Journal of Fisheries
Volume 9 Issue 2 August 2021
Peer Reviewed | Open Access | Online First

eISSN 2311-3111
pISSN 2311-729X

Original Article

Species suitability for small indigenous species (SIS) of fish farming in carp polyculture ponds under drought prone area

Md. Harun-Ur-Rashid • Md. Akhtar Hossain • Md. Mostafizur Rahman Mondol • S.M. Nurun Nabi • Md. Abu Sikendar • Md. Anwar Hossain

Department of Fisheries, University of Rajshahi, Rajshahi 6205, Bangladesh

Correspondence
Md. Harun-Ur-Rashid; Department of Fisheries, University of Rajshahi, Rajshahi 6205, Bangladesh
harunsohag42@gmail.com

Manuscript history
Received 11 March 2021 | Revised 24 May 2021 | Accepted 25 May 2021 | Published online 27 May 2021

Citation
Harun-Ur-Rashid M, Hossain MA, Mondol MMR, Nabi SMN, Sikendar MA, Hossain MA (2021) Species suitability for small indigenous species (SIS) of fish farming in carp polyculture ponds under drought prone area. Journal of Fisheries 9(2): 92201.

Abstract
Reduced culture period with lack of guidelines in selecting appropriate species are major constraints for promotion of small indigenous species (SIS) based carp polyculture in ponds under drought prone area. In order to address this issue, an experiment was conducted to determine the suitable species for farming of SIS fishes in carp polyculture ponds in Rajshahi district, Bangladesh. Three different species of SIS fishes were tested under three treatments (T_1, *Heteropneustes fossilis*; T_2, *Clarias batrachus*; T_3, *Mystus cavasius*). Carp species were *Hypophthalmichthys molitrix*, *Gibelion catla* and *Labeo rohita*. Stocking density of SIS fishes (37050 individuals ha^{-1}) and carps (*H. molitrix*, 500; *G. catla*, 250 and *L. rohita* 250 individuals ha^{-1}) were same for all the treatments. Fishes were fed 35% protein containing supplementary feed twice a day at the rate of 6% of biomass. Common water quality parameters were monitored monthly and found within the suitable range for fish culture. Treatment T_2 was significantly higher than others in terms of fish yield and cost benefit ratio. Further research is also recommended to optimize the stocking density of *C. batrachus* based carp polyculture.

Keywords: Carp; drought; polyculture; pond; SIS

1 | INTRODUCTION

Fisheries and aquaculture is the fastest growing food-producing sector in the world (Little *et al.* 2016; FAO 2020). It is developing, expanding and intensifying in almost all regions of the world. The demand for fish and other aquatic food products is increasing with the growing global population. Bangladesh is one of the major contributors to the world's fisheries, ranked fifth for aquaculture production (FAO 2018). In Bangladesh, 60% of animal protein comes from fish and the fisheries sector contributes 3.50% to the country's GDP (DoF 2020). Fish are rich source of protein, fatty acids, essential vitamins and minerals which are important for the cognitive and physical development of humans (Roos *et al.* 2007). Fishes constitute an important portion in human diets and serves as an irreplaceable source of animal protein for the poor rural households in Bangladesh (Samad *et al.* 2010; Galib *et al.* 2013, 2016). Aquaculture and fisheries is the most productive and dynamic sectors that has significant contribution in food security through providing safe and quality animal protein in Bangladesh (Ghose 2014; Islam *et al.* 2016). In Bangladesh, decreasing water retention capacity is a major problem and many ponds hold water for only 5 to 6 months a year. These water bodies are primarily being used for different purposes of households but some are left abandoned due to their derelict and marshy nature (Saokat *et al.* 2017). But such ponds can potentially be used by adopting appropriate fish culture technologies involving fish species of short life cycle, faster growth and high market value. For the poor and pro-poor people in Bangladesh, small indigenous species (SIS) of fishes are important sources of animal protein and other nutrients. SIS contain large amount of vitamin A and vitamin D which are essential for human bones, skin, eyes and teeth (Roos *et al.* 2003). There are 260 freshwater fish species in Bangladesh, among them 143 fishes are classified as SIS (Rahman 2005). Although, historically, SIS fishes were commonly abundant in natural habitats of Bangladesh including beels (a large waterbody that accumulates surface runoff water through internal drainage channels), rivers, lakes, haors (an wetland ecosystem in the north eastern part of Bangladesh which is physically a bowl or saucer shaped shallow depression) and baors (dead arm of a river) but their richness and abundance are declining rapidly in recent times (Galib *et al.* 2010; Samad *et al.* 2010; Chaki *et al.* 2014). And efforts through monoculture or polyculture practices are therefore, necessary to increase the production of nutrient rich SIS fishes (DoF 2007). Importance of pond based polyculture as a popular technique for fish production in Bangladesh is well documented (Azim and Wahab 2003; Asadujjaman and Hossain 2016; Hossain 2017). The motivating principle is that fish production in ponds may be maximized by raising a combination of species having different food habits. There are also some merits of polyculture such as maximum production, more profit and employment opportunities. Carps have been recommended as co-species for farming of nutrient rich SIS in polyculture ponds (Hussain *et al.* 2008; DoF 2014). There are also research efforts on SIS-carp polyculture (Roy *et al.* 2002, 2003; Hossain *et al.* 2013, 2018; Mondal *et al.* 2018; Nabi *et al.* 2020) but no comprehensive study found on incorporating suitable species of SIS fish in carp polyculture ponds under drought prone area. Moreover, a same technology may not be suitable for all the geographic locations. Therefore, present study aimed at finding out the species suitability for SIS fish farming in carp polyculture ponds under drought prone area. Specific objective of this study were to monitor water quality and fish growth; to evaluate fish yield and economics of SIS-carp polyculture; and to recommend suitable SIS fish for carp-SIS polyculture in ponds under drought prone area.

2 | METHODOLOGY

2.1 Location and duration of study

The experiment was conducted for a period of 4 months from July to October, 2019 in nine experimental ponds (Mean area: 0.053 ± 0.001 ha; depth: 1.39 ± 0.013 m) of Paba upazila (sub-district) under Rajshahi district, Bangladesh (Table 1). Experimental ponds were well exposed to sunlight. Embankments of the ponds were high enough (0.25 – 0.5 m) to protect the run off.

2.2 Experimental design

Three different species of SIS fishes were tested in carp polyculture ponds under three treatments namely T_1: stinging catfish, *Heteropneustes fossilis*; T_2: walking catfish, *Clarias batrachus*; and T_3: Gangetic mystus, *Mystus cavasius*, each with 3 replications. Stocking density of SIS fishes (37050 individuals ha^{-1}) and carps (*H. molitrix*, 500; *G. catla*, 250 and *L. rohita* 250 individuals ha^{-1}) were same for all the treatments (Table 1).

TABLE 1 Layout of experimental design.

Parameters	**T_1 (*Heteropneustes fossilis* + carp)**			**T_2 (*Clarias batrachus* + carp)**			**T_3 (*Mystus cavasius* + carp)**		
	T_1R_1	**T_1R_2**	**T_1R_3**	**T_2R_1**	**T_2R_2**	**T_2R_3**	**T_3R_1**	**T_3R_2**	**T_3R_3**
Pond area (ha)	0.048	0.052	0.060	0.052	0.048	0.052	0.056	0.052	0.052
Pond depth (m)	1.45	1.34	1.42	1.32	1.41	1.38	1.39	1.4	1.41
Stocked SIS (individuals pond^{-1})	1800	1950	2250	1950	1800	1950	2100	1950	1950
Stocked carps (individual pond^{-1})	48	52	60	52	48	52	56	52	52

2.3 Pond management

Aquatic vegetation was removed manually from ponds. Unwanted and pre-existing predatory species were removed from the experimental ponds through repeated netting. Regular liming was done at 250 kg ha^{-1} as basal and 50 kg ha^{-1} fortnight^{-1} as periodic dose. Inorganic fertilizers (urea: 40 kg ha^{-1} and TSP, triple super phosphate: 40 kg ha^{-1}) were used for enhancing natural feed in ponds. Fertilization was done after five days of liming. TSP was wetted overnight and spread over the ponds at following day whereas instant application was done for urea. Wild seeds of *G. catla* and *L. rohita*; and hatchery seeds of *H. fossilis*, *C. batrachus*, *M. cavasius* and *H. molitrix* were used for stocking into the experimental ponds. Carp seeds were subjected to overwintering process whereas seeds of SIS fishes were shifted from nursery rearing to farmer managed grow out ponds for stocking. SIS were fed floating pelleted feed containing 35% protein at the rate of 6% of the body weight (10% at first, 8% at second, 6% at third and fourth, 5% at fifth and sixth and

4% at rest of the fortnights). Twice daily feeding (morning and evening) was followed for all the treatments. Feed ration was adjusted through fortnightly sampling.

2.4 Monitoring of water quality parameters

Water quality parameters of the experimental ponds were monitored between 09:00 and 10:00 am. Temperature was recorded with the help of a Celsius thermometer at 20–30 cm below the water surface. Water transparency (cm) was measured by a Secchi disk. Dissolved oxygen (mg L^{-1}), pH and total dissolved solids (TDS, mg L^{-1}) were determined by a Multimeter (HQ 40D, HACH, USA). Alkalinity (mg L^{-1}) and ammonia-nitrogen (mg L^{-1}) were determined by the help of a HACH kit (FF2, USA).

2.5 Determination of fish growth and yield

Fortnightly sampling of fishes was done to monitor growth performance and to adjust the feeding ration. In each sampling date, 10% of the stocked fishes were caught from each pond with the help of a cast net for the study of growth performances of fish. The examined fishes were then immediately released into the ponds without any harm. Growth (in terms of initial weight; final weight; weight gain; specific growth rate, SGR; and survival rate) and yield of fishes were determined after Brett and Groves (1979) as follows:

Initial weight = Weight of fish at stock

Final weight = Weight of fish at harvest

Weight gain = Mean final weight – Mean initial weight

$$SGR\ (\%,\ bwd^{-1}) = \frac{L_n\ final\ weight - L_n\ initial\ weight}{Culture\ period} \times 100$$

$$Survival\ rate\ (\%) = \frac{No.\ of\ fish\ harvested}{No.\ of\ fish\ stocked} \times 100$$

Fish yield = Fish biomass at harvest – Fish biomass at stock

2.6 Economic analysis

Simple cost-benefit analysis was done to explore the economics of SIS-carp polyculture in ponds under different treatments. At the end of the experimental period, all the fishes were sold in a local market. The prices of inputs and fish corresponded to the market prices in Rajshahi, Bangladesh and were expressed in Bangladesh currency (Taka) as BDT (1 US$ = 84.24 BDT, as of October 2019). Data on both fixed and variable costs were recorded to determine the total cost. The net benefit and cost benefit ratio (CBR) were calculated as follows (after Shang 1990):

Net benefit = Total return– Total cost (investment)

CBR = Net benefit / Total investment

2.7 Statistical analysis

Water quality parameters; fish growth and yield; and economics of SIS-carp polyculture under different treatments were analyzed by one-way analysis of variance (ANOVA). When a mean effect was significant, the ANOVA was followed by Duncan Multiple Range Test (Duncan 1955) at 5% level of significance (Gomez and Gomez 1984). The percentages and ratio data were analyzed using arcsine transformed data. All analyses were performed using SPSS (Statistical Package for Social Science) version 20.0 (IBM Corporation, Armonk, NY, USA).

3 | RESULT AND DISCUSSION

3.1 Water quality parameters

The mean values of water quality parameters under different treatments are presented in Table 2. During the study period, variations in species had no significant effect ($p > 0.05$) on temperature, DO, transparency, pH, alkalinity and TDS of the pond water and all the parameters were within the suitable limit for SIS-carp farming (Alikunhi 1957; Boyd 1998). However, treatments showed a significant variation ($p < 0.05$) in NH_3-N concentration of water in ponds due to species variation. NH_3-N was higher in T_3 and lower in T_2. These features could be explained by the utilization of supplementary feed and production of fecal materials. The quantity and quality of fecal materials produced is species-, feed- and system-dependent (Verdegem 2013). Therefore it may be assumed that T_2 produced less fecal materials and utilized supplementary feed effectively than others.

TABLE 2 Water quality parameters in different treatments of SIS-carp farming.

Water quality	Treatments			*F*-value	*p*-value
	T_1	T_2	T_3		
Temperature (°C)	33.54 ± 0.11^a	33.55 ± 0.08^a	33.40 ± 0.19^a	0.35	0.720
DO (mg L^{-1})	5.37 ± 0.10^a	5.38 ± 0.05^a	5.32 ± 0.08^a	0.15	0.870
pH	7.32 ± 0.04^a	7.37 ± 0.14^a	7.34 ± 0.17^a	0.02	0.980
Alkalinity (mg L^{-1})	120.83 ± 3.81^a	117.75 ± 2.75^a	119.17 ± 3.75^a	0.10	0.910
Transparency (cm)	25.25 ± 0.25^a	25.16 ± 0.08^a	25.17 ± 0.17^a	0.07	0.930
NH_3-N (mg L^{-1})	0.05 ± 0.00^b	0.04 ± 0.01^b	0.07 ± 0.00^a	2.54	**0.040**
TDS (mg L^{-1})	633.67 ± 5.11^a	627.75 ± 13.02^a	648.00 ± 12.76^a	0.75	0.360

Figures bearing common letter(s) in a row as superscript do not differ significantly ($p > 0.05$)

There was no noticeable effect of environmental parameters on productivity of fish species. Mondal *et al.* (2018) recorded temperature range of 27.53 to 29.38°C, alkalinity ranging from 87.85 to 102.61 mg L^{-1} and pH value from 7.70 to 8.06 in carp-SIS polyculture ponds. Hossain *et al.* (2018) recorded temperature range of 31.49 to 31.74°C, DO range of 5.93 to 6.32 mg L^{-1} and pH range of 7.12 to 7.93 mg L^{-1} in polyculture of stinging catfish (*H. fossilis*) with Indian major carps in ponds. The transparency of productive water bodies should be 40 cm or less according to Rahman (1992). Ali *et al.* (2018), in their study on *H. fossilis*, *Oreochromis niloticus* and *Barbonymus gonionotus* culture in ponds, recorded temperature between 30.33 and 31.42°C, DO between 5.61 and 6.03 mg L^{-1}, transparency between 28.67 and 46.33 cm and total alkalinity between 129.17 and 151.83 mg L^{-1}. However, TDS of 268.44 to 280.02 mg L^{-1} was reported in homestead pond (Nabi *et al.* 2020) which is comparatively lower than the present study. This variation in TDS might be due to the variation in soil-water quality. This assumption is all most agreed with Hossain (2011) while working on water quality and fish growth in red soil area of Bangladesh. However, the TDS values recorded in this study seem to be within suitable range for fish culture as fish do not appear to be affected by standard concentrations of 2000 mg L^{-1} (Rana and Jain 2017).

3.2 Fish growth and yield

Variations among the treatments in growth performances were recorded across treatment groups (Table 3). Despite no variation in growth of most of carps species overall production varied significantly across treatments ($p < 0.05$) which is due to growth performances of SIS fishes. The growth performance of *C. batrachus* in T_2 was better than *H. fossilis* in T_1 and *M. cavasius* in T_3. Dietary protein content is also considered an important factor for biomass increase within shorter period in ponds with higher density stocking of catfishes. Mean weight gain (87.92 ± 1.56 g 4-month^{-1}) of *C. batrachus* was recorded in this study and this was found comparatively better than the weight gain (41.14 ± 0.15 – 56.10 ± 0.86 g 6-month^{-1}) recorded by Reza *et al.* (2021) using 28% protein containing diet. Hussain *et al.* (2008) recommended 30 – 35% protein content in diet for farming of *C. batrachus* in ponds. However, higher protein content in feeds has also been used for *Clarias gariepinus* farming in earthen ponds (e.g. 43%, Oke *et al.* 2016). The current findings also agreed with Ali and Jauency (2003) and Rasowo *et al.* (2008) who recommended 35% protein content in diet for farming of *Clarias* spp.

TABLE 3 Fish growth in different treatments of SIS-carp farming.

Species	Treatment	Initial weight (g)	Final weight (g)	Weight gain (g 4-month^{-1})	SGR (%, bwd^{-1})	Survival rate (%)
SIS (*H. fossilis / C. batrachus / M. cavasius*)	T_1	0.51 ± 0.02^{a}	72.06 ± 4.15^{b}	71.55 ± 4.17^{b}	4.12 ± 0.07^{b}	82.11 ± 0.89^{a}
	T_2	0.50 ± 0.01^{a}	88.43 ± 1.57^{a}	87.92 ± 1.56^{a}	4.31 ± 0.02^{a}	85.52 ± 1.73^{a}
	T_3	0.52 ± 0.02^{a}	17.16 ± 0.42^{c}	16.64 ± 0.41^{c}	2.91 ± 0.02^{b}	69.96 ± 2.00^{b}
F value		0.22	209.69	209.03	278.08	25.57
p value		0.810	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Gibelion catla	T_1	164.77 ± 2.36^{a}	727.68 ± 33.04^{a}	562.90 ± 34.29^{a}	1.23 ± 0.04^{a}	79.49 ± 3.74^{a}
	T_2	164.09 ± 2.32^{a}	738.36 ± 48.44^{a}	574.27 ± 46.19^{a}	1.25 ± 0.04^{a}	79.35 ± 1.53^{a}
	T_3	165.70 ± 2.57^{a}	730.96 ± 35.96^{a}	565.26 ± 35.30^{a}	1.23 ± 0.04^{a}	80.16 ± 3.37^{a}
F value		0.11	0.01	0.02	0.04	0.02
p value		0.890	0.980	0.970	0.960	0.980
Hypophthalmichthys molitrix	T_1	229.75 ± 1.38^{a}	922.70 ± 11.18^{a}	692.95 ± 11.83^{a}	1.15 ± 0.02^{a}	81.57 ± 1.30^{a}
	T_2	230.26 ± 2.01^{a}	917.78 ± 10.09^{a}	687.52 ± 9.68^{a}	1.15 ± 0.01^{a}	80.30 ± 1.26^{a}
	T_3	231.15 ± 1.65^{a}	925.07 ± 14.66^{a}	693.92 ± 13.50^{a}	1.16 ± 0.01^{a}	81.71 ± 1.81^{a}
F value		0.17	0.09	0.08	0.08	0.28
p value		0.840	0.910	0.920	0.920	0.760
Labeo rohita	T_1	142.52 ± 1.39^{a}	572.39 ± 18.75^{a}	429.87 ± 20.14^{a}	1.15 ± 0.04^{a}	76.11 ± 3.29^{a}
	T_2	142.34 ± 2.55^{a}	573.06 ± 19.59^{a}	430.72 ± 18.31^{a}	1.16 ± 0.02^{a}	75.71 ± 3.44^{a}
	T_3	143.47 ± 2.30^{a}	565.40 ± 31.31^{a}	421.93 ± 30.51^{a}	1.14 ± 0.04^{a}	76.65 ± 1.76^{a}
F value		0.08	0.03	0.04	0.09	0.02
p value		0.920	0.960	0.950	0.910	0.970

Figures bearing common letter(s) in a column as superscript do not differ significantly ($p > 0.05$)

Variations in fish yield under the treatments are shown in Table 4 and Figure 1. Fish yield in T_2 was 18.78% and 73.27% higher than T_1 and T_3, respectively. This study almost agreed with Samad and Imteazzaman (2019) who worked on the monoculture of *C. batrachus* in ponds and recoded survival rate as 92% and yield as 1498.2 ± 345.2 kg ha^{-1} 3-month^{-1}. The overall fish yield recorded in T_2 was also closer to the yield (6610.27 Kg ha^{-1} 6-month^{-1})

recorded by Hossain *et al.* (2018) in polyculture of *H. fossilis* with Indian major carps in ponds. However, comparatively higher growth and yield performance in T_2 might be due to the effect of individual size and metabolism. Although there was no significant difference in initial stocking weight of catfishes across treatments, but comparatively highest weight gain was recorded for *C. batrachus* followed by *H. fossilis* and *M. cavasius*. In adult condition, the highest length recorded as 45.7 cm in *C. batrachus* and 30 cm each for *H. fossilis* and *M. cavasius* (DoF 2018). Actually the fish with lower body size results higher metabolic activity and thus produces lower biomass (Boyd 1998).

3.3 Economics of SIS-carp farming

Variations in the mean values of total cost, total return, net benefit and CBR are shown in Table 5. Total return in T_2 was 17.99% and 74.02% higher than T_1 and T_3, respectively. Treatments varied significantly ($p < 0.05$) for the net benefit and CBR. Although there was no significant difference between T_1 and T_2 but the highest net benefit (446179.80 ± 29972.56 BDT ha^{-1}) and CBR (0.81 ± 0.05) were recorded in T_2. Findings of this study more or less agreed with Samad and Imteazzaman (2019) who have reported the CBR of 0.67 to 1.05 in farming of *C. batrachus* at varying stocking densities. The better economic performance (in terms of total return, net benefit and CBR) in T_2 might be due to the better growth and yield performance of SIS species in the treatment. During study, feed was found as the major cost involving area (41.39 – 75.24% of the total cost). However, this is a common phenomenon in intensive fish farming (New and Csavas 1993; Mukhopadhyay and Jena 1999) as well as carp polyculture in Bangladesh (Mohsin *et al.* 2012).

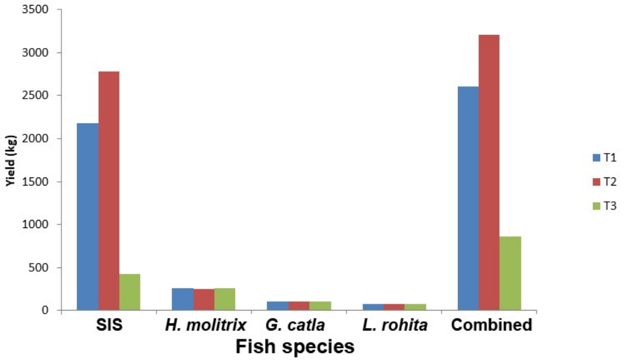

FIGURE 1 Variation in yield in different treatments of SIS-carp farming.

TABLE 4 Fish yield (kg ha^{-1} 4-month^{-1}) in different treatments.

Species	Treatments			*F*-value	*p*-value
	T_1	T_2	T_3		
SIS	2175.64 ± 148.02^{b}	2785.50 ± 105.53^{a}	424.84 ± 2.72^{c}	136.29	**<0.001**
Hypophthalmichthys molitrix	258.42 ± 9.14^{a}	250.18 ± 1.91^{a}	259.11 ± 8.11^{a}	0.48	0.640
Gibelion catla	102.46 ± 11.60^{a}	104.16 ± 9.03^{a}	103.23 ± 2.99^{a}	0.01	0.990
Labeo rohita	72.23 ± 4.05^{a}	72.08 ± 7.08^{a}	71.34 ± 3.51^{a}	0.01	0.980
All species	2608.76 ± 134.76^{b}	3211.93 ± 98.56^{a}	858.53 ± 3.51^{c}	160.73	**<0.001**

Values in the same row having different superscript letters are significantly different ($p < 0.05$)

TABLE 5 Economics of SIS-carp farming in pond (cost, return and benefit are in BDT ha^{-1}).

Items	Treatments			*F*-value	*p*-value
	T_1	T_2	T_3		
Variable cost					
Seed	103738.04 ± 39.51^{a}	103739.59 ± 208.11^{a}	94600.13 ± 76.53^{b}	1646.31	**<0.001**
Feed	325691.13 ± 2972.70^{b}	411853.33 ± 5208.94^{a}	89306.67 ± 1022.75^{c}	2260.34	**<0.001**
Fixed cost					
Lime	5760 ± 0.00	5760 ± 0.00	5760 ± 0.00	-	-
Fertilizer	2550 ± 0.00	2550 ± 0.00	2550 ± 0.00	-	-
Labour	13500 ± 0.00	13500 ± 0.00	13500 ± 0.00	-	-
Harvest	10100 ± 0.00	10100 ± 0.00	10100 ± 0.00	-	-
Total cost	461239.70 ± 2984.22^{b}	547402.92 ± 5297.49^{a}	215716.80 ± 960.16^{c}	2358.46	**<0.001**
Total return	814878.11 ± 48181.02^{b}	993582.73 ± 33758.89^{a}	259884.05 ± 769.90^{c}	126.86	**<0.001**
Net benefit	353638.41 ± 453339.32^{b}	446179.80 ± 29972.56^{a}	44167.25 ± 330.61^{c}	45.01	**<0.001**
CBR	0.76 ± 0.09^{a}	0.81 ± 0.05^{a}	0.20 ± 0.02^{b}	30.87	**<0.001**

Values in the same row having different superscript letters are significantly different ($p < 0.05$); market price (BDT kg^{-1}) was 340, 330 and 430 for *Heteropneustes fossilis*, *Clarias batrachus* and *Mystus cavasius* respectively.

4 | CONCLUSIONS

Considering the water quality, yield and economics, *C. batrachus* was found as the best species for farming in polyculture pond. Further study is also needed to optimize the stocking density and finding out the suitable feeding strategy in *C. batrachus* based carp polyculture in ponds under drought prone area.

ACKNOWLEDGEMENTS

Authors gratefully acknowledge PIU-BARC, NATP-2 Project (ID-037) of Bangladesh Agricultural Research Council (BARC) for financial support.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTION

MH fieldwork and manuscript preparation; **MAH** research design, supervision and manuscript review and editing; **MMRM** manuscript review; **SMNN** fieldwork; **MAS** manuscript review; **MAH** fieldwork.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author.

REFERENCES

Ali A, Rahman MR, Alam MJ, Nishat AA, Rabbi MF, Haque MA, ... Ullah MA (2018) Production of stinging catfish (*Heteropneustes fossilis*) in different stocking densities with GIFT (*Oreochromis niloticus*) and Thai sharpunti (*Barbonymus gonionotus*) in ponds. Journal of Fisheries and Life science 3(1): 9–15.

Ali MZ, Jauncey K (2003). Effect of restricted feeding on compensatory growth responses in (*Clarias gariepinus*). Indian Journal of Fisheries 50(4): 489–497.

Alikunhi KH (1957) Fish culture in India. Farm Bulletin. No. 20. Indian Council of Agricultural Research, New Delhi. 144 pp.

Asadujjaman M, Hossain MA (2016) Fish growth, yield and economics of conventional feed and weed based polyculture in ponds. Journal of Fisheries 4(1): 353–360.

Azim ME, Wahab MA (2003) Development of a duckweed-fed carp polyculture system in Bangladesh. Aquaculture 18: 425–438.

Boyd CE (1998) Water quality for fish pond. Aquaculture Research and Development Series No. 43. Auburn University, Alabama, USA. 37 pp.

Brett JR, Groves TDD (1979) Physiological energetics. In: Hoar WS, Randall DJ, Brett JR (Eds) Fish physiology, volume III, bioenergetics and growth. Academic Press, New York. pp. 280–352.

Chaki N, Jahan S, Fahad MFH, Galib SM, Mohsin ABM (2014) Environment and fish fauna of the Atrai River: global and local conservation perspective. Journal of Fisheries 2(3): 163–172.

DoF (2007) National fish week compendium 2007. Department of Fisheries, Ministry of Fisheries and Livestock, Bangladesh. 95 pp. (in Bangla).

DoF (2014) National fish week compendium 2014. Department of Fisheries, Ministry of Fisheries and Livestock, Bangladesh. 144 pp. (in Bangla).

DoF (2018) Album: freshwater fishes of Bangladesh. Department of Fisheries, Ministry of Fisheries and livestock, Bangladesh. 201 pp. (in Bangla).

DoF (2020) National fish week compendium 2020. Department of Fisheries, Ministry of Fisheries and Livestock, Bangladesh. 160 pp. (in Bangla).

Duncan DB (1955) Multiple range and multiple '*F*' tests. Biometrics 11: 1–42.

FAO (2018) The state of world fisheries and aquaculture 2018 – meeting the sustainable development goals. Food and Agriculture Organization of the United Nations, Rome. 227 pp.

FAO (2020) The state of world fisheries and aquaculture. Sustainability in action. Food and Agriculture Organization of the United Nations, Rome. 224 pp.

Galib SM, Hoque MN, Akter S, Chaki N, Mohsin ABM (2016) Livelihood, climate change and fisheries: a case study of three fishing communities of northwestern Bangladesh. International Research Journal of Social Sciences 5(8): 18–25.

Galib SM, Naser SMA, Mohsin ABM, Chaki N, Fahad MFH (2013) Choice of fishes for consumption by the rural people of Bangladesh. Trends in Fisheries Research 2(1): 20–23.

Galib SM, Samad MA, Hossain MA, Mohsin ABM, Haque SMM (2010) Small Indigenous Species of Fishes (SISF) in Chalan Beel with reference to their harvesting and marketing. Bangladesh Journal of Progressive Science and Technology 8(2): 251–254.

Ghose B (2014) Fisheries and aquaculture in Bangladesh: challenges and opportunities. Annals of Aquaculture and Research 1(1): 1001.

Gomez KA, Gomez AA (1984) Statistical procedure for agricultural research, second edition. John Wiley & Sons, New York. 680 pp.

Hossain F, Halim KMA, Saddiqe AB, Shanta NS, Rabbi MF, ... Rahman MR (2018) Poly culture of stinging catfish (*Heteropneustes fossilis*) with Indian major carp in ponds. International journal of Fisheries and Aquatic Studies 6(6): 37–42.

Hossain MA (2011) Effect of fertilization techniques on fish growth in ponds under red soil zone of northern Bangladesh. Bangladesh Journal of Progressive Science and Technology 9(2): 192–196.

Hossain MA (2017) Fish culture in ponds and rice fields by poor Adivasi (ethnic) households in northwest Bangladesh: performances evaluation and livelihood aspects. Bangladesh Journal of Progressive Science and Technology 15(1): 1–6.

Hossain MA, Alam MR, Haqiue MR, Ferdous M (2013) Study on present status of carp-SIS polyculture in Dinajpur district of Bangladesh. Bangladesh Research Publication Journal 2: 123–130.

Hussain MG, Halder GC, Ahammad SU, Alam MJ, Zaher M, ... Mahmud Y (2008) A guide book on aquaculture technologies. Bangladesh Fisheries Research Institute, Ministry of Fisheries and Livestock, Bangladesh. 96 pp.

Islam MS, Jahan H, Al-Amin AKMA (2016) Fisheries and aquaculture sectors in Bangladesh: an overview of the present status, challenges and future potential. Journal of Fisheries and Aquaculture Research 1(1): 2–9.

Little DC, Newton RW, Beveridge MCM (2016) Aquaculture: a rapidly growing and significant source of sustainable food? Status, transitions and potential. Proceedings of the Nutrition Society 75(3): 274–286.

Mohsin ABM, Islam MN, Hossain MA, Galib SM (2012) Cost-benefit analyses of carp polyculture in ponds: a survey study in Rajshahi and Natore districts of Bangladesh. Bangladesh Journal of Environmental Science 23: 103–107.

Mondol S, Wahab MA, Barman BK, Hossain MMM (2018) Impact on environment intervention of carps-SIS polyculture in north-west of Bangladesh. Journal of Entomology and Zoology Studies 6(5): 528–537.

Mukhopadhyay PK, Jena JK (1999) Use of nonconventional dietary ingredients in fish feed formulation, In: Saksena DN (Ed) Recent research advances in ichthyology. Oxford IBH Publishing House Co. Pvt. Ltd., New Delhi and Calcutta. pp. 225–248.

Nabi SMN, Hossain MA, Alam MM, Harun-Ur-Rashid M, Hossain MA (2020) Effect of carp species combination on production and economics of stinging catfish, *Heteropneustes fossilis* based polyculture in homestead ponds under drought prone area of Bangladesh. Journal of Fisheries 8(3): 920–927.

New MB, Csavas I (1993) Aquafeeds in Asia - a regional overview. In: New MB, Tacon AGJ, Csavas I (Eds) Farm-made aquafeeds. Proceedings of the FAO/AADCP Regional Expert Consultation on Farm Made Aqua feeds, Bangkok, Thailand. pp. 14–18.

Oke V, Abou Y, Adite A, Kabre JAT (2016) Growth performance, feed utilization and body composition of *Clarias gariepinus* (Burchell 1822) fed marine fish viscera-based-diet in earthen ponds. Fisheries and Aquaculture Journal 7: 4.

Rahman AKA (2005) Freshwater fishes of Bangladesh, second edition. Zoological Society of Bangladesh, Department of Zoology, University of Dhaka, Dhaka. 394 pp.

Rahman MS (1992) Water quality management in aquaculture. BRAC Prokashana, Dhaka, Bangladesh. 84 pp.

Rana N, Jain S (2017) Assessment of physico-chemical parameters of freshwater ponds of district Bijnor (U. P), India. Journal of Entomology and Zoology Studies 5(4): 524–528.

Rasowo J, Auma E, Ssanyu G, Ndunguru M (2008) Does African catfish (*Clarias gariepinus*) affect rice in integrated rice-fishculture in Lake Victoria Basin, Kenya. African Journal of Environmental Science and Technology 2(10): 336–341.

Reza MS, Samad MA, Ferdous J (2021) Effects of feeding frequency on the growth and production performance of indigenous catfish, *Clarias batrachus* (Linnaeus, 1758) in ponds of Northern Bangladesh. Journal of Fisheries 9(1): 91201.

Roos N, Chamnan C, Loeung D, Jakobsen J, Thilsted SH (2007) Freshwater fish as a dietary source of vitamin A in Cambodia. Food Chemistry 103(4): 1104–1111.

Roos N, Islam MM, Thilsted SH (2003) Small indigenous fish species in Bangladesh: contribution to vitamin A, calcium and iron intakes. The Journal of Nutrition 133: 4021–4026.

Roy NC, Kohinoor AHM, Wahab MA (2002) Evaluation of performance of carp-SIS polyculture technology in the rural farmers pond. Asian Journal of Science 15: 43–52.

Roy NC, Wahab MA, Islam M, Thilsted SH (2003) Economics of carp-SIS poly culture in rural farmers pond. Pakistan Journal of Science 6(1): 61–64.

Samad MA, Asaduzzaman M, Galib SM, Kamal MM, Haque MR (2010) Availability and consumer preference of small indigenous species (SIS) of the River Padma at Rajshahi, Bangladesh. International Journal of BioResearch 1(5): 27–31.

Samad MA, Imteazzaman AM (2019) Growth and production performance of indigenous threatened cat fish, *Clarias batrachus* (Linn. 1758) based on stocking density in North Western Bangladesh. International Journal of Fisheries and Aquatic Studies (5): 267–274.

Saokat A, Khandaker RH, Maliha H, Yahia M, Rahman MK (2017) Adaptability of polyculture of stinging catfish (*Heteropneustes fossilis*) in seasonal water bodies of greater northern region, Bangladesh. International Journal of Fisheries and Aquatic Studies 5(1): 433–439.

Shang YC (1990) Aquaculture economic analysis: an introduction. The World Aquaculture Society, Baton Rouge. 211 pp.

Verdegem MJ (2013) Nutrient discharge from aquaculture operations in function of system design and production environment. Review in Aquaculture 5(3): 158–171.