increasing trends of total alkalinity over time in all treatments might be due to containing an increased amount of dissolved organic carbon in water through applying an increasing amount of maize flour for maintaining a high C/N ratio with the increasing growth of prawn at monthly sampling by which organic anions may add additional alkalinity (Wetzel and Likens 1991). Boyd (1982) stated that the total alkalinity should be more than 20 ppm in fertilized ponds and fish production increased with the increase of total alkalinity which might be an evidence of increased production of prawn and fin fishes over time.

The mean concentrations of all nitrogenous compounds with the ranges were approximately identical as suggested by Boyd (1998) in pond aquaculture. The significant temporal effects as well as the decreasing trends of all nitrogenous compounds with a few exceptions over time could be attributed to the addition of maize flour as carbohydrate to maintain a C/N ratio of 20 in all treatments and presence of periphyton substrates (Asaduzzaman et al. 2008, 2009a, b) as well as uptake by plankton. The increasing trends of PO_4-P in all treatments over time might be attributed to inducing nutrient release by the tilapia driven re-suspension with increasing body size from the accumulated organic matter of the sediment into the water phase through the mud-water exchange mechanism, which enhances the overlying water PO_4-P concentration (Asaduzzaman et al. 2010). Chlorophyll *a* in water body is widely used as an indicator of productivity. The observed temporal effects as well as the decreasing trends of chlorophyll *a* in all treatments might be due to higher grazing pressure of phytoplankton and phyto-periphyton of the cultured herbivorous/omnivorous fish over time, which might be the evidence resulted an increasing trends of transparency in all treatments over the experimental period. The significantly lower chlorophyll *a* in the T_{20000} treatment might be a higher grazing pressure of the cultured herbivorous/omnivorous species followed by T_{15000} and T_{10000} treatments. Khatrai (1984) reported a positive relationship between phytoplankton and chlorophyll *a*, whereas Rahman et al. (2010b) found a negative co-relation between chlorophyll *a* and transparency in their all-male freshwater prawn-finfish polyculture research. Besides, chlorophyll *a* has a close relation with total nitrogen but not with total phosphorus and nitrogen can limit the algal biomass (MacLean et al. 1994), which might be reflected as the decreasing trends of nitrogenous compounds (NH_3-N; NO_2-N NO_3-N) over time. Asaduzzaman et al. (2010) reported similar pattern of findings for chlorophyll in their CN-CP-based prawn culture research. However, the mean values and the ranges of water quality parameters were comparable to the values found by some researchers as temperature and total alkalinity (Kunda et al. 2008; Asaduzzaman et al. 2010; Rahman et al. 2010a), transparency (Asaduzzaman et al. 2009a, b; Asaduzzaman et al. 2010), DO concentration (Kunda et al. 2008; Asaduzzaman et al. 2008, 2009a, b, 2010; Rahman et al. 2010a, b), all nitrogenous compounds and PO_4-P concentrations (Asaduzzaman et al. 2008, 2009a, b, 2010; Rahman et al. 2010b), and chlorophyll *a* (Kunda et al. 2008; Asaduzzaman et al. 2008, 2009a, b, 2010; Rahman et al. 2010b) of this region in prawn polyculture systems.

Abundance of plankton and benthos

Phytoplankton, zooplankton, and benthos are the key natural food in an aquatic environment influencing fish production. Their abundance is influenced to a great extent by fish feeding habits, both directly by consumption and indirectly through influencing food web and nutrient availability (Asaduzzaman et al. 2010). The species composition of plankton identified in the present experiment was representative of that found in fish or prawn farming ponds and rice fields in Bangladesh (Kunda et al. 2008; Asaduzzaman et al. 2009b, 2010; Rahman et al. 2010a, b). The significant temporal effects as well as the decreasing trends of total phytoplankton in all treatments over time might be due to increased grazing pressure by of both silver carp and tilapias. The silver carp is a phytoplanktivorous filter feeder, which feeds on algae of various sizes (Smith 1989) and can effectively prevent sudden algal bloom (Hepher and Pruginin 1981). Tilapia affected phytoplankton directly by grazing and indirectly by nutrient re-suspension. The direct effect was more pronounced than the indirect effect, indicating that tilapia had a higher grazing pressure on phytoplankton (Asaduzzaman et al. 2009b) over time. On the contrary, the observed significant temporal effects as well as the decreasing trends of total zooplankton over time might be attributed to an increased grazing pressure by an increased biomass of prawn or partially by increased tilapia biomass due to less preference on zooplankton over phytoplankton or entirely by tilapia biomass as a major component of their diet. It is reported that green, brown (diatoms), and blue green algae as well as numerous species of rotifers, cladocerans, and copepods are major components of the tilapia diet (Cuvin-Aralar 2003). Tilapia feed on zooplankton in fry and juvenile stages and then shift to filter feeding at the later stages (Bowen 1982).

The significant temporal effects as well as the decreasing trends on benthos over time might be accounted to increased grazing pressure with increased biomass of both prawn and tilapia. It is evident that freshwater prawn feed on benthic organisms (Tidewell et al. 1995) or preferred to forage on animals like trichopterans, chironomids, oligochaeta, nematods, gastropods, and zooplankton in ponds (Tidewell et al. 1997). On the contrary, tilapias are omnivorous fish species feeding on benthic and attached algal and detrital aggregates (Bowen 1982; Shelton and Popma 2006). In another study, Asaduzzaman et al. (2010) reported that tilapia might directly feed on the benthic fauna or indirectly facilitated the feeding by freshwater prawn during sediment burrowing. However, the mean values of total benthos were comparable to the values of Asaduzzaman et al. (2009b, 2010) found their CN-CP-based prawn culture research.

Periphyton composition and biomass

The periphyton community comprises a variety of organisms including bacteria, fungi, protozoa, phytoplankton, zooplankton, benthic organisms, and a range of other invertebrates and their larvae (Azim 2001). In the present experiment, phyto-periphyton and zoo-periphyton were only identified as periphyton. The periphyton species composition was comparable to that found in Bangladesh prawn/fish ponds (Uddin et al. 2006; Asaduzzaman et al. 2009b). The significant temporal effects as well as the decreasing trends of total phyto-periphyton in all treatments over time might be attributed to an increased grazing pressure by increasing biomass of tilapias. This grazing might be also higher with increasing tilapia density resulting a significant higher values in treatment T_{20000} followed by T_{15000} and T_{10000} treatments. It is stated that periphyton is a preferable natural food for omnivorous tilapias (Azim et al. 2002) and they can ingest more plant-based food per unit time when presented as periphyton than as plankton (Dempster et al. 1993, 1995). The similar abundance of periphytic zooplankton in all treatments indicates that the zooplankton communities were less preferable for the tilapias or escaped predation (Asaduzzaman et al. 2009b). The observed temporal effects as well as same trends like phyto-periphyton were reflected for zoo-periphyton which might be analogous as stated previously in the case of zooplankton. The significant lower values of total periphyton in T_{20000} treatment followed by T_{15000} and T_{10000} treatments were influenced by the total phyto-periphyton indicating that phytoplankton were the major community of periphyton, which were more or less reflected at the range of the autotrophic index (APHA 1992).

The mean values of periphyton biomass in terms of DM, ash, AFDM, and chlorophyll *a* content were comparable to the values reported by some authors in this region (Asaduzzaman et al. 2008, 2009a, b, 2010). The significantly lower mean values of periphyton biomass in the T_{20000} treatment might be due to the same as periphytic abundance reflected by their overall gross as well as net yield production. The observed temporal effects as well as the decreasing trends of periphytic biomass with an exception to some extent in all treatments might be attributed to an increased grazing pressure of tilapias with their increasing biomass over time. The more or less similar pattern of trends was observed by Asaduzzaman et al. (2008, 2009a, b, 2010) in tilapia added treatments of CN-CP prawn culture ponds. Periphytic algae is needed to graze constantly and kept at low biomass to maintain their high productivity (Huchette et al. 2000). The mean values of autotrophic index with the ranges were comparable to the values of Bangladeshi ponds (Asaduzzaman et al. 2009a, b, 2010). According to APHA (1992), AI values between 100 and 200 are considered as algae dominating periphytic matter. The more/less observed similar ranges of AI values in this experiment indicated that the periphytic biofilms were algae dominated which might be an evidence resulting higher abundance of periphytic algae in terms of numbers and genera in all treatments.

Growth and yield parameters of prawn, tilapia, and silver carp

Growth and yield of fish depend on the stocking size, stocking density, species combination, inclusion of shelter, management practices, etc. Growth and yield parameters including individual harvesting weight, individual weight gain, specific growth rate, FCR (for prawn only), survival (%), gross, and net yields of prawn and silver carp did not vary significantly ($P > 0.05$) among the treatments. This might be due to the fact that the density of both species was similar in all treatments and there was no inter-specific competition among the cultured species in the CN-CP prawn farming system. It is stated that substrates might have minimized the territoriality of the cultured species (Uddin et al. 2006). The individual harvesting weight of tilapia was decreased with increased their own stocking density. This might be due to the intra-specific competition from the same food resources. It is reported that the individual final weight of cultured fish may be reduced with the increase of their stocking density due to intra-specific competition for the same resources (Rahman 2010b). However, the production does not depend only the average individual weight, individual weight gain as well as specific growth rate (SGR) of fish but also depend on the number of individuals stocked and survival rate (Rahman 2010b). As the survival rate of tilapia was similar in all treatments, the higher density of tilapia significantly contributed to the overall higher gross as well as net yield of tilapia in the T_{20000} treatment than T_{15000} and T_{10000} treatments, respectively. This higher growth and yield might occur as a result of the significantly lower values of periphyton qualitatively and quantitatively consumed by tilapia due to an increased biomass over time. This might be also an indication that the tilapia mainly relied on periphyton, while the surface/filter feeder silver carp utilized plankton. The bottom feeder prawn utilized mainly supplied feed with little or no dietary competition indicating synergistic effect among the species. Similar synergistic effects for various species combinations have been reported by some other authors in the polyculture system (Hepher 1988; Milstein 1992). It is claimed that the provision of substrates may enhance the synergism among the fish species (Azim and Wahab 2005).

The combined gross as well as net yield was satisfactory and those were also significantly higher in the T_{20000} treatment than T_{15000} and T_{10000} treatments, respectively, might be reflected by the higher density of tilapia. This indicates that natural foods, chiefly in the form of periphyton, compensated the demand of supplementary feed of tilapia were higher in the T_{20000} treatment than T_{15000} and T_{10000} treatments, respectively. Loeb et al. (1983) noted that periphyton contributed 43–97% of the total productivity in shallow (2–3 m) zone of five oligotrophic lakes. In addition, tilapias are regularly observed grazing on substrates for periphyton. Uddin et al. (2006) reported that the artificial feed can be only provided to freshwater prawn, while tilapia can only depend on natural food. Moreover, re-suspension of the bottom nutrients by tilapia-driven movements increased the bottom dissolved oxygen availability leading to better mineralization and stimulating the natural food web (Jiménez-Montealegreet al. 2002), which in turn might be consumed chiefly by tilapia with more densities resulting in higher yields. It is indicated that higher yields in polyculture attributed to the complementary fish species interactions and the improvement of the environmental conditions (Milstein 1992). However, the combined gross as well as net yield of three species (prawn, tilapia, and silver carp) in the CN-CP-based system was higher than that of found by Asaduzzaman et al. (2010). This might be due to the difference in stocking density, stocking weight, species combination, culture season, and so on.

Economics

The estimated net profit in the best-performed treatment was US$2547 per hectare with a benefit cost ratio (BCR) of 0.53 in a 122-day culture period, although the total cost was significantly higher than other treatments, due to the cost of additional stocking of tilapia fry. The net profit with BCR was more or less comparable with the findings of Asaduzzaman et al. (2009a, b, 2010) in their C/N controlled periphyton-based research. Although the net fresh-water prawn production (about 21% of the total net production) was less than the finfish production (about 79%) in terms of biomass, its higher sale price contributed 59.28% of the total benefit in this treatment confirming that freshwater prawn as prime species and cash crop, and the finfish could be considered as secondary/bonus species. In most polyculture systems, there is a target species and some minor species. The minor species contributes as a bonus to the yield of the target species (Garcia-Perez et al. 2000). Prawn, as a prime species, has a greater international market; the bonus was finfish which has a greater acceptance in the local market as well as for household consumption.

Conclusion

It may be concluded that silver carp, as an indispensable species in the polyculture of Bangladesh, may be included in the C/N-CP prawn farming system due to their synergistic effects on both prawn and tilapia. This fishes have also a wide acceptance in the local market and household consumption, especially for the poorer section of the people of Bangladesh. The findings of the present research also confirmed that tilapia (2 fish m^{-2})-driven re-suspension in freshwater prawn ponds improves the natural food utilization efficiency, pond productivity, and economic benefit. Therefore, the outcomes of the present study could be useful in improving sustainability in terms of ecological, social as well as economic benefit of freshwater prawn farming in the C/N-CP system. There exists enough scope for the further improvement of economic sustainability in the future by identifying cheaper carbohydrate sources such as sugarcane wastes and molasses for manipulating the C/N ratio as well as periphyton substrates. In the present study, the density of prawn and silver carp was same in different treatments. Therefore, further researches are needed to optimize the effects of stocking density of prawn and co-species, especially silver carp, in order to refine this CN-CP technology before the wide-scale dissemination.

Acknowledgements The authors are grateful to the field staff of Fisheries Field Laboratory, Bangladesh Agricultural University, Mymensingh, for their kind assistance during sampling and feeding of fishes and prawns.

Funding information This research was financially supported by the Ministry of Science and Technology, Bangladesh.

Compliance with ethical standards

Conflict on interest The authors declare that they have no conflicts of interest.

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