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Growth and yield of fish under high-density stocking and phased harvesting in rice-fish system

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ABSTRACT

This study was carried out to enhance the productivity of rice-fish system following the management strategies like high-density initial stocking and phased harvesting, when the growth curve of carp and catfish starts to slow down. Impact of phased harvesting on overall growth performance of carp and catfish was reflected in faster growth of all species after 90 days of rearing, probably due to periodic phased harvesting that minimized the competition for food and space. Comparative lower apparent feed conversion ratio (1.78), higher survival rate 62.28±4.44 and higher fish yield (8.01±1.72 t/ha were also recorded in T_1 (rice-fish culture with phased harvesting) than T_2 (rice-fish culture without phased harvesting). The highest rice yield (7.6 t/ha) was recorded in T_1 resulting from increased number of panicles per unit area as well as number of filled grains /panicle. Increase in rice yield over its monocrop (T_3) was, higher in T_1 followed by T_2 because of improving soil fertility, recovering lost energy, adjusting energy flow by consuming plankton, weeds, insect and bacteria which used to compete with rice for nutrient. From economic point of view T_1 also recorded better performance over other treatments. Treatment T_4 was designed with only carp and cat fishes provided with a commercial fish feed, 'Saudi-Bangla' (32.10% crude protein) regularly. Overall performances indicated that this eco-friendly dual production system (rice and fish) and on-dyke horticulture technology generated a profitable return in a shortest possible time and helps in improving nutritional security, socio-economic status and employment opportunity.

Key words: Growth performance, high-density stocking, phased harvesting and rice-fish culture.

Rice-fish culture is a viable option for diversification and maximizing farm income (Ofori *et al*., 2005). Integrated rice-fish farming accommodate crop diversification, increase productivity, generate employment opportunity, enhance income and provide nutritional security to resource poor farming community. Fish rearing in rice fields is a successful practice in, Bangladesh where fishes are stocked with the aim of increasing and diversifying the rice field productivity and is probably the most promising alternative to rice mono cropping (Ofori *et al.,* 2005). Besides, adding fish to the rice field ecology, it helps to increase production and achieves social, economic and ecological benefits (Bandyopadhyay and Puste, 2001). Fish culture in this ecosystem is concurrent or rotational with rice, carried out at four intensities: traditional (capture), low intensity culture (without feed and fertilizer), medium intensity (only fertilization) and high-density culture (with feed and fertilizer). Although, several works has been carried out on different aspects of rice-fish farming (Lu and Li, 2006), no work has been carried out in the line of enhancing water productivity of rice-fish farming system. In this back drop, an attempt was made to enhance the yield, economic output and water productivity in rice-fish system following the principle of high density stocking and selective (phased) harvesting.

MATERIALS AND METHODS

The study was carried out in farmers' fields (Sonaly, Model, Lalon and Progoti Farms) at Model bazaar and Shohagi village of Old Mymensingh district, Bangladesh, where 2 ha waterlogged area was devoted into treatment T_1 (rice-fish with phased harvesting) and treatment T_2 (rice-fish without phased harvesting) with another 1ha adjacent land exclusively for rice only treatment T_3, to study the impact of fish on rice yield. Fish culture without rice (treatment T_4) was also undertaken in another adjacent pond of 0.50 ha area, to study the economics and water productivity of the system. Fifty percent of the land (treatment T_1 and T_2) was excavated upto a depth of 100 cm and the excavated soil was utilized for peripheral dyke construction upto a height of 1.4 m (Fig.1). The experiment was conducted for a period of ten months from January to October, 2008 in the four farms. The refuges were dewatered, freed from aquatic vegetation, exposed to full sunlight and had a well designed system of inlet and outlet. The refuges were having similar rectangular size, depth, basin configuration, contour and bottom type. The growth performance of fish and rice was evaluated under four treatments and was replicated twice. All the refuges were filled with ground water.

Rice variety (*Oryza sativa*, BR-29) was transplanted in the unexcavated land (50% area, 5000 m^2) of treatment T_1 and T_2 and 100% area of T_3 plot during 2^{nd} week of January for that study. Rice area under treatment T_1 and T_2 were divided into two sub-plots and treatment T_3 were divided in to four sub-plots. Rice was transplanted with a spacing of 20×20 cm. The fertilizer dose was 80:50:40 (nitrogen: phosphorous: potassium in kg/ha); 50% of N and full dose of P and K were applied as basal at the time of transplanting. The rest nitrogen was applied at two equal splits during tillering and panicle initiation stages (30 and 60 DAT). Crop growth and yield parameters were recorded at regular intervals. No pesticide was used in the experimental plots to prevent fish mortality. Final yield and yield components of the crops were recorded at the time of harvest. Standard agronomic and aquaculture package of practices were adopted.

Pre-stocking refuge (T_1 and T_2) and pond (T_4) preparation were accomplished through horizontal and longitudinal ploughing followed by application of lime (CaCO3) @ 247 kg/ha. Six days after liming, the refuge/pond were fertilized with organic manure (cowdung @ 6175 kg/ha) and chemical fertilizer (@ urea 61.75 kg/ha and triple super phosphate 30.88 kg/ha. Seven days after refuge/pond preparation (3rd week of February), fish fingerlings such as *Catla catla* (5.15±0.65), *Labeo rohita* (4.56±0.45), *Labeo bata* (3.25±0.12) and fry of *Heteropneustes fossilis* (3.18±0.21) were stocked @ 1,00,000 ha^{-1} with a species composition of 30:30:15:25 (*C. catla*: *L. rohita*: *L. bata*: *H. fossilis* :: 30000: 30000: 15000:25000) in the excavated refuge ($5000m^2$) of treatment T_1, T_2 and T_4. In order to meet up the increasing dietary demand, a commercial fish feed (Saudi Bangla) was supplied regularly. Proximate composition of the feeds was analyzed according to AOAC (1995) method, nitrogen free extract (NFE) by subtraction (Castell and Tiews, 1980). Proximate composition (crude protein, crude lipid, crude fiber, ash and Nitrogen-free extract) of experimental feeds (% dry matter) was 32.10%, 7.71%, 10.18%, 18.16% and 31.85%, respectively. Feeds were supplied to the fish at the rate of (3 to 5) % of their total biomass twice daily in the morning and afternoon commencing from the first day of stocking. Daily ration was adjusted by estimating the standing crop once in each fortnight by random sampling of the stock. Periodic manuring with cowdung (500 kg/ha), Urea (394 kg/ha), TSP (247 kg/ha) and liming (124 kg/ha) were carried out at every 15 days interval to maintain plankton population in the eco-system. Periodic observation on water quality, fish growth parameters, yields and yield components and water balance related studies were carried out at regular intervals at the experimental site. Cull/selective harvesting of fish were undertaken after 90, 150 and 240 days of stocking (DAS).

On the entire peripheral dyke of each unit, bottle gourd (*Cucurbita maxima*) and cucumber (*Cumcumis sativus*) were sown on both sides (400 numbers each) with a spacing of 1.5 m between plants. In the middle of the embankment, dwarf varieties of Papaya were grown at a spacing of 1.5 m as an additional component. Irrigation to those plants was given using the refuge/pond water.

Physico-chemical parameters of pond water were monitored weekly between 9.00 and 10.00 hours. Water temperature was recorded using a Celsius thermometer and transparency (cm) was measured by using a Secchi disc of 20 cm diameter. Dissolved oxygen and pH were measured directly using a digital electronic oxygen meter (YSI, Model 58, USA) and an electronic pH meter (Jenway, Model 3020, UK). Total alkalinity was determined by titrimetric method (Clesceri *et al.*1989). Total ammonia, Nitrate-nitrogen, Nitrite-nitrogen and Phosphate-phosphorus were measured with the help of a Hach Kit (Model DR 2010, USA) and chlorophyll-a was determined by glass microfibre filter paper (Whatman 4 GF/C) and a spectrophotometer (Milton Ray Spectronic, Model 1001). The plankton sample was collected every week using 0.55 blotting silk plankton net and later analyzed numerically with the help of Haemocytometer and Sedgewick-Rafter counting cell (SR-cell) under a compound microscope (APHA, 1995). Calculation of the abundance of plankton was done according to Stirling, (1985).

Fishes were sampled by using a seine and cast net. The weight (g) of individual fish was recorded separately on treatment-wise with the help of a measuring scale and a portable sensitive balance. Twenty individuals of *C. catla*, *L. rohita*, *L. bata* and *H. fossilis* species from each treatment were sampled fortnightly. Growths in terms of weight, average daily gain (ADG), specific growth rate (SGR) and food conversion rate (FCR) were estimated. SGR and FCR were calculated according to Brown (1957), Castell and Tiews (1980), Gangadhara *et al.* (1997) and Mohanty (1999), respectively. After 240 days, the table size fishes were harvested by repeated netting, followed by draining or drying the ponds. The number of species were counted and weighed. Survival (%) and production (number/ha) of fish were then calculated and compared among the treatments.

To assess the output from the plot as a single unit, rice equivalent yield (REY) was computed considering the local market price of rice, fish fingerling and marketable fish, respectively, and the proportional area devoted to rice and fish cultivation. Economic indices of water productivity were estimated as suggested by Boyd (2004). Ratio of the output value to the cost of cultivation of the integrated farming system was estimated.

The data were analyzed through one way analysis of variance (ANOVA) using MSTAT software followed by Duncan's New Multiple Range test to find out whether any significant difference existed among the treatment means (Duncan 1955 and Zar 1984). The results were calculated and expressed as mean ±S.D. A simple cost-benefit analysis was done to estimate the net benefits from different treatments.

RESULTS AND DISCUSSION

Excess water conservation and management

During 2008, the annual rainfall was nearly normal. The water level in the refuges/pond was observed to be sufficient enough till the end of October for short duration fish culture. During the experimental period, the depth of water available in the refuge was more than the desirable depth (February-October) for short-duration aquaculture and was not a problem for survival during the study period. The water available in the surrounding rice field was adequate enough during the study period. Vegetables grown on the dyke were, however, irrigated using the refuge water when needed during the whole study period.

Soil quality

Soil texture of the experimental area varied from sandy loam to clay. The composition of soil was sandy 10.3±6.11%, sand 48.5±3.88 and clay 41.2±4.80, respectively. The textural class of soil was clay having pH (6.8-7.2).

Water qualities in relation to fish production

Mean levels of physico-chemical parameters over the 240 days culture of rice-fish are presented in Table 1. Water quality is a dynamic property of a system affected by physico-chemical and biological factors, which influence the aquatic environment and production of rice-fish farming systems. Total dissolved oxygen (DO) concentration showed a decreasing trend with the advancement of rearing period while, slightly higher values of nitrite, nitrate, ammonia and total alkalinity were recorded towards the later part of the experiment. The decreasing trend in DO in all the treatments (except rice monocrop) with the advancement of fish rearing period, attributed to fluctuation in plankton density and gradual increase in biomass, resulting in higher oxygen consumption. In the present study, DO level did not drop below 3.56 mg/L in any treatment. Fishes decreased the DO and pH values when supplemental feed was supplied. Furthermore, fishes stimulated the growth of phytoplankton and increased chlorophyll-a concentration (Frei and Becker, 2005). Gradual increases in nitrite, nitrate and ammonia were attributed by intermittent fertilization, increased level of metabolite and decomposition of unutilized feed in absence of water replenishment (Mohanty *et. al.*, 2004). The mean water temperature, pH and dissolved oxygen, nitrite-N, nitrate-N and phosphate-P in treatments T_1, T_2 and T_4 were not significantly ($p>0.05$) different during the study period. Mean Secchi disk transparency, total alkalinity and chlorophyll-a differed significantly ($p<0.05$) among the different treatments. Despite those variations, water quality parameters in all the treatments were within the normal range for fish culture.

The most important factor limiting aquatic photosynthesis in rice fields was the shading by the growing rice biomass. Besides the competition for light, rice also competed with the field water's photosynthetic active biomass (PAB) for available nutrients, especially N, the most limiting nutrient in the rice fields. Heckman (1979) and Kropff *et al*. (1993) made similar observation. At the onset of the experiment, the high pH values (7.4-8.7), together with high dissolved oxygen (3.56-6.80) and chlorophyll-a values (66.57-90.22) suggested that an autotrophic pathway was dominated within the aquatic phase of the rice fields. However, with the increase in rice biomass, the chlorophyll-a concentration, NH4+, pH, dissolved oxygen decreased which indicated a reduced aquatic photosynthesis and suggested that the autotrophic pathway lost importance. With the increasing rice biomass, surface feeder and column feeder fishes gradually switched over from feeding on plankton biomass to supplemental feed, a process which resulted in interspecific competition with bottom feeders. (Vromant *et. al*., 2004). In general, poor growth performance of cultured species took place at pH <6.5 while, higher values of total alkalinity (>90 ppm) indicated a better productive ecosystem and increased plankton density, reflects higher nutrient status of the water body. However, the recorded minimum and maximum range of total alkalinity during the experimental period was 122.32-166.28 mg/L, respectively, which was maintained due to periodic liming (Table 1).

Plankton population

The quantities of phytoplankton and zooplankton were particularly dominant during the months of June and July and the lowest count was obtained in October (Table 2). The phytoplankton consisted of 26 genera in the three treatments in four broad groups namely, *Chlorophyceae*, *Bacillariophyceae*, *Cyanophyceae* and *Euglenophyceae*. *Chlorophyceae* contributed the genera were *Clasterium*, *Chlorococcum*, *Eremesphaera*, *Gonotozygon*, *Kirchneriella*, *Mesotenium*, *Microspora*, *Oocystis*, *Ophiocytium*, *Pediastrum*, *Penium*, *Protococcus*, *Spyrogyra*, *Tetraedron*, *Volvox*, *Zygnema*. *Bacillariophyceae* included various species belonging to genera

Diatoma, *Fragilaria*, *Melosira*, and *Navicula*. *Cyanophycea*e incorporated the genera of *Anabaena, Chroococcus, Merismopedia, Mycrocystis* and *Oscillatoria*. *Euglenophyceae* included the genera of *Euglena*. *Chlorophyceae* was the dominant group which was higher (p<0.05) during the study period. The abundance of *Bacillariophyceae* also varied significantly (p<0.05). The mean abundance of total phytoplankton was found to differ significantly (p<0.05). The phytoplankton consisted of 26 genera. Among the zooplanktons, the represented genera were *Bosmina, Brachionus, Cyclops, Daphnia, Diaptomus, Filinia, Keratella, Lecane, Moina, Nauplius, Oicomonas* and *Trichocerca* belonging to two groups. The zooplankton population consisted of 12 genera excluding nauplii in two groups, viz, Rotifera, Crustacea and other groups, which were almost similar with the observation of Sugunan and Bhattacharyya (2000). Rotifera and Crustacea were different (p<0.05) during the investigation period.

In this study, fluctuating trend in plankton density was recorded in different treatments (Table 2), which ultimately reflected both fish and rice yield in T_1 and T_2. In all the treatments, average primary production in the first month of cultivation improved with the advancement of rearing period. Low primary production in the initial phase of rearing was probably due to the fixation of nutrient ions by suspended soil or clay particles as well as rich organic matter. Mohanty, (2003) made similar observation

Growth and yield performance of rice

The highest grain yield of rice was recorded in T_1, which was significantly superior to that of T_3 and T_2, mainly contributed by higher number of panicles/m^2 (139.5) and number of filled grains/panicle (111.5). Percentage increase in grain yield over rice monocrop was however, higher in T_1 (8.57%) followed by T_2 (5.56%). Lower number of panicles (122.2/m^2) and number of filled grain (101.5 grains/panicle) in rice monocrop was probably due to the absence of fish. Fish in the field which helped in improving soil fertility, recovering lost energy, adjusting energy flow by consuming plankton, weeds, insect and bacteria these competed with rice for nutrient. Further, fish helped in break down of the soil surface, oxidize layers of soil that increased the supply of oxygen to promote root growth and tillering capability of rice plant. Since fish in rice field also helped in improving the physico-chemical properties of arable layer soil of rice field, enhancing growth period of rice, increasing dry matter and leaf area index (LAI) of different growth stages, increasing area of top three leaves which improved photosynthetic rate and grain filing as well as and deterring the degeneration function of leaves function. Growth and yield performance of rice was enhanced in T_1 and T_2 (Table 5) than T_3 (rice monocrop). Between T_1 and T_2, comparatively higher yield was recorded in T_1 (7.6 t/ha) probably due to lower chlorophyll-a and plankton density (Table 5) which minimized the competition for nutrient with rice plant. Kropff *et al*, (1993) reported alike.

Impact of selective harvesting on growth, survival and yield of fish in rice-fish system

Fish fingerlings of *C. catla* (5.15±0.65 g), *L. ruhita* (4.56±0.45 g), *L. bata* (3.25±0.12 g) and *H. fossilis* (3.18±0.21 g) were stocked @ 1, 00,000 /ha), faster growth rate was recorded for Catla followed by ruhu, bata and shing (Table 4) in rice-fish culture with phased harvesting (T_1) while in rice-fish culture without phased harvesting (T_2), faster growth rate was recorded for *C. catla* (Figs. 2, 3 and 4). Similarly the growth performance of *H. fossilis* was much faster in T_1 than T_2. Impact of phased harvesting on overall growth performance and yield of fish (Table 3) was reflected in faster growth of all the species after 90 days of rearing (Figs. 2, 3 and 4) and higher yield in T_1 (52.86% increase over T_2). Like wise, higher survival rate, higher specific growth rate (SGR) and lower feed conversion ratio (FCR) were also recorded in treatment T_1 than treatment T_2. As density-dependent growth performance took place at higher population density selective harvesting helped in reducing size heterogeneity, weight distribution and stunting growth of fish. Further, due to selective harvesting of fish, yield was enhanced by 52.86% in treatment T_1 than T_2 while FCR by 1.78±0.06 (Table 4). In treatment T_1, T_2 and $T_{4,}$ column feeder (*C. catla*) registered better growth rate than that of bottom feeder (*H. fossilis*s) probably due to its superior feed utilizing capability and high degree of fluctuation of dissolve oxygen.

H. fossilis (bottom feeder) was attributed to effective utilization of ecological niches and rich detrital food web that was maintained through periodic manuring and liming. Comparative slow growth and lower survival rate in T_2 was probably due to the fact that, under crowded condition, fish suffered stress due to aggressive feeding interaction and eat less resulting in a retardation of growth (Bjoernsson, 1994) and rate of higher yield (p<0.05) and species-wise faster individual growth performance (p<0.05) in T_1 and T_4 than T_2 were probably due to periodic phased harvesting that minimized the competition for food and space among the cultured species. In the present study, the net of *L. bata* was more or less similar to the above findings but in consideration of the endangered stage and nutritional aspects *L. bata* fish culture was more important to enhance fish production and save the fish from endanger (Chakraborty and Mirza, 2007)

Interesting trend towards the growth performance of *H. fossilis* was noticed when grown together with fish in water on rice-fish system. Faster growth was recorded in T_1 than T_2 probably due to periodic harvesting. Significantly higher mean body weight ($p<0.05$) was recorded **(**Table 4**)** at 150 and 240 days of rearing. At 90, 150 and 240 days after stocking (DAS) the population had attained 22.3±0.82 g, 44.2±0.98 g and 90.4±3.02 g mean body weight (MBW) in treatment T_1 and 20.2±0.77 g, 40.4±0.82 g and 75.2±2.11 g mean body weight (MBW) in treatment T_4. While in treatment T_2, at 240 days after stocking (DAS) the population attained 40.1±1.22 g only which was more or less similar to monoculture study of *H. fossilis* (Chakraborty and Mirza, 2008). But the reduction in growth of *H. fossilis* in treatment T_2 (without phased harvesting) was probably due to the competition for food, space and physiological stress at higher density, which was in agreement the findings of Mohanty (2004).

Effect of fish on the growth and yield of rice

Fish movements in the shallow water broke the surface membrane (interface) formed by the microorganisms covering the soil. Thereby, increased the dissolved oxygen level in the soil and elevated its oxidation and reduction potential during the period of rice growth. Those changes improved the oxygen content and effectively increased the utilization rate of soil nutrients. Fish, in the rice-fish system, promoted more efficient use and distribution of NPK, thus reduced loss of fertilizer and increased soil fertility. In this rice-fish experiment, highest rice yield was recorded 7.6 t/ha in treatment $T_{1,}$ second highest production was recorded in treatment T_2 and the lowest production was 6.8 t/ha in treatment T_3 (mono-crop), respectively (Table 5). The lowest production in treatment T_3 was probably due to reduced water levels that decreased the number of panicles/m^2 and rice yield. Bottom feeder fish, is known to bring minerals and organic matter from the sediment into suspension through its feeding activity. This results in increased water turbidity and particulate inorganic mater (PIOM), in the rice field, P release from the sediment and establishes contact between the benthic and pelagic compartments which are otherwise fully separated. Moreover, fish stimulated the growth of phytoplankton and increased chlorophyll-a concentration (Frei and Becker, 2005) in rice field, which competed with rice for nutrient and energy, resulting in reduced rice yield as in the case of T_2.

On-dyke horticulture and Rabi crop

The dyke constructed for preventing escape of fish from the integrated system was utilized for growing vegetables and other fruit trees like papaya to make the system more economically viable. The average yield of bottle gourd, cucumber and papaya was 2.50 t, 1.99 t and 0.44 t /ha of rice-fish unit (treatment T_1 and T_2). Irrigation to those plants was given using the refuge/pond water.

System's rice equivalent yield (REY) and water productivity

The average sale price of fish, rice and rice straw in treatment T_1 were Tk. 147.22±45.26 /kg, Tk. 12.50 /kg and 1.50 /kg. There were fish Tk. 110.00±60.0 /kg, paddy Tk. 12.50 /kg and straw 1.50 /kg in treatment T_2, respectively. In case of treatment $T_{3,}$ paddy and paddy straw were sold at Tk. 12.50 /kg and 1.50 /kg. Only fish in treatment T_4 was sold at Tk. 110.00±60.0 /kg (Table 6). There were variations in the price of different species of fishes according to size and weight categories. The highest rice equivalent yield REY (Table 5) was recorded in T_1 followed by T_2 and T_3. Considering the selling price of additional produce from on-dyke horticulture Bottle gourd, (*Cucurbita maxima*) [Tk 4.00/kg], cucumber, (*Cumcumis sativus*) [Tk 6.00/kg] and second crop papaya, (*Carica papaya*) [Tk. 8.00 /kg], respectively, the net return from different treatments were calculated to compute the water productivity.

System's economic evaluation

The results of benefit-cost analysis were shown for $T_{1,}$ T_2, T_3 and T_4, respectively (Table 6). The gross margin (GM) were TK.504373.00, 69979.00, 72105.00 and 142213.00 but net return were TK. 426244.00, 246.00, 51351.00 and 67498.00 in treatment $T_{1,}$ T_2, T_3 and T_4, respectively. Cost and benefit analysis showed that treatment T_1 generated the highest net return of 504373.00 /ha for 10 months and lowest net return was found Tk. 246.00/ha for 10 months in treatment T_2, where size of the fish comparatively was not bigger due to absence of phased harvesting and higher stocking density. The second highest net return was recorded in treatment T_4, where phased harvesting was practised but no rice was added and differed significantly ($p<0.05$) from T_1. Treatment T_2 appeared to give the lowest net return and also differed significantly ($p<0.05$) from T_1, T_3 and T_4. This infers that, initial high stocking density, followed by phased harvesting; in rice-fish culture is more beneficial, compared traditional rice-fish farming. Rabi crop seems to be a viable solution for increasing the income of small and marginal farmers. Rice-fish eco-friendly dual production system (rice and fish) and on-dyke horticulture helps in generating additional income, employment opportunity and nutritional security. Moreover, income can further be enhanced, if high-density initial stocking followed by phased harvesting of fish is practised in rice-fish culture. Further multi-location studies should be conducted recommending this technology package to the integrated agriculture-aquaculture practices.

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Table 1. Water parameters in different treatments of rice- fish integration system

Parameters	Treatment T_1	Treatment T_2	Treatment T_4
Temperature (^oC)	27.18±6.22 (14.08-32.20)	27.22±5.76 (14.14-32.50)	27.33±6.44 (14.22-32.55)
Transparency (cm)	25.44±3.11^c (22.55-39.25)	29.30±3.42^b (23.40-38.40)	33.28±3.52^a (22.33-38.77)
pH	72±0.42 (7.4-8.7)	7.75±0.36 (7.1-8.7)	7.52±0.44 (6.8-8.8)
Dissolved oxygen (mg/L)	4.48±0.66 (3.56-6.80)	4.04±0.65 (3.60-6.02)	4.82±0.58 (3.58-6.11)
Total alkalinity (mg/L)	140.25±8.44^a (122.41-155.24)	135.33±9.61^b (125.55-166.28)	131.22±8.55^c (122.32-162.11)
Nitrite-N (mg/L)	0.03±0.01 (0.005-0.06)	0.032±0.01 (0.004-0.07)	0.031±0.01 (0.003-0.07)
Nitrate-N (mg/L)	0.32±0.02 (0.1-0.52)	0.34±0.01 (0.1-0.66)	0.33±0.02 (0.1-0.72)
Phosphate-P (mg/L)	0.21±0.02 (0.7-0.34)	0.22±0.01 (0.6-0.38)	0.27±0.02 (0.8-0.38)
Chlorophyll-a(µg/L)	80.33±5.66^a (66.57-90.22)	74.19±6.21^b (60.55-88.62)	72.70±4.74^c (59.19-91.50)

Values with different superscripts in the same row varied significantly (P<0.05). Figures in the parenthesis are range.

Table 2: Phytoplankton (individual/ml) and zooplankton (organism/ml) population in rice- fish integration system

Group	Treatment T_1	Treatment T_2	Treatment T_4
Plankton (cell/ml×10^3) Chlorophyceae	103.22±6.20^a (92.33-111.00)	97.36±5.22^b (92.22-108.31)	99.22±5.55^c (90.33-107.04)
Bacillariophyceae	96.25±2.12^a (91.67-98.35)	85.81±1.58^b (80.05-95.60)	88.24±1.35^c (79.33-88.67)
Cyanophyceae	60.22±1.03^a 57.05-64.33)	51.52±1.48^b (53.35-58.11)	55.00±1.07^c (48.04-55.00)
Euglenophyceae	3.18±0.35^a (1.88-2.77)	2.81±0.38^c (2.17-3.61)	3.09±0.31^b (2.40-4.44)
Total Phytoplankton	262.87±45.75^a	237.50±42.43^c	245.55±43.17^b
Zooplankton (organism/ml×10^3) Rotifera	12.82±1.22^a (10.67-14.33)	10.81±1.53^c (9.88-13.07)	11.62±1.42^b (9.34-12.60)
Crustaceae	7.34±0.41^a (5.22-6.82)	4.50±0.49^c (4.20-4.85)	5.58±0.45^b (3.01-3.92)
Others	2.51±0.12^a (2.01-2.40)	2.04±0.11^c (1.55-1.78)	2.27±0.08^c (1.10-2.12)
Total Zooplankton	22.67±5.16^a	17.35±4.52^c	19.47±4.74^b

Values with different superscripts in same row varied significantly (P<0.05). Figures in the parenthesis are range.

Table 3: Cull harvesting at different days after stocking in rice- fish integration system

Treat -ment	Species composition	Cull harvesting						Species wise survival rate (%)	Final survival rate (%)
		1st cull		2nd cull		Final harvesting			
		MBW (g)	NH	MBW (g)	NH	MBW (g)	NH		
T_1	*C. catla*	90.4 ±1.12	12000	248.4 ±2.02	4000	620.2 ±4.12	2130	60.43 ±1.41	62.28 ±4.44[a]
	L. rohita	75.2 ±1.02	12000	180.1 ±1.74	4000	492.5 ±3.66	1940	59.80 ±1.04	
	L. bata	54.4 ±0.95	5000	98.8 ±1.05	2500	202.3 ±2.88	1630	60.47 ±0.85	
	H. fossilis	22.3 ±0.82	4000	44.2 ±0.98	2000	90.4 ±3.02	11050	68.20 ±1.04	
T_2	*C. catla*	-	-	-	-	218.6 ±3.54	10447	34.82 ±0.77	39.58 ±3.53[c]
	L. rohita	-	-	-	-	198.2 ±4.04	10052	33.51 ±1.01	
	L. bata	-	-	-	-	98.4 ±1.44	5932	39.55 ±1.10	
	H. fossilis	-	-	-	-	40.1 ±1.22	9725	38.90 ±0.64	
T_4	*C. catla*	80.2 ±1.44	12000	178.2 ±2.12	4000	500.3 ±5.08	1812	59.37 ±1.02	59.54 ±2.44[b]
	L. rohita	68.1 ±1.35	12000	145.3 ±1.52	4000	415.2 ±3.82	1704	58.01 ±0.87	
	L. bata	49.8 ±0.81	5000	81.8 ±0.95	2000	165.4 ±1.72	1332	55.55 ±0.51	
	H. fossilis	20.2 ±0.77	4000	40.4 ±0.82	2000	75.2 ±2.11	10055	64.22 ±0.54	

Values with different superscripts in same column varied significantly (P<0.05).

Table 4: Impact of different treatments on growth performance and yield of fish in rice- fish integration system

Traeatment	Species stocked	No. of fish stocked/ ha	Initial MBW (g)	Per day increment (g)			SGR (% bw/ day)	Species wise yield (mt)	Total production (mt/ha/yr)	FCR
				90 DAS	91-150 DAS	151-240 DAS				
T_1	*C. catla*	30000	5.15 ±0.65	0.95	1.62	2.56	2.68 ±0.02	3.40 ±0.02	8.01 ±1.20[a]	1.78 ±0.06[a]
	L. rohita	30000	4.56 ±0.45	0.78	1.17	2.03	1.95 ±0.03	2.58 ±0.28		
	L. bata	15000	3.25 ±0.12	0.68	0.64	0.83	1.72 ±0.02	0.85 ±0.05		
	H. fossilis	25000	3.18 ±0.21	0.30	0.27	0.36	1.39 ±0.01	1.18 ±0.04		
T_2	*C. catla*	30000	5.15 ±0.65	-	-	0.89	1.56 ±0.03	2.28 ±0.03	5.24 ±0.96[c]	2.01 ±0.11[c]
	L. rohita	30000	4.56 ±0.45	-	-	0.81	1.57 ±0.03	1.99 ±0.01		
	L. bata	15000	3.25 ±0.12	-	-	0.40	1.43 ±0.01	0.58 ±0.03		
	H. fossilis	25000	3.18 ±0.21	-	-	0.15	1.05 ±0.01	0.39 ±0.01		
T_4	*C. catla*	30000	5.15 ±0.65	0.83	1.15	2.06	1.91 ±0.02	2.58 ±0.03	6.71 ±1.01[b]	1.88 ±0.08[b]
	L. rohita	30000	4.56 ±0.45	0.71	0.94	1.71	1.88 ±0.02	2.11 ±0.02		
	L. bata	15000	3.25 ±0.12	0.52	0.52	0.68	1.64 ±0.01	0.68 ±0.03		
	H. fossilis	25000	3.18 ±0.21	0.19	0.25	0.31	1.32 ±0.01	0.88 ±0.04		

Values with different superscripts in same column varied significantly (P<0.05).

Table 5: Impact of different treatments on growth performance and yield of rice in rice- fish integration system

Treatments	Number of panicles/m^2	Number of filled gain/panicle	Straw yield (t /ha)	Rice yield (t /ha)	% Increase in grain yield over rice monocrop
T_1	239.4	126.5	3.92	7.6^a	8.57
T_2	231.2	128.1	3.94	7.2^b	2.89
T_3	222.2	110.2	3.91	7.0^c	-

Values with different superscripts in same column varied significantly (P<0.05).

Table 6: Cost and return of rice-fish yield under rice-fish integration system over a period of 240 days.

Item	Amount TK/ha/yr$^{5/6}$				Remarks
	Treatment T_1 (Tk)	Treatment T_2 (Tk)	Treatment T_3 (Tk)	Treatment T_4 (Tk)	
Total Return (TR)					Price related according to size and weight
a. Fish	989411	471772	-	679176	
b. Agricultural products	123356	122637	89455	-	
Total return (TR)	1112767^a	594409^c	89455^d	699176^b	
2. A.**Variable cost**					
a. (Fish):	200000	200000		200000	
1. Price of fingerlings					
2. Feed	315676	231712		277525	Tk. 22.00 /kg
3. Fertilizer	30968	30968		30968	Cowdung: Tk. 0.75, Urea:Tk. 9.00 and TSP: Tk.40.00/kg
4. Human labor cost	36000	36000		36000	Tk. 150.00 /day
5. Chemicals	5400	5400		7470	
6. Miscellaneous	5000	5000		5000	
Total Variable cost	593044	509080		556963	
b. Agriculture:					According to the Agricultural department.
Nonmaterial and materials	27350	27350	17350	-	
Total Variable cost (TVC) (a+b)	608394^a	524430^c	17350^d	556963^b	
2. B. Fixed cost :					
1.Pond rental value	17290	17290	17290	17290	Tk. 70.00 /dec. according to MAEP, Mymensingh
2.Interest of operating capital	60839	52443	3464	57425	10% interest according to BKB, Bangladesh
Total fixed cost (TFC)	78129	69733	20754	74715	
Total cost (TC= TVC+TFC)	686523^a	594163^c	38104^d	631678^b	
Gross margin (GM= TR-TVC)	504373^a	69979^d	72105^c	142213^b	
Net return (TR-TC)	426244^a	246^d	51351^c	67498^b	

Values with different superscripts in same row varied significantly (P<0.05). Values in the parenthesisare range.
[a]One Bangladeshi TK= US$ 0.0142
MAEP = Mymensingh Aquaculture Extension Project, BKB= Bangladesh Krishi (Agricultural) Bank
Sale price of T_1: Fish Tk. 147.22±45.26 /kg and Paddy 12.5 /kg, T_2: Fish Tk. 110.00±60.0 /kg and Paddy 12.5 /kg, T_3: Paddy 12.5 /kg and T_4: Fish Tk. 111.67±26.26 /kg

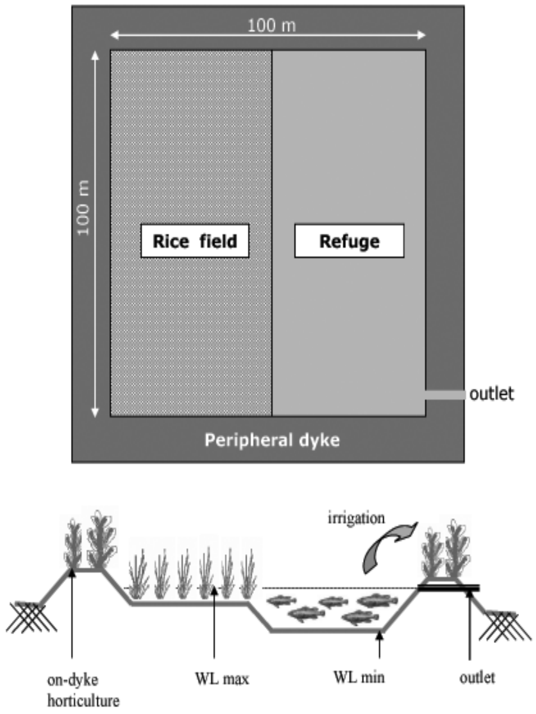

Fig. 1: Design and structure of rice-fish integration system

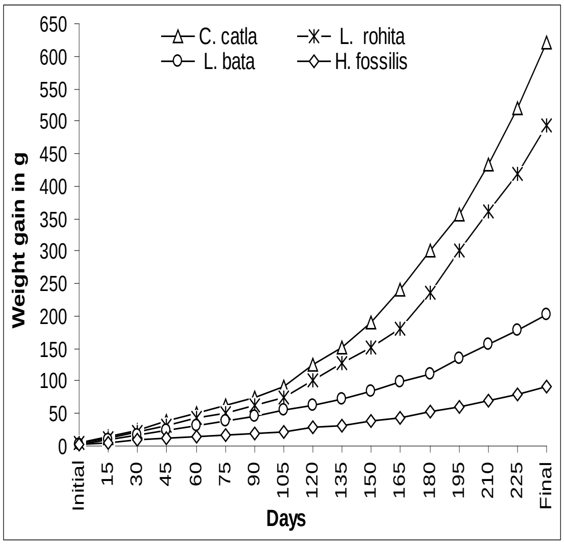

Fig. 2: Impact of phased harvesting on growth performance of fish in rice-fish system in treatment T_1

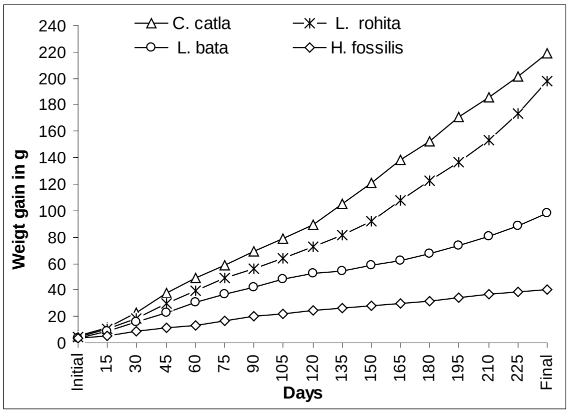

Fig. 3: Impact of without phased harvesting on growth performance of fish in rice-fish system in treatment T_2

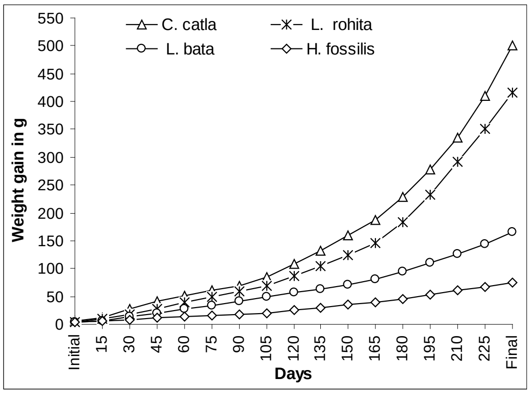

Fig. 4: Impact of phased harvesting on growth performance of fish in treatment T_4