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Optimization of stocking density for *Azolla* based carp polyculture pond

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Abstract
The study optimized the stocking density for *Azolla* based carp polyculture ponds under 3 different treatments like T_1: 10000 fish ha^{-1}, T_2: 11500 fish ha^{-1} and T_3: 12500 fish ha^{-1}. Fishes (*Hypophthalmichthys molitrix, Catla catla, Labeo rohita, Cirrhinus cirrhosus, Cyprinus carpio, Ctenopharyngodon idella* and *Barbonymus gonionotus*) were also grown for a period of six months. Mean initial stocking weight of *H. molitrix*, *C. catla*, *L. rohita*, *C. cirrhosus*, *C. carpio*, *C. idella* and *B. gonionotus* were 60, 65, 58, 52, 61, 70 and 22 g respectively. There were 3 replications for each treatment under this experiment. Liming (250 kg ha^{-1}) and basal fertilization (cow dung: 1500 kg ha^{-1}, urea: 60 kg ha^{-1} and TSP: 60 kg ha^{-1}) were done for all the treatments. Triple Super Phosphate (TSP) (2.5 kg ha^{-1}day^{-1} in all treatments) was applied as periodic fertilization. Water quality parameters (temperature, transparency, DO, pH, alkalinity and free CO_2) were monitored fortnightly and fish growth parameters (weight gain and Specific Growth Rate (SGR)) were monitored monthly. Economics (in terms of total cost, gross benefit, net profit margin and Cost Benefit Ratio (CBR)) of fish farming was also evaluated. No significant difference in the mean values of water quality parameters was found between the treatments. The significant difference ($P<0.05$) with the treatments was found in all the growth parameters except survival rate. Treatment T_3 varied more significantly ($P<0.05$) for the mean values of total yield, but in terms of total cost, gross benefit, net benefit, net profit margin and CBR, treatment T_1 (stocking density of 10000 fish ha^{-1}) was found best. Findings indicated that the stocking density of 10000 fish ha^{-1} could be a good option for low cost *Azolla* based fish farming in Bangladesh.

Keywords: *Azolla*, weed based aquaculture, polyculture, production, economics, macrophytophagous

Introduction
Polyculture or composite culture is the system in which fast growing compatible species of different feeding habits are stocked in different proportions in the same ponds [1]. The basic principles of the polyculture, species of different feeding habits are cultured in the same pond to avoid food competition and best utilization of natural foods of different habits without any harm to each other. It is a fact that, polyculture may produce an expected result if the fish with different feeding habits are stocked in proper ratios and combinations [2]. Selection of species plays an important role for any cultural practices. For better utilization of different strata and zones of a pond three or more species must be stocked. Stocking density is an important parameter in fish culture operations, since it has direct effects on the growth and survival and fish production [3]. It is an established fact that the growth rate progressively increases as the stocking density decreases and vice-versa. This is because of the relatively less number of fish in a pond of similar size could get more space food and dissolved oxygen at the same time. The growth of fishes is dependent on population density [4], Generally direct relationship exists between food abundance and growth rate as well as between population density of the species and its growth rate, whereas the population density of the species and its growth rate tend to be inversely related [4]. However, there may be no relationship between food abundance and growth rate, when a space limiting effect operates on the population. Higher stocking density may cause crowding effects and reduction of growth rate. Smaller fish is affected by the larger one due to size variation. In many fish culture practices where the fish are confined in a restricted space, this size dominance in feeding is often of considerable significance [5]. The aqua farmers have been exploring the possibilities of utilizing alternative sources having high food value like plant leaves and aquatic vascular plants for producing the much required animal protein at low cost [6]. A *Azolla*-fed fish pond provides with a complete and balanced diet for those fish that consume it directly, while the faeces of *Azolla* feeding species are consumed directly by detritus feeders, or indirectly used as fertilizer, enhancing plankton and other food organisms, which can be utilized by remaining surface and column feeding fish species.

By providing *Azolla* as supplementary feed in this system could minimize the food competition between native carps and macrophytes [7].

Quantitative data on this issue are thus still very scarce to make reliable predictions of optimization of stocking density for *Azolla* based carp polyculture in the pond. So far little or no experimental evidence exists for optimization of stocking density for *Azolla* based carp polyculture in the pond polyculture system in Bangladesh or elsewhere in the region. Therefore, the present study aimed at evaluating the production and economics of *Azolla* based carp polyculture under different treatments of stocking densities.

2. Materials and Methods

The study was conducted for a period of six months from April 2012 to September 2012 at the Alampur village of Sadar Upazila under the Kushtia district, Bangladesh (fig. 1).

Fig 1: Map of Kushtia Sadar Upazila and location of present study Area.

A total of 9 ponds (average water area of 0.18ha and depth of 1.9 m) was selected for the present study. All the ponds were rain-fed and well exposed to sunlight. The experiment was designed under Randomized Completely Block Design (RCBD) with three treatments (T_1, T_2 and T_3) of carp stocking densities each with three replications. The treatment assignment was as T_1: 40 fish/decimal (10000 fish ha^{-1}), T_2: 45 fish/decimal (11500 fish ha^{-1}) and T_3:50 fish/decimal (12500 fish ha^{-1}). A stocking ratio / combination of fish species was same for all the treatments. Aquatic weeds were removed from all the ponds manually. Predatory fish and other unwanted species were removed through repeated netting. All the ponds were facilitated well with *Azolla* bank. Liming was done at a rate of 250 kg ha^{-1}before 7 days of fertilization. All the ponds were fertilized with cow dung (1500 kg ha^{-1}), urea (60 kg ha^{-1}) and TSP (60 kg ha^{-1}) as basal dose. One tenth area of the research ponds was used as *Azolla* bank. *Azolla* bank was prepared by bamboo fencing (locally called 'Bana'). In *Azolla* bank, compost manure was deposited (2470 kg ha^{-1}). *Azolla* seeds were introduced in *Azolla* bank at the rate of 1000 kg $ha^{-1}$for available supply of *Azolla* at the culture period. Fishes were stocked in all ponds after five days of basal fertilization. All the ponds were stocked with seven species of fishes (mean initial weight of *Hypophthalmichthys molitrix*, *Catla catla*, *Labeo rohita*, *Cirrhinus cirrhosus*, *Cyprinus carpio*, *Ctenopharyngodon idella* and *Barbonymus gonionotus* were 60, 65, 58, 52, 61, 70 and 22 g respectively). Fish seeds were collected from local government fish farm. Stocking of fish seeds were done at early morning. Stocking density and stocking ratio/combination are shown in Table 5.1 [8]. After stocking, TSP was applied (2.5 kg $ha^{-1}day^{-1}$) for ponds under all treatments as periodic fertilization. In ponds under all treatments, *Azolla* (100%) was supplied as supplementary feed daily at the rate of 100% of the body weight of herbivorous fishes (*C. idella* and *B. gonionotus*). *Azolla* was supplied from *Azolla* bank and made available 24 hours per day.

Some important water quality parameters of the experimental ponds such as water temperature, transparency, dissolved Oxygen, pH, alkalinity and CO_2 were monitored fortnightly during the present study. Water temperature was recorded with the help of a Celsius thermometer at 20-30 cm depth of water. Transparency was measured by a secchi disc. Dissolved oxygen (DO), pH, alkalinity and free carbon dioxide (CO_2) was determined by the help of a HACH kit (FF-2, USA).

At least 10% (by number) of the fish in each pond were randomly sampled on a monthly basis with a cast net. On each sampling day, individual fish from each pond were weighed and measured. The purpose was to determine fish growth in weight and to adjust the ration. Following growth parameters were used for the present study.

Weight gain (g) = Mean final weight (g) - Mean initial weight (g)

Final weight (g) = Weight of fish at harvest (g)

Specific Growth Rate (SGR, % bwd^{-1}) = [L_n (final weight) – L_n (initial weight)] / culture period (days) × 100

$$\text{Survival rate (\%)} = \frac{\text{Number of fish harvested}}{\text{Number of fish stocked}} \times 100$$

Fish yield (kg ha-1/6months) = Fish biomass at harvest – Fish biomass at stock

2.1 Economics

The following parameters were used to explore the economics of different treatments:

Net benefit (Tk.) = total return (sale) – total cost (investment)

$$\text{Net profit margin (\%)} = \frac{\text{Net benefit}}{\text{Total investment}} \times 100$$

$$\text{CBR} = \frac{\text{Net benefit}}{\text{Total investment}}$$

2.2 Statistical analysis

Data on water quality parameters, fish production and economics under different treatments were subjected to one way ANOVA (Analysis of Variance) using computer software SPSS (Statistical Package for Social Science, version-11). The mean values were also compared to check the significant difference from the Duncan Multiple Range Test [9].

3. Results

3.1 Water quality parameters

The variations in the mean values of different water quality parameters in different treatments are presented in Table 1 and Fig.2. During the study period the maximum values of different water quality parameters (such as- water temperature, transparency, dissolved Oxygen, pH and alkalinity) were observed in treatment T_1 except for free CO_2. No significant difference was found among the treatments for mean values of different water quality parameters.

Table 1: Variations in mean values of water quality parameters under different treatments.

Parameters \ Treatments	T_1	T_2	T_3
Water temperature (°C)	31.93±0.27^a	31.84±0.31^a	31.76±0.30^a
Transparency (cm)	33.11±0.33^a	32.25±0.34^a	32.61±0.29^a
DO (mg/l)	5.41±0.09^a	5.35±0.11^a	5.32±0.09^a
pH	7.35±0.09^a	7.25±0.07^a	7.29±0.10^a
Alkalinity (mg/l)	112.56±0.94^a	111.78±1.32^a	110.81±0.85^a
Free CO_2 (mg/l)	2.64±0.07^a	2.81±0.09^a	2.87±0.08^a

Figures bearing common letter(s) in a row as superscript do not differ significantly (P<0.05)

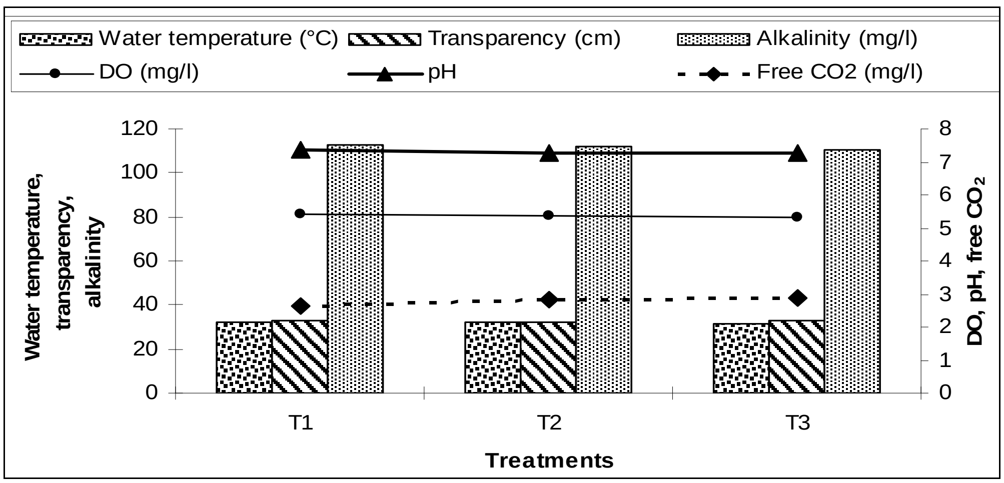

Fig 2: Different water quality parameters under different treatments during study period

3.2 Growth of fishes

3.2.1 Mean variations

Variations in the mean values of growth parameters of fishes under different treatments are shown in table 2. The maximum specific growth rate (SGR, %, bwd^{-1}) was observed in treatment (T_1) and minimum was in treatment (T_3) for all species. Among the species the highest SGR was observed in as 1.43±0.44%, bw^{-1} in *P. gonionotus* and the lowest was in *L. rohita* as 0.96±0.21%, bw^{-1}(Table 2).The lowest combined SGR value was found as 1.14±0.05 (T_3) and the highest combined SGR as 1.21±0.05 (T_1). A significant difference was found between the treatments for the mean values of SGR of all the species in table 2.

3.2.2 Weight gain (g/6 months)

Among the species, the highest weight gain was observed in as 105.28±2.88 g in *C. idella* and the lowest was in *P. gonionotus* as 38.28±2.75 g (Table 2). The lowest mean weight gain was found as 62.54±7.36 g (T_3) and the highest weight gain as 72.21±8.15 g (T_1) for all the species. A significant difference was found between the treatments for the mean values of weight gain of all the species in table 2.

3.3 Survival rate (%)

Among the species, the highest survival rate was observed in as 94.53±0.61% in *C. carpio* and the lowest was in *P. gonionotus* as 80.50±1.15% (Table 2). The lowest mean survival rate was found as 85.20±1.55% g (T_3) and the highest survival rate as 87.14±1.94% (T_1) for all the species. No significant difference was found between the treatments for the mean values of survival rate of all the species except *C. mrigala* in table 2.

3.4 Yield (Kg ha^{-1}/6 months)

The lowest yield was found in the treatment (T_1) and the highest (T_3) for all the species in table 2. Among the species, the highest yield was observed in as 982.67±50.35 (T_3) kg ha^{-1}/6 months in *H. molitrix* and the lowest was in *C. catla* as 241.00±1.53 (T_1) kg ha^{-1}/6 months. A significant difference was found between the treatments for the mean values of the yield of all the species (Table 2).

3.5 Total yield (Kg ha-1/6 months)

The lowest total yield (Kg ha^{-1}/6 months) was found as 3894.33±18.00 (T_1) and the highest total yield was found as 4038.33±84.41 (T_3) (Table 2). A significant difference was found between the treatments.

Table 2: Variations in the mean values of growth parameters of fishes under different treatments.

Species	Treatments	Survival rate (%)	SGR (%, bwd^{-1})	Weight gain (g)	Final weight (g)	Yield (kg ha-1/6 months)
H. molitrix	T_1	90.33±2.91^{a}	1.23±0.32^{a}	80.83±1.55^{a}	545.00±9.61^{a}	969.00±17.16^{a}
	T_2	85.50±0.76^{a}	1.19±0.31^{b}	74.39±1.17^{b}	506.33±2.73^{ab}	979.00±5.13^{a}
	T_3	85.33±1.17^{a}	1.16±0.30^{b}	71.33±1.18^{b}	468.00±24.01^{b}	982.67±50.35^{a}
F		4.653	90.92	15.81	14.17	4.32
P value		0.097	0.001	0.02	0.02	0.085
C. catla	T_1	83.63±0.75^{a}	1.21±0.32^{a}	84.72±2.78^{a}	573.33±3.71^{a}	241.00±1.53^{c}
	T_2	83.00±1.26^{a}	1.18±0.30^{a}	79.67±3.32^{a}	543.00±5.57^{b}	330.33±3.38^{b}
	T_3	80.87±0.58^{a}	1.16±0.29^{a}	76.00±3.62^{a}	521.00±6.25^{c}	411.67±4.81^{a}
F		1.653	2.00	2.58	60.05	45.24
P value		0.268	0.23	0.18	0.001	0.001
L. rohita	T_1	83.10±2.18^{a}	1.01±0.25^{a}	50.22±2.89^{a}	359.33±3.18^{a}	603.67±5.21^{c}
	T_2	84.13±1.21^{a}	0.97±0.22^{a}	45.83±2.87^{a}	333.00±4.00^{b}	699.00±8.50^{b}
	T_3	83.87±1.02^{a}	0.96±0.21^{a}	45.22±2.73^{a}	329.33±3.71^{b}	781.00±8.62^{a}
F		1.187	3.12	0.24	51.48	84.70
P value		0.337	0.15	0.65	0.002	0.001
C. mrigala	T_1	91.53±1.13^{a}	1.10±0.26^{a}	60.72±3.49^{a}	422.33±11.61^{a}	375.67±10.17^{b}
	T_2	85.50±0.58^{b}	1.01±0.28^{b}	53.83±2.67^{ab}	381.00±7.00^{b}	400.00±7.57^{ab}
	T_3	85.73±0.62^{b}	0.98±0.23^{b}	46.78±1.96^{b}	338.67±10.17^{c}	426.33±12.84^{a}
F		20.44	37.39	11.41	110.19	131.98
P value		0.011	0.004	0.03	0.0005	0.0003
C. carpio	T_1	94.53±0.61^{a}	1.21±0.28^{a}	79.61±4.65^{a}	538.67±3.84^{a}	252.67±1.86^{c}
	T_2	93.07±0.81^{a}	1.17±0.25^{a}	73.84±4.99^{a}	504.00±11.15^{b}	336.00±7.37^{b}
	T_3	93.47±1.55^{a}	1.14±0.25^{a}	68.56±3.71^{a}	472.33±3.71^{c}	419.67±3.38^{a}
F		0.406	2.048	0.37	14.05	6.72
P value		0.559	0.226	0.58	0.02	0.04
C. idella	T_1	86.37±0.52^{a}	1.28±0.38^{a}	105.28±2.88^{a}	701.67±7.22^{a}	884.00±9.07^{a}
	T_2	85.07±0.96^{a}	1.22±0.35^{b}	97.11±2.57^{b}	652.67±10.27^{b}	684.67±10.81^{b}
	T_3	85.43±1.16^{a}	1.21±0.34^{b}	91.61±1.09^{b}	619.67±16.48^{b}	520.33±13.87^{c}
F		0.572	11.50	15.97	86.53	20.46
P value		0.492	0.03	0.02	0.001	0.01
P. gonionotus	T_1	80.50±1.15^{a}	1.43±0.44^{a}	44.06±2.64^{a}	287.67±1.67^{a}	568.33±3.33^{a}
	T_2	80.73±1.30^{a}	1.39±0.41^{a}	40.83±2.54^{a}	267.00±2.52^{b}	527.67±4.70^{b}
	T_3	81.73±0.79^{a}	1.35±0.39^{a}	38.28±2.75^{a}	251.33±4.06^{c}	496.67±8.11^{c}
F		2.427	1.11	3.38	16.44	208.37
P value		0.194	0.35	0.14	0.02	0.0001
All species	T_1	87.14±1.94^{a}	1.21±0.05^{a}	72.21±8.15^{a}	3428.00±11.21^{a}	3894.33±18.00^{a}
	T_2	85.29±1.45^{a}	1.16±0.05^{b}	66.50±7.67^{ab}	3187.00±14.05^{b}	3956.67±43.72^{a}
	T_3	85.20±1.55^{a}	1.14±0.05^{b}	62.54±7.36^{b}	3000.33±13.25^{b}	4038.33±84.41^{a}
F		0.504	2.06	33.37	93.05	86.72
P value		0.517	0.22	0.004	0.001	0.001

3.6 Economics

The economics of fish farming under different treatments are presented in table 3. Total cost significantly varied from 136862.00±606.45 (T_1) to 145754.00±57.35 Tk/ha/6 months (T_3). Gross benefit significantly varied from 384562.35±1890.32 (T_1) to 402667±8862.88 Tk/ha/6 months (T_3). Net benefit significantly varied from 247700.35±1890.32 BDT/ha/6 months (T_1) to 256913.35±8862.88 Tk/ha/6 months (T_3). The Net profit margin significantly varied from 176.31±5.55 (T_3) to 181.00±1.53% (T_1). The CBR significantly varied from 1.76±0.06 (T_3) to 1.81±0.02 (T_1).

Table 3: Economics of fish production under different treatments

Components \ Treatments	T_1	T_2	T_3
Lease value (Tk.)	45000.00±0.00^{a} (32.88%)	45000.00±0.00^{a} (31.85%)	45000.00±0.00^{a} (30.87%)
Pond preparation (Tk.)	11480.00±57.74^{c} (8.39%)	11480.00±98.56^{b} (8.12%)	11480.00±59.65^{a} (7.88%)
Fertilizer (Tk.)	26790.00±0.00^{a} (19.57%)	26790.00±0.00^{a} (18.96%)	26790.00±0.00^{a} (18.38%)
Fish seed (Tk.)	33592.00±0.00^{a} (24.54%)	38038.00±0.00^{a} (26.92%)	42484.00±0.00^{a} (29.15%)
Feed (Tk.)	00.00±0.00^{a} (0.00%)	00.00±0.00^{a} (0.00%)	00.00±0.00^{a} (0.00%)
Harvesting cost (Tk.)	20000.00±0.00^{a} (14.61%)	20000.00±0.00^{a} (14.15%)	20000.00±0.00^{a} (13.72%)
Total cost (Tk.)	136862.00±606.45^{c}	141308.00±57.74^{b}	145754.00±57.35^{a}
Gross benefit (Tk.)	384562.35±1890.32^{b}	392651.95±4590.61^{b}	402667.35±8862.88^{a}
Net benefit (Tk.)	247700.35±1890.32^{b}	251343.95±4590.61 $^{a\,b}$	256913.35±8862.88^{a}
Net profit margin (%)	181.00±1.53^{a}	178.33±2.96 $^{a\,b}$	176.31±5.55 ^{b}
CBR	1.81±0.02^{a}	1.78±0.03 $^{a\,b}$	1.76±0.06 ^{b}

Figures bearing common letter(s) in a row as superscript do not differ significantly ($P<0.05$)
% of total cost in parentheses

4. Discussion

4.1 Water quality parameters

The water quality parameters prevailing in different experimental ponds were within optimum ranges throughout the culture period. The mean value of water temperature varied from 31.76±0.30 (T_3) to 31.93±0.27 °C (T_1) which was quite similar to the findings of Kabir *et al.* [10] who recorded water temperature ranged between 29.50 to 31.65 °C in duckweed fed polyculture pond as well as the findings of Azim and Wahab [11], and Efiong *et al.* [12] in duckweed fed experiment. *Azolla* plays a significant role in the fluctuation of water transparency due to release of huge quantity of nitrogen. The mean value of water transparency was consistent with Azim and Wahab [11], who reported in duck weed, fed polyculture pond and was also similar with the findings of Chowdhury *et al.* [13] and Wahab *et al.* [14]. The mean value of dissolved oxygen varied from 5.32±0.09 (T_3) to 5.41±0.09 mg/l (T_1). The higher value of dissolved oxygen was found in T_1 might be due to comparatively lower stocking density. Almost similar types of results were recorded by Kabir *et al.* [10] as 4.90-6.45 mg/l while working on duckweed fed carp polyculture system. The dissolved oxygen was low in ponds stocked with a high density of fish compared to ponds stocked with a low density. The result of dissolved oxygen in the present study was consistent with what was observed by Saha *et al.* [15] and Rahman and Rahman [16] in a recent study.

The mean values of pH varied from 7.25±0.07 (T_2) to 7.35±0.09 (T_1) which was similar to the range of Azim and Wahab [11]. Slight alkaline condition (7.35) was good for fish culture. The range of pH obtained in the recent study is suitable for fish culture which has agreed with Majhi *et al.* [17] and Talukdar *et al.* [18]. Moreover, it has desirable to have an alkalinity of above 20 $mgL^{-1}$for optimal fish production [19]. Mairs, [20] measured a total alkalinity of 40.0 mgL^{-1} was to be productive than lower alkalinity. Ferdoushi *et al.* [21] recorded total alkalinity as 133.87±18.95 mg/l in *Azolla* fed fish pond. In another study, Kabir *et al.* [10] recorded alkalinity value ranged from 61 to 97.5 mg/l in duckweed fed polyculture pond which was lined with the present findings.

Moreover, results from the study indicated that the value of CO_2 varied from 2.64±0.07 (T_1) to 2.87±0.08 mg/l (T_3) was not harmful for fish culture. This assumption was supported by Boyd [22]. Talukdar *et al.* [18] have recorded free CO_2 value of 2.85±0.30 mg/l in their study on the suitability of duckweed as fish feed which was also strongly agreed with the findings of the present study.

4.2 Growth of fishes

Analysis of specific growth rate of exotic carps, *viz*., grass carp, silver carp, common carp and thai puti showed higher values than those of Indian major carps, *viz*., *catla*, rohu and mrigal. The higher growth rates of exotic carp species over Indian major carps in the present study are in agreement with the observations by earlier workers [23, 24]. Further, among the exotic species, *P. gonionotus* showed the highest specific growth rate (1.35±0.39–1.43±0.44%) than those of the other two, attributed to its inherent higher growth potential and taking *Azolla* as feed. Kabir *et al.* [10] reported the SGR value of *H. molitrix*, *C. mrigala*, *P. gonionotus* and *C. carpio* as 1.38, 1.25, 1.24 and 1.34%, respectively in duckweed fed fish culture ponds. The SGR in *catla* in the present study (1.16–1.21%) was nearly similar to 1.17–1.25% as observed by Chakraborty *et al.* [1] under carp polyculture system. So, these findings were strongly agreed with the present findings. Combined specific growth rate (SGR, % bwd^{-1}) of all fishes was significantly higher in T_1 where the stocking density was low compared to those of T_2 and T_3 although the same food was supplied in all the treatments at an equal ratio. Higher growth rates in T_1 might be due to low biomass contained at lower stocking densities of T_1 and other associated favourable environmental parameters compared to the treatments (T_2 and T_3) with higher densities. Papoutsoqlou *et al.* [25] observed the growth at lower density was better than higher density that was lined with the present findings.

The low growth rate of fishes in treatment T_2 and T_3 appeared to be related to higher densities and increased competition for food and space. A similar experience with regard to growth, i.e. retardation of fish growth at higher densities, was observed by several earlier workers working with carps and other fish species [26, 27]. The survival of each species (except mrigal) was not significantly affected by their own stocking density. Talukdar *et al.* [18] have observed survival rate as 82% (*C. catla*), 88% (*P. gonionotus*) on the weed based carp poly culture system. In a yearlong grow-out carp polyculture trial with olive barb as a component species at different species combinations and ratios, Chakraborty *et al*. [1] in Bangladesh observed 75.5–78.6% survival in silver carp and catla, 73.2–82.4% in rohu and 65.2–75.4% in mrigal. Similar survival levels of silver carp followed by rohu, mrigal and *catla* have also been reported earlier in some grow-out carp polyculture trials [24, 28]. In contrast, we recorded higher survivals in all the species, attributed to relatively larger stocking size and lower stocking density (except *P. gonionotus*). The lowest mean survival rate was found as 85.20±1.55% (T_3) and the highest survival rate as 87.14±1.94 % (T_1) for all the species. Variation in stocking density of fish may change growth and survival rates [29].

No marked differences in survival levels between different densities were observed, indicating that a higher stocking density of even 12500ha^{-1} did not cause much stress to the fish species. Similar high survival levels were also reported by Sinha and Saha [23] and Tripathi *et al.* [24]. The good survival levels recorded during the present experiment are attributable to the considerable size of stock material together with best management practices applied during the study.

4.3 Yield (Kg ha-1/6 months)

The result revealed that yield of rui, *catla*, mrigal and carpio significantly increased from T_1 to T_3 while the yield of *C. idella* and *P. goninotus* trends to be decreased from T_1 to T_3 with the increase of other carp's density. This might be due to the higher competition for *Azolla* between native carps (increased stocking density) and macrophages. Journey *et al.* [30] have reported that both *catla* and common carp competed aggressively for available duckweed feed and consumed it directly during the polyculture trial in Tangail, Bangladesh. In addition, it is assumed that the uneaten dead duckweed along with fish faeces settled onto the bottom and consumed directly by common carp and supplied nutrients for phytoplankton. Moreover, the used of *Azolla* for culture of *C. idella* provided encouraging economic result [31]. However, the yield of silver carp was insignificant in all treatments, indicating that there is no effect of *Azolla* on silver carp at different stocking rate.

The analysis of the combined yield of the three different treatments showed that significantly the net production in T_3 at a stocking density of 12500 individuals' ha^{-1} was higher than those of T_1 and T_2. The increased growth and production with higher density of fish might have been due to the proper stocking density, maximum number of species, good water quality, regular supply of *Azolla* and synergistic interaction and confounding effects of additional numbers of silver, rui, *catla*, mrigal and carpio whereas the lowest combined yield (Kg ha^{-1}/6 months) was found as 3894.33±18.00 (T_1) due to low stocking density. The net production of this experiment is comparable to other reported productions in semi-intensive polyculture in Bangladesh. Gopakumar *et al.* [32] mentioned that the production of weed based carp polyculture was 3-4 tonnes ha^{-1} $year^{-1}$ which was consistent with the production of the present study. Lakshmanan *et al.* [26] also reported high net production levels of 3286.5 kg $ha^{-1}year^{-1}$ at a stocking density of 5000/ha compared to 2232 kg ha^{-1} $year^{-1}$ at a lower density of 4450 ha^{-1}. Grover *et al.* [8] mentioned that the possible production of *Azolla* based carp polyculture was 5575 kg ha^{-1}which was more or less closer to the findings of the present study.

4.4 Economics

Along with the increase in production, the purpose of aquaculture practices is to earn a profit. Wyban *et al.* [33] indicated that stocking density, growth rate, survival and market price are the most sensitive factors to increase profit. Total investment cost and total return were directly related to stocking density. The highest density required the highest, total investment cost and also provides the highest return.

The total cost was higher in Treatment T_3 might be due to the higher stocking density i.e. seed cost (24.54% of total cost). Roy *et al.* [34] studied the economics of carp-SIS polyculture and their economic analysis under 3 treatments and they mentioned the operational cost was 32,450.00, 39,950.00 and 42,450.00 Tk/ha/7 months in treatments T_1, T_2 and T_3 respectively, which was lower than the present study might due to the comparatively smaller size of stocked fish seed. In another Grover *et al.* [8] assumed total cost as 85,000.00 BDT/ha which more or less similar to the present study. Gross benefit was higher than the findings of Roy *et al.* [34] who reported the gross benefit was 128,000.00, 128,280.00 and 110,720.00 Tk./ha/7 months in treatments T_1, T_2, and T_3 respectively because of lower production rate than the present study. In case of net benefit, Majhi *et al*. [18] reported the net benefit of 227338.00 BDT/ha was obtained from *Azolla* fed pond, which was slightly lower than the present findings. Shamugasundaram and Balusamy, [35] stated that the benefit cost ratio was 1.88 which was similar to the present study. Khan *et al*. [36] also mentioned BCR value of 1.22 which was lower than the findings of the present study was due to high initial biomass of all the species and also the higher survival rate. Data on economics indicated that the treatment T_1 (lower stocking density) was more profitable than that of others.

Inspite of having lowest total fish production with treatment T_1 best growth performance of macrophytophagus species was found with that treatment. This indicated that treatment T_1 was found most potential for the development of low cost fish farming, which was reflected by having significantly lowest total cost and highest CBR with that treatment. The study indicated that *Azolla* based carp polyculture with stocking density of 10000 fish ha^{-1}could be used for low cost weed based fish farming in Bangladesh.

5. Conclusion

Considering the water quality, production and economics, it can be concluded that *Azolla* based carp polyculture with stocking density of 10000 fish ha^{-1} be used for low cost *Azolla* based fish farming in Bangladesh.

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7. References

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