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Optimizing Mixed Culture of *Mystus vittatus* (Tengra) for Climate Resilience and Food Security in Small-Scale Aquaculture in Bangladesh

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ABSTRACT

Targeting a holistic approach for a threatened native species of economic and conservative high value of the Indian subcontinent, a study was conducted to evaluate the culture potentiality of *M. vittatus* in the semi-arid northern region of Bangladesh to emphasize the growth and yield of *Mystus vittatus* (Tengra) in polyculture systems. The experiment focused on determining optimal stocking densities and species combinations for Tengra alongside other short-cycle fish species. Two culture patterns were tested: Pattern-I (Tengra + Pabda + Magur + Rajpunti + GIFT) and Pattern-II (Tengra + Shing + Magur + Rajpunti + GIFT), with each pattern trialed at three stocking densities (500, 600, and 700 Tengra per decimal) across 18 upazillas. Each treatment was replicated three times. Results indicated that the T2 combination, with a stocking density of 600 Tengra, yielded the best growth performance, production, and benefit-cost ratio (BCR) in both patterns. Specifically, the combinations of 600 Tengra + 100 Pabda + 50 Magur + 25 Rajpunti + 10 GIFT and 600 Tengra + 100 Shing + 50 Magur + 25 Rajpunti + 10 GIFT showed significantly higher yields (P<0.05) and were selected for further multi-location testing (MLT) in six upazillas across northern Bangladesh. The MLT trials confirmed improved performance over the first-year results, reinforcing the potential of these polyculture combinations. The findings suggest that *Mystus vittatus* is well-suited for polyculture with short-cycle species in seasonal ponds in the semi-arid regions of Bangladesh. These stocking combinations could be a valuable strategy for enhancing aquaculture productivity and profitability for fish farmers in the region.

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Introduction

The interdependent relationships among global freshwater and a high number of natural and anthropogenic stressors are extremely complex and impact the aquatic ecosystems and their organisms, including fish, all around the world [1-3]. Beyond this general human determined circumstances, the climate changes jeoperdize accentuatelly and continuously too the natural fish habitats, populations, and species and consequently a major meat protein reservoir, and the world food security and socio-economic stability. In this global risky complex paradigm, animal perpetuation, reproduction, and thriving, based on inovative approaches and techniques, are of high interest. At the top of the list, fish as one of the main reservoirs of excellent quality protein should be a key objective for the scientific work [4-7].

The high vitamin D, excellent quality and flavor, and omega-3 fatty eaten in a variety of ways are often viewed as a delicacy. The catfishes (Order Siluriformes) are a group of ray-finned fish of considerable commercial importance; some of them have been farmed or fished for food for thousands of years and others are important for aquarium hobbyists. In Bangladesh and adjacent geographical areas, catfish are popular and eaten as a favored delicacy [8-10].

The threatened small indigenous fish in the Indian subcontinent area *Mystus vittatus* (Teleostei, Siluriformes, Bagridae), is a freshwater, brackish, demersal species with a known range in the Indian subcontinent. It reaches a maximum of 21 cm [11-13].

Adults inhabit standing and flowing waters, usually found among marginal vegetation in lakes and swamps with a mud substrate It naturally breeds during monsoons in flooded rivers and ponds [14].

Mystus vittatus is a commercially important fish due to its good taste, offering food, nutrition, subsistence, and supplemental income to the great majority of rural people in its range area. It has a high demand both in rural and urban markets, particularly to the poor and disadvantaged group [15].

However, due to indirectly anthropogenic activities impacting the aquatic ecosystems, the fragmentation and loss of natural habitats for spawning, feeding, refuge, nursery, etc.; fishing pressure; water

pollution; indiscriminate drying of water bodies; and reclamation of wetlands, its populations are affected and slowly diminishing, and there is a direct impact on these fish species populations [16-18]. At all the above causes for this species abundance and range diminishing should be added the natural disasters, climate changes, and excessive floodplain siltations . Also, due to the pollution, these fish have a genotoxic and mutagenic potential with adverse effects on the species [19].

Though it is a delicious and demandable species, the production of the candidate fish is gradually declining; as a result, it has also been listed as a threatened fish [20]. As the production is gradually declining, the development of management and conservation measures is urgently required. Also, developing aquaculture techniques is critical to safeguarding this valuable native fish. Conservation and domestication studies in controlled environments are vital for preventing its populations from diminishing.

The fish farmers are unable to go for its production for want of seeds; consequently, seeds of this species are often collected from the natural habitat, which is unpredictable. Moreover, this practice may seriously affect the natural fry production rate in the near future. Furthermore, because of the harmful effects of pesticides, chemicals, and industrial wastes, natural spawning grounds are being destroyed day by day. As a result, the overall seed supply from natural sources has shrunk to the minimum (only about 2-3%).

More than 900 fish hatcheries scattered all over Bangladesh have kept the freshwater aquaculture industry growing over the country by supplying about 99% of the required seeds. Recently, the Bangladesh Fisheries Research Institute, Freshwater, Sub-Station, Saidpur, has developed induced breeding and nursery rearing techniques in captive conditions for this species The development will help to protect this threatened species from its extinction in nature, and fish farmers can easily culture this fish alone or with short-cycle fishes in their seasonal waters and possibilities of increasing fish production per unit area, which play a pivotal role in improving their family nutrition and improving their social and economic status. However, until now, it has not practiced with tengra polyculture with different patterns with other short-cycle fishes. or monoculture in farmer's fields, and not much research work has been done on it. In the northern districts of Bangladesh, about 55% ponds are seasonal, of which 60% retain water for 4-6 months, while 40% retain it for 6 to 9 months in a year and even more in some areas (Ahamed et al.) These small water bodies are being used mainly for household activities but some are still abandoned due to their derelict and marshy nature. Greater Rangpur district is such an area where this culture technique will be the most wanted and effective for all kinds and types of fish farmers for increasing fish production and income generation [21].

This study is expected to provide financial support for poor fish farmers and a source of quick return of money also. From the aquaculture perspective, those water bodies have great potential, except for a few that are brought under for culturing of tengra

with short life cycle fish species, which have faster growth and require low inputs, such as shing (*Heteropneustes fossilis*), magur (*Clarias batrachus*), pabda (*Ompok pabda*), silver barb (*Barbodes gonionotus*), genetically improved farmed tilapia (GIFT), etc [22-24]. Tengra should be polycultured with short-cycle species to guarantee proper use of these ponds; this will be improved to achieve maximum yield. The demands for those fish are owing to their taste and medical values. Unfortunately, the culture technologies of tengra with short-cycle species have yet to be optimized and evaluated, especially in the northern part of Bangladesh. Hence, the present research has been designed and proposed to demonstrate these research results at farmer's fields as well as to validate the technologies, especially in the semi-arid zone of Bangladesh.

Material and Methods
Polyculture of Tengra (Pattern I) with Short-Cycle Fishes in the Farmer's Ponds
Experimental Procedure and Design
The experiment was conducted at the farmer's ponds of the Rangpur region for a period of 05 (five) months. A total of 09 (nine) seasonal ponds were selected, and the ponds were selected with the concern of the relevant Upazilla Fishery Officer (UFO/SUFO). The nine ponds are divided into three groups. Each group was used for one treatment viz., treatment-I (T_1), treatment-II (T_2), treatment-III (T_3), and each pond was considered for one replication. The ponds were 10-20 decimal in size. The cultural trial on tengra, *M. vittatus*; pabda, Ompok pabda; magur, *C. batrachus*; rajpunti, *B. gonionotus*; and BFRI GIFT in the seasonal ponds of the Northern region is envisioned. The experimental design is presented in Table 1.

Table 1: Polyculture of Tengra (Pattern 1) Under Different Stocking Densities in the Farmer's Ponds

Treatments	Species combination	Stocking density (indi. dec.$^{-1}$ dec.$^{-1}$)
T1	Tengra+Pabda+Magur+Rajpunti+GIFT	500+100+50+25+10
T2		600+100+50+25+10
T3		700+100+50+25+10

Pond Preparation: The selected ponds were prepared by dewatering and drying. Aquatic weeds were removed from the ponds manually. Then, lime was applied @ 1.0 kg decimal ^{1}. After 7 days of liming, urea @100 g decimal^{-1} and TSP @75 g decimal^{-1} were applied at the initial stage of pond preparation.

Stocking of Fingerlings: The hatchery-produced fingerlings (5-10 cm) of selected fishes were stocked as per experimental design (Table 1).

Feeding Regime: Commercially available fish feed (containing 30-35% protein) was fed at 10-8% BW day^{-1} of the fishes.

Feed Composition: Feed Ingredients and Proximate Composition for feed of Catfishes (Company: Quality Feeds Limited)

Proximate Composition (Dry Matter Basis)

Moisture (Max)	Crude Protein (Min)	Fat (Min)	Carbohydrate (Max)	Fiber (Max)	Ash (Max)	Calcium (Max)	Phosphorus (Min)
11%	32%	7%	20%	3.5%	10%	2%	1%

Feed Ingredients

Fish Meal	Wheat Broken	Soybean Meal	Full Fat Soybean	Mustard Oil Cake	Rice Bran	Vitamins & Other Macronutrients
50%	15%	10%	10%	10%	4%	1%

Sampling
Length and weight data were collected fortnightly in the morning at 8.00 am to 9.00 am. Sampling was done by cast net. Fish length was measured using a measuring meter scale (cm), and weight was taken by precision weighing balance (measuring range from 1.0 g to 1.0 kg). Water quality parameters such as water temperature (°C), transparency (cm), water pH, dissolved oxygen (DO) (mg l^{-1}), and ammonia (NH$_3$) (mg l^{-1}) of the experimental ponds were monitored fortnightly.

Harvesting and Estimation of Growth Parameters and BCR Analysis
The ponds were completely dewatered, harvested all the fish at the end of the experiment, and counted species-wise. Then the final length-weight of each species was recorded. The parameters such as length gain, weight gain, % weight gain, SGR, FCR, and survival rate (%) and also the benefit-cost ratio (BCR) were calculated and evaluated for the growth and yield of fish.

Polyculture of Tengra (Pattern-II) with Short-Cycle Fishes in the Farmer's Ponds
Experimental Procedure: The Design
The experiment was conducted at the farmer's ponds of the Rangpur region for a period of 05 (five) months. The size of ponds, experimental methodology, feeding management, data collection and observations were performed as previously described. The experimental design is presented in Table 2.

Table 2: Polyculture of Tengra (pattern-2) Under Different Stocking Densities in the Farmer's Ponds

Treatments	Species combination	Stocking Density (indi. dec.-1)
T1	Tengra+Shing+Magur+Rajpunti+GIFT	500+100+50+25+10
T2		600+100+50+25+10
T3		700+100+50+25+10

Dissemination of suitable polyculture patterns of short-cycle fish species in different part of semi-arid zone (northern part) of Bangladesh (2020-21)

Experimental Procedure and Design
Multi-Location Testing (MLT) Program
Multi-location testing programs were conducted in different upazilas of the northern region of Bangladesh to verify the research results of previously tested suitable culture patterns and exchanged views among the researcher, extension people (DoF), and farmers. A total of 06 (six) seasonal ponds were selected in 06 (six) different Upazilas of the Rangpur region (Table 3). The ponds were selected with the concern of relevant Senior Upazila Fisheries Officer/Upazila Fisheries Officer (SUFO/UFO). The six ponds (one pond in one upazila) were divided into two groups, viz., *group-I* (Trail-1) and group-II (Trail-2), and each pond (upazila) was considered as one replication. The areas of ponds ranged between 10 and 15 decimals. The experimental design is presented in Table 3.

Table 3: Experimental Design in Different Upazila of Rangpur Region

Cultural pattern	Replication (one pond/Upazila)	Species combination	Stock. density (indi. decl^{-1})
Trial-1	Domar, Nilphamari+Aditmari, Lalmonirhat+Parbotipur, Dinajpur	Tengra+Pabda+Magur+ Rajpunti+GIFT	600+100+50+25+10
Trial -2	Debiganj, Panchagarh, Chirirbondor, Dinajpur, and Rangpur Sadar	Tengra+Shing+Magur+ Rajpunti+GIFT	600+100+50+25+10

Growth Parameters
a) Weight Gain
Weight gain (g) = Final weight (g) – Initial weight (g)

b) Percent Weight Gain (%)

$$\text{Percent weight gain (\%)} = \frac{\text{Final weight gain (g)} - \text{Initial weight (g)}}{\text{Initial weight (g)}}$$

a) Specific Growth Rate (SGR % day^{-1})
The SGR is the momentary change in weight of fish calculated as the percent increase to body weight per day over a given time interval and written as

SGR (%) = (InW$_2$ - InW$_1$) / (T$_2$ -T$_1$) × 100

Where
W_1 = The initial live body weight (g) at the time T_1 (day)
W_2 = The final live body weight (g) at time T_2 (day)

b) Survival rate (%)
Survival of fish was calculated by using the following equation:

$$\text{Survival rate (\%)} = \frac{\text{Final no of fish}}{\text{Initial no of fish}} \times 100$$

Food Conversion Ratio (FCR)
Food conversion ratio is defined as the amount of dry food fed per unit live weight gain. It is calculated by the following formula:

$$\text{FCR} = \frac{\text{Total dry feed intake (g)}}{\text{Total wet weight gain (g)}}$$

After the termination of the experiment, an economic analysis was performed to estimate the net return and benefit-cost ratio on the basis of different stocking densities of every treatment. By using the following simple equation, economic analysis was determined:
Net profit (BDT treatment^{-1}) = Gross return – variable cost
BCR = Gross return / variable cost (BDT)

Net Profit
Net profit = Gross production value – Total production costs.
A benefit-cost ratio (BCR) is a ratio used in a cost-benefit analysis to summarize the overall relationship between the relative costs and benefits of a treatment. BCR can be expressed in monetary or qualitative terms. If a treatment has a BCR greater than 1.0, the treatment is expected to deliver a positive net present value. The treatment that has a higher BCR is more profitable from a financial aspect.

It can be calculated by the following formulae:
Benefit Cost Ratio (BCR) = Total production value / total production costs (BDT)

Analytical Methods and Statistical Analysis
Data were analyzed using MS Excel and one-way analysis of variance (ANOVA) and SPSS 20 (Chicago, USA) to detect significant differences among the treatments at a 5% significance level.

Results and Discussion
Polyculture of Tengra (Pattern-1) Under Different Stocking Densities in Farmer's Pond
An experiment was executed in the farmer's ponds under three treatments: T_1 (500 tengra + 100 pabda + 50 magur + 25 rajpunti + 10 GIFT indi. dec-1), T_2 (600 tengra + 100 pabda + 50 magur + 25 rajpunti + 10 GIFT indi. dec.-1), and T_3 (700 tengra + 100 pabda + 50 magur + 25 rajpunti + 10 GIFT indi. dec^{-1}) to find out the growth and production of *M. vittatus* in a polyculture system. The growth parameters such as weight gain, SGR, survival, production of tengra, and total production of the experimental fish, and water quality parameters of experimental ponds were observed. The results are presented in Tables 4 and 5, respectively. In this experiment, the final weight of tengra was 19.5, 17.8, and 16.3 g in T_1, T_2, and T_3, respectively. The highest weight gain (16.9 g) was found in T_1, and the lowest (14.1 g) was found in T3. The weight gain of tengra was found to be significantly ($p < 0.05$) higher in T_1, followed by T_2 and T3. The SGR of tengra were 1.43, 1.38, and 1.32% day^{-1} in T_1, T_2, and T_3, respectively, and significantly ($p<0.05$) different from each other. The FCR values were the highest in T_3 (2.88) and the lowest in T_1 (2.45), which were directly related to the stocking density of fish. The survival rate was estimated after harvesting fish at the end of the experiment. Survival rates of tengra were 88, 86, and 73% in T_1, T_2, and T_3, respectively, which were significantly ($p<0.05$) different. The production of tengra was recorded as 2106, 2302, and 2091 kg ha^{-1} in T_1, T_2, and T_3, respectively. The production of tengra and total production in T_2 were found to be significantly ($p<0.05$) higher, followed by T_1 and T_3 (Table 4). The results revealed that the production of tengra, total fish production, and BCR were higher in T_2 among the treatments.

Table 4: Growth Performances of Tengra Under Polyculture in Three Treatments

Parameters	Treatments		
	T_1	T_2	T_3
Culture period (months)	05	05	05
Initial weight (g)	2.25 ± 0.03	2.25 ± 0.03	2.25 ± 0.03
Final weight (g)	19.15 ± 1.2[a]	17.85 ± 1.5[b]	16.37 ± 1.7[c]
Weight gain (g)	16.9 ± 1.1[b]	15.6 ± 1.5[a]	14.12 ± 1.7[c]
SGR (% day^{-1})	1.43 ± 0.02[b]	1.38 ± 0.01[b]	1.32 ± 0.02[c]
FCR	2.45 ± 0.01[a]	2.56 ± 0.01[b]	2.88 ± 0.02[c]
Survival (%)	88.0 ± 3.0[a]	86.0 ± 3.5[b]	73.0 ± 4.5[c]
Production of tengra (kg ha^{-1})	2106 ± 15.0[a]	2302 ± 34.0[b]	2091 ± 92.0[c]

Total production (kg ha^{-1})	$5750 \pm 4.0c$	$6756 \pm 71.0b$	$5830 \pm 95.0a$
Benefit cost ratio (BCR)	1.54	1.63	1.27

Within rows, values with different superscripts are significantly different ($p < 0.05$)

Physico-Chemical Parameters of the Experimental Ponds

The water quality parameters viz., temperature (°C), transparency (cm), water pH, DO (mg l 1) and ammonia (mg l 1) of the experimental pond under 3 different treatments were studied and presented in Table 5. The water temperature varied between 27.8 and 28.5°C during the experiment, and there was no significant difference among the treatments. The water transparency was 26.5, 26.6, and 27.1 cm in T_1, T_2, and T_1, respectively. The pH was 7.8, 7.7, and 7.6 in T_1, T_2, and T_3, respectively. The DO concentration ranged from 5.4 to 6.0 mg l^{-1} during the experiment and no significant difference was observed among the treatments. Analytical results showed the pH and DO values were inversely related with the stocking density. The ammonia varied from 0.16 to 0.17 mgl^{-1} among the treatments. Water quality parameters were observed in congenial for fish culture.

Table 5: Water Quality Parameters in Different Treatments Under Polyculture of Tengra

Water quality parameters	Treatments		
	T_1	T_2	T_3
Air temperature (°C)	29.0 ± 2.3	28.8 ± 2.0	29.5 ± 2.5
Water temperature (°C)	28.0 ± 2.5	27.8 ± 3.0	28.5 ± 2.0
Transparency (cm)	26.5 ± 1.5	26.6 ± 2.0	27.1 ± 1.0
Water pH	7.8 ± 0.6	7.7 ± 0.43	7.6 ± 0.56
DO (mg l^{-1})	6.0 ± 0.5	5.5 ± 0.6	5.4 ± 0.5
NH$_3$ (mg l^{-1})	0.16 ± 0.01	0.17 ± 0.02	0.17 ± 0.03

Economic Analysis of Polyculture of Mystus Vittatus

Economic analysis was performed to estimate the benefit-cost ratio from different treatments of the tengra polyculture system (Table 6). The production cost (Tk. ha^{-1}) was 1,041,875/-, 1,162,375/-, and 1,270,500/- in T_1, T_2, and T_3, respectively. The gross return value (Tk. ha^{-1}) was 1,610,000/-, 1,891,680/-, and 1,632,400/- in T_1, T_2, and T_3, respectively, with a significant difference ($p < 0.05$) among the treatments. Furthermore, the gross margin (Tk. ha^{-1}) was 568,125/-, 729,305/-, and 361,900/- in T_1, T_2, and T_3, respectively, which were significantly ($p<0.05$) different. The highest BCR was achieved in T_2 (1.63), followed by T_1 (1.54) and T_3 (1.27), which were significantly ($p<0.05$) different. The production and BCR in the present study were more or less similar to the findings of Kohinoor and Rahman (2014), who stated that the production of gulsha, Mystus cavasious, in polyculture varied between 4050 and 4650 kg ha^{-1} in a 6-month culture period. On the basis of total production and BCR, it can be concluded that T_2 (600 tengra + 100 Pabda + 50 magur + 25 rajpunti + 10 GIFT indi. dec.$^{-1}$) was the best combination for tengra polyculture in seasonal ponds at the semi-arid zone of Bangladesh.

Table 6: Benefit and Cost Analysis of Tengra Under Polyculture in Three Treatments

Item-Wise Expenditure	T_1	T_2	T_3
Pond preparation (Tk ha^{-1})	25,000	25,000	25,000
Fingerling cost (Tk ha^{-1})	250,000	295,000	340,000
Lime and fertilizer (Tk ha^{-1})	12,500	12,500	12,500
Feed cost (Tk ha^{-1})	704,375	779,875	843,000
Transport, labor, etc. (Tk ha^{-1})	50,000	50,000	50,000
Total production costs (Tk ha^{-1})	$10,41,875 \pm 2598c$	$1162375 \pm 1670b$	$1270500 \pm 940a$
Income and Output	T_1	T_2	T_3
Total production (Tk ha^{-1})	$5,750 \pm 40.0b$	$6756 \pm 71.0a$	$5,830 \pm 95.0c$
Gross return (Tk ha^{-1})	$16,10,000 \pm 125b$	$1891680 \pm 620a$	$16,32,400 \pm 326c$
Gross margin (Tk ha^{-1})	$568,125 \pm 3195b$	$729,305 \pm 1280a$	$361,900 \pm 860c$
Benefit cost ratio	$1.54b$	$1.63a$	$1.27c$

Within rows, values with different superscripts are significantly different ($p < 0.05$)

Polyculture of Tengra (Pattern-II) under different Stocking Densities in Farmer's Pond

An experiment was carried out in the farmer's ponds under three treatments: T_1 (500 tengra + 100 Shing + 50 magur + 25 rajpunti + 10 GIFT indi. dec^{-1}); T_2 (600 tengra + 100 Shing + 50 magur + 25 rajpunti + 10 GIFT indi. dec.$^{-1}$); and T_3 (700 tengra + 100 Shing + 50 magur + 25 rajpunti + 10 GIFT indi. dec^{-1}) to find out the growth and production of Mystus vittatus in a polyculture system. The growth parameters such as weight gain, SGR, survival, production of tengra, and total production of the experimental fish and water quality parameters of experimental ponds were observed, and the results are presented in Tables 7 and 8, respectively. In this

experiment, the final weight of tengra was found to be 20.1, 19.2, and 17.75 g in T_1, T_2, and T_3, respectively. The highest weight gain (16.9 g) was observed in T_1, and the lowest (14.5 g) was found in T_3. The weight gain of tengra was found to be significantly ($p < 0.05$) higher in T_1, followed by T_2 and T_3. The SGR of tengra was 1.22, 1.19, and 1.14% day^{-1} in T_1, T_2, and T_3, respectively. Additionally, the SGR of tengra was significantly ($p < 0.05$) higher in T_1, followed by T_2 and T_3. The FCR value was the highest in T_2 (2.24) and the lowest in T_3 (2.18). Analytical results showed the FCR values were directly related to the stocking density. The survival rate was estimated after harvesting the experimental fish at the end of the study. In the case of tengra, the values of the survival rate were 83, 85, and 81% in T_1, T_2, and T_3, respectively, which was significantly ($p < 0.05$) different. The production of tengra was recorded as 2096, 2241, and 1942 kg ha^{-1} in T_1, T_2, and T_3, respectively. On the basis of analysis, the production of tengra and total production in T_2 were found to be significantly ($p < 0.05$) higher, followed by T_1 and T_3 (Table 7).

Table 7: Growth Performances of *Mystus vittatus* under a Polyculture System in Three Treatments

Water quality parameters	Treatments		
	T_1	T_2	T_3
Initial weight (g)	3.25 ± 0.03	3.25 ± 0.03	3.25 ± 0.03
Final weight (g)	20.11 ± 1.2	19.25 ± 1.0	17.75 ± 1.3
Weight gain (g)	16.91 ± 1.1 [a]	16.05 ± 1.5 [b]	14.55 ± 1.7 [c]
SGR (% day-1)	1.22 ± 0.02 [a]	1.19 ± 0.01 [b]	1.14 ± 0.02 [c]
FCR	2.20 ± 0.01 [c]	2.24 ± 0.01 [a]	2.58 ± 0.02 [a]
Survival (%)	83.0 ± 3.0 [a]	85.0 ± 3.5 [ab]	81.0 ± 4.5 [a]
Production of Tengra (kg ha^{-1})	2096 ± 2.0 [a]	2241 ± 34.0 [a]	1942 ± 92.0 [a]
Total production ha-1)	5625 ± 4.0 [a]	6873 ± 71.0 [a]	5734 ± 95.0 [a]
Benefit cost ratio (BCR)	1.53 [a]	1.60 [b]	1.32 [a]

Physico-Chemical Parameters of the Experimental Ponds
The water quality parameters viz., temperature (°C), transparency (cm), water pH, DO (mg l 1) and ammonia (mg l 1) of the experimental pond under 3 different treatments were studied and presented in Table 8. The water temperature varied between 28.3 and 29.0°C during the experiment, and there was no significant difference among the treatments. The pH was 7.4, 7.5, and 7.7 in T_1, T_2, and T_3, respectively. The DO concentration ranged from 5.4 to 6.0 mg l^{-1} during the experiment, and no significant difference was observed among the treatments. Analytical results showed the pH and DO values were inversely related with the stocking density. The ammonia varied from 0.04 to 0.10 mg l^{-1} among the treatments. Water quality parameters were observed at optimum levels for fish culture.

Table 8: Water Quality Parameters in Different Treatments Under Polyculture of Tengra

Water quality parameters	T_1	T_2	T_3
Water Temperature (°C)	29.0 ± 2.2	28.8 ± 2.0	28.3 ± 2.3
Water pH	7.4 ± 0.20	7.5 ± 0.24	7.7 ± 0.30
DO (mg l^{-1})	6.0 ± 0.5	5.5 ± 0.2	5.4 ± 0.15
NH_3 (mg l^{-1})	0.04 ± 0.01	0.06 ± 0.01	0.10 ± 0.02

Economic Analysis of Polyculture of Mystus Vittatus
Economic analysis was performed to estimate the benefit-cost ratio from different treatments of the tengra polyculture system (Table 9). The production cost (Tk. ha^{-1}) was 1,012,500/-, 1,241,650/-, and 1,201,590/- in T_1, T_2, and T_3, respectively. The gross return value (Tk. ha^{-1}) was 1,575,000/-, 1,924,440/-, and 1,605,520/- in T_1, T_2, and T_3, respectively, with a significant difference ($p < 0.05$) among the treatments. Furthermore, the gross margin (Tk. ha^{-1}) was 562,500/-, 682,790/-, and 403,930/- in T_1, T_2, and T_3, respectively, and the gross margin was found to be significantly higher in T_2, followed by T_1 and T_3. The highest BCR was achieved in T_2 (1.60), followed by T_1 (1.55) and T_3 (1.33), which was significantly different ($p < 0.05$) among the treatments. The production and BCR in the present study were more or less similar to the findings of who stated that the production of gulsha, Mystus cavasious, in polyculture varied between 4050 and 4650 kg ha^{-1} in a 6-month culture period [25].

On the basis of total production and BCR, it can be concluded that T_2 (600 tengra + 100 shing + 50 magur + 25 rajpunti + 10 GIFT indi. dec.$^{-1}$) was the suitable combination for tengra polyculture in seasonal ponds at the semi-arid zone of Bangladesh

Table 9: Benefit and Cost Analysis of Tengra Under Polyculture in Three Treatments

Item Wise Expenditure	T_1	T_2	T_3
Pond preparation (Tk ha^{-1})	25,000	25,000	25,000
Fingerling cost (Tk ha^{-1})	2,50,000	2,95,000	3,40,000
Lime and fertilizer (Tk ha^{-1})	12,500	12,500	12,500
Feed cost (Tk ha^{-1})	6,75,000	8,15,000	7,74,090
Transport, labor etc. (Tk ha^{-1})	50,000	50,000	50,000

Total production costs (Tk ha-1)	10,12,500 ± 2272[c]	12,41,650 ± 1870[b]	12,01,590 ± 940[a]

Income and Output	T1	T2	T3
Total production (Tk ha-1)	5,625 ± 40.0 [b]	6853 ± 71.0[a]	5,734 ± 95.0 [c]
Gross return (Tk ha-1)	15,75,000 ± 105 [b]	19,24,440 ± 620 [a]	16,05,520 ± 326 [c]
Gross margin (Tk ha-1)	5,62,500 ± 312[b]	6,82,790 ± 1180 [a]	4,03,930 ± 860 [c]
Benefit cost ratio	1.55 [b]	1.60 [a]	1.32

Polyculture of Tengra, *Mystus vittatus,* in Multi-location Testing
Name of Study: Dissemination of Suitable Polyculture Patterns of Short-Cycle Fish Species in Different Part of Northern Region of Bangladesh
After the culture of 05 months, the water quality parameters, production of tengra, total production of cultured fishes, and their economics in different locations are presented in Tables 10, 11, and 12. The final growth (18.7 g) was found higher in trial-I (Domar, Aditmari, and Parbotipur) upazila, followed by trial-II (Debigang, Chirirbandar, and Rangpur sadar) upazila. The weight gain (17.5 g) and SGR (1.83) were also higher in trial-I (Domar, Aditmari, and Parbotipur) upazilas. The highest survival (86%) was in trial I, but there was no significant difference among the locations. Similarly, the production of tengra (kg ha⁻¹), the total production (kg ha⁻¹) of cultured fishes, gross return (Tk. ha⁻¹), gross margin (Tk. ha⁻¹), and BCR were found identical in three locations. On the basis of multi-location results, the production of tengra, total production of fishes, and the BCR were higher and satisfactory, which may be due to suitable stocking density and also proper culture period. Thus, it can be suggested that the two combinations of 600 tengra + 100 pabda + 50 magur + 25 rajpunti + 10 GIFT indi. dec. -1 and 600 tengra + 100 shing + 50 magur + 25 rajpunti + 10 GIFT indi. dec. -1 are suitable in the northern region of Bangladesh. It can also be recommended that two types of combinations are appropriate in seasonal mini ponds and culture during May to September.

Table 10: Growth Performances of Mystus vittatus Under Polyculture Two Trails

Parameters	Trial	
	Trial-I	Trial-II
Stock. dens. of tengra (indi. dec-1)	600	600
Culture period (months)	05	05
Initial weight(g)	1.2±.2	1.2±.2
Final weight (g)	18.7±1.2	17.8±1.5
Weight gain (g)	17.5±1.1	16.6±1.5
SGR (% day-1)	1.83±0.02	1.80±0.01
FCR	2.40±0.01	2.56±0.01
Survival (%)	86.0±3.0	85.0± 3.5
Production of tengra (kg ha-1)	2,418±15.0	2,267±34.0
Total production (kg ha-1)	6,650±54.0	6,111±71.0
Benefit cost ratio (BCR)	1.64	1.56

Physico-Chemical Parameters of the Experimental Ponds
The water quality parameters viz., temperature (°C), water pH, DO (mg l⁻¹) and ammonia (mg l⁻¹) of the experimental pond under two trials were studied and presented in Table 11. The water temperature varied between 33.2 and 34.00°C during the experiment, and there were no significant differences between the trials. The pH was 7.4, 7.5 in trail-I and trail-II respectively. The DO concentration ranged from 5.5 to 6.0 mg l⁻¹ during the experiment, and no significant difference was observed among the treatments. Analytical results showed the pH and DO values were inversely related with the stocking density. The ammonia was found at 0.01 mg l⁻¹ between two trails. On the basis of observation, water quality parameters were found quite friendly for fish culture.

Table 11: Water Quality Parameters Under Polyculture of Tengra in Two Trails

Water Quality Parameters	Trial -I	Trial -II
Water Temperature (ºC)	34.0±2.2	33.2±2.0
Water pH	7.4±0.20	7.5±0.24
DO (mg l -1)	6.0±0.5	5.5±0.2
NH3 (mg l -1)	0.01±.01	0.01±.01

Economic Analysis of Polyculture of *Mystus vittatus*
Economic analysis was performed to estimate the benefit-cost ratio from different trials of the tengra polyculture system (Table 12). The production cost (Tk. ha⁻¹) was 1,133,000 and 1,117,250 in trial I and trial II, respectively. The gross return value (Tk. ha⁻¹) was 1,862,000 and 1,711,080 in trail-I and trail-II, respectively. Furthermore, the gross margin (Tk. ha⁻¹) was 729,000 and 593,830, respectively, in trial I and trial II, and the gross margin was found to be significantly higher in trial I than in trial II. The higher BCR

was achieved in trial-I (1.64) than in trial-II (1.56). The production and BCR in the present study were more or less similar to the findings of who stated that the production of gulsha, *Mystus cavasious*, in polyculture varied between 4050 and 4650 kg ha⁻¹ in 06 months culture. On the basis of total production and BCR, it can be concluded that trail-I (600 tengra + 100 pabda + 50 magur + 25 rajpunti + 10 GIFT indi. dec.-1) was the suitable combination for tengra polyculture in seasonal ponds at the northern part of Bangladesh [25].

Table12: Benefit and Cost Analysis of Tengra Under Polyculture in Two Trails

Pond preparation (Tk ha-1)	25,000	25,000
Fingerling cost (Tk ha-1)	2,50,000	2,50,000
Lime and fertilizer (Tk ha-1)	10,000	10,000
Feed cost (Tk ha-1)	7,98,000	7,82,250
Transport, labor etc. (Tk ha-1)	50,000	50,000
Total production costs (Tk ha-1)	11,33,000±2272	11,17,250±1870
Total production costs (Tk ha⁻¹)	11,33,000±2272	11,17,250±1870

Income and Output	Trial -I	Trial -II
Total production (Tk ha⁻¹)	6,650±40.0	6111±71.0
Gross return (Tk ha⁻¹)	18,62,000±105	17,11,080±620
Gross margin (Tk ha⁻¹)	7,29,000±312	5,93,830±1180
BCR (Tk ha⁻¹)	1.64	1.56

Discussions
Growth Performance
After five months of culture period, we evaluate the growth performance of *M. vittatus* in patterns 1 & 2 was satisfactory. Although the initial weight was the same as the final weight, weight gain, SGR, and FCR were significantly different among the three treatments (Table 4). Ahamed et al. 2023 also evaluate the culture technique of Tengra (*Mystus vittatus*) with short-cycle fishes in the semiarid zone of Bangladesh. In his study, he found almost similar patterns of growth performances (final weight 18.5-14.2 g, weight gain 16.2-11.9 g, SGR 1.38-1.21, and FCR 15-2.70). with a five-month culture period maintaining the 500-700 stocking density in 03 different treatments. There is a reverse relationship with growth parameters with stocking density [26]. obtained suitable growth performance with lower stocking density compared to higher stocking density in gulsha fish farming. Lower stocking density generally provides more space for fish movement and less food competition. [28]. In another study , it was stated that stocking density directly affects the growth and survival of fish. The FCR value of the present study was an acceptable limit in both patterns (2.45-2.88 in pattern-1 and 2.20-2.58 in pattern-2), which indicates better food utilization. These findings agree with several research works done by [29,30]. According to Kohinoor et al. (2009), a mixed culture of Indian major with pabda and gulsha produced between 2,393 and 2,986 kg/ha in six months, where the relative contributions of gulsha and pabda were 9.04% and 5.2%. Therefore, a space-limiting effect, a stressful circumstance brought on by additional nutrition, some changes in environmental parameters, and a lack of natural food could all be contributing factors to the faster growth seen in lower densities. The current findings concurred with those of who found that while individual growth was higher at lower densities, the highest production was reached at higher stocking densities [31]. In the current investigation, the Tengra survival and individual growth values had a more reasonable effect on T2 production than T1 and T3 production. The current results are corroborated by research, which indicated that while a higher stocking density increased production, it also had a negative relationship with individual growth. Significantly, the survival range was recorded in pattern-1

(73-88%) with total production (5760-6756 kg ha⁻¹); on the other hand, in the pattern-2 range, the survival rate in three treatments was (81-85%) and the total production range was (5625-6873 kg ha⁻¹). The highest individual growth was in T1, which may be because T2 had comparatively more fry stocked than T1. Therefore, the observed low growth at greater stocking densities may be caused by a lack of natural food, space-limiting effects, stressful situations brought on by supplemental feed, and some differences in ambient characteristics. These findings agree with in the case of *Mystus vittatus* polyculture in a semi-arid zone with different combinations [32]. also found a similar pattern of findings in the case of *Heteropneustes fossilis* [33].

Economic analyses were assessed to find out the profitability of the culture system with two different patterns and combinations. This new alternative species in aquaculture. The cost ratio was satisfactory in both patterns after the total investment. 1.54, 1.63, and 1.27 in pattern 2. BCR in T2 was significantly different from other treatments. In case of pattern -2, also follow the similar pattern of BCR (1.53 in T1, 1.60 in T2, and 1.32 in T3) due to the lower production cost in T2 and relatively lower FCR than the other treatments. This BCR in the present study aligned with the findings of who stated that the BCR ranged from 1.32 to 1.69 when the stocking density of Shing ranged from 500 to 700 ind. dec. induring a five-month polyculture. In the case of Thai koi, Rahman et al. (2013) also found better BCR with a five-month culture period in seasonal ponds. In the case of small indigenous fishes, mention that the BCR ratio varied from 1.30 to 1.65 in the case of Osteobrama cotio in a polyculture system [35].

Water Quality Parameters
Experimental ponds under two distinct patterns in three different treatments had their water quality parameters-temperature (°C), transparency (cm), water pH, DO (mg l⁻¹), and ammonia (mg l⁻¹)-monitored and displayed in Tables 5, 8, and 11. No discernible differences were found between the treatments, and the water temperature fluctuated between 28°C and 34°C during the trial. According to and the preferred temperature range for fish cultivation is 25.5°C to 30.0°C. For this reason, the range was

chosen [36,37]. Transparency of water was 26.5, 26.6, and 27.1 cm in T1, T2, and T3, respectively. In successful koi culture ponds, reported similar transparency values, ranging from 26.8 to 30.4 cm. In treatment T1, treatment T2, and treatment T3, the mean pH values were 7.8, 7.7, and 7.6. As stated by, the water's pH levels Results ranging from 7.3 to 9.0 showed that the experimental ponds were appropriate for raising fish. No discernible variation was found between the treatments, and the DO concentrations during the experiment varied from 5.4 to 6.0 mg l^{-1}. For fish culture, the dissolved oxygen content should be kept between 5.0 and 8.0 mg l^{-1}, according to [39]. The dissolved oxygen level in the current investigation was therefore presumed to be appropriate for fish culture. Treatments ranged in ammonia from 0.08 to 0.12 mg l^{-1}. Shing polyculture ponds in the northern part of Bangladesh have ammonia levels ranging from 0.16 to 0.24 mg l^{-1}, according to [40]. This result is consistent with what the current study found. It may be inferred from the experimental findings and the discussion above that the water quality parameters used in this study were optimal for fish culture.

Dissemination of Culture Pattern

To verify the culture technology, we disseminate the suitable culture pattern with suitable stocking density based on growth and economic analysis We test the result in different locations of the northern region of Bangladesh with small-scale fish framers. Although the region is a drought-prone area and farmers always have a crisis of water in their pond, we identify the suitable period and types of culture fish that were applicable in their pond. M. vittatus is a new species in aquaculture, but it has tremendous potential in drought-prone areas due to a shorter culture period with a good profit return after harvesting fishponds. Nonetheless, the current study outperformed previous studies in terms of survivorship [41]. In contrast to Siddiky et al., 2007 the stocking density of Vietnamese koi in polyculture over a 4-month period ranged from 300 to 500 ind. dec.$^{-1}$, and the BCR of the two trials varied between 1.64 and 1.56. That is very close to each other's. The findings correlated with in the case of M. vittatus. The findings also related to [42]. and applied to small native fish species [43-60].

Various factors constrain the existence and development of inland fishes and fisheries in the researched area. The need for a concerted effort to prevent and reduce aquatic habitat degradation as well as the protection of the studied fish species and fisheries adaptation to new methods are all obvious. The fish conservation strategy adapted to this study's specific fish species and geographical area characteristics followed an in situ tailored approach, namely an in situ (protecting the existing natural populations) and ex situ (moving the economic pressure of controlled ponds) conservation [61-73].The natural habitat degradation under human activities impact and climate change's effects on Mystus vittatus ecosystems need new conservative management methods, and last but not least, aquaculture techniques for increasing farm production and protecting the species in nature. Polyculture of tengra (Mystus vittatus) in seasonal waters at the semi-arid zone is proved as an economically viable and easy-to-implement approach and technique. Considering the growth and survival, 600 ind. dec-1 was found to be a suitable stocking density for the polyculture system. The combination of 600 tengra, 100 shing, 50 magur, 25 rajpunti, and 10 GIFT indi. dec.-1 and 600 tengra, 100 pabda, 50 magur, 25 rajpunti, and 10 GIFT indi. dec.-1 is suitable for tengra polyculture. The appropriate culture period is from May to September with overwinter fingerlings regarding successful culture. The involved experiments and not only fish farmers were very much interested in tengra polyculture due to new and modern technology. The study results can be used, and also this technique in similar neighboring geographical areas with semi-arid characteristics, to improve fishery and aquaculture social-ecological systems [73].

Ethical Approval

The Ethics Committee/Technical Committee of the Bangladesh Fisheries Research Institute, Mymensingh, Bangladesh, approved the research theme.

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