Punjab University Journal of Zoology

OPEN ACCESS

36(1): 101-110 (2021)
https://dx.doi.org/10.17582/journal.pujz/2021.36.1.101.110

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Research Article

Growth Performance and Culture Economics of Mud Eel Semi-Intensively Cultured Under Varying Stocking Densities in Rain-fed Earthen Ponds

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Article History
Received: June 26, 2020
Revised: April 17, 2021
Accepted: May 18, 2021
Published: June 15, 2021

Authors' Contributions
SKB collected the data and prepared the initial draft. AKP assisted in data collection and analysis. MAH designed the study and supervised. UA and SI prepared the initial draft, revised it, helped in data analysis and preparation of illustrations. MNU assisted in lab work, while AMF helped in data collection and research project. MMR and MSI assisted in data analysis.

Keywords
M. cuchia, Semi-intensive, Culture economics, Specific growth rate, Water quality, Stocking density

Abstract | This investigation provides details on the production and culture economics of cuchia (*Monopterus cuchia*) in semi-intensive aquaculture ponds. The cuchia eel was reared in rainfed earthen fishponds and supplemented with poultry viscera in three different stocking densities of T_1 (9880 cuchia/ha), T_2 (14820 cuchia/ha) and T_3 (19760 cuchia/ha). The results divulged that the physicochemical water quality factors varied significantly in different ponds. Similar was the case with the mean outcomes about the final body weight, net weight gain, specific growth rater (SGR), fish survival rate, and net yield. The final body weight varied significantly from 274.53 ± 1.93 in T_3 to 349.40 ± 1.58 in T_1, while the SGR difference was recorded from 0.45 ± 0.00 in T_3 to 0.58 ± 0.01 in T_1. However, the cuchia survival varied between 76.07 ± 0.75 in T_3 to 85.14 ± 0.51 in T_1 with the means difference of net yield as 5878.40 ± 40.93 from T_1 to significantly higher (8251.90 ± 40.09) in T_3. The economic indicators revealed that the net benefit and enormously varied from 741570.00 ± 510.26 (T_1) to 1231500.00 ± 1559.20 (T_3), while the cost-benefit ratio showed encouraging improvements from 0.17 ± 0.14 in T_3 to 0.39 ± 0.01 in T_1. Overall, lower stocking density yielded the most promising production and economic performance. The outcomes of this study provided valuable insights into the profitable production of eel fish meat.

Novelty Statement | This study highlights that the mud eel can be reared at lower stocking densities in rain-fed earthen ponds. Furnishing cheaper shelter alternatives and enhancing habitat features may not alter the pond water quality instead gives higher yield and economic benefits.

To cite this article: Bashak, S.K., Paul, A.K., Hossain, M.A., Atique, U., Iqbal, S., Uddin, M.N., Farhaduzzaman, A.M., Rahman, M.M. and Islam, M.S., 2021. Growth performance and culture economics of mud eel semi-intensively cultured under varying stocking densities in rain-fed earthen ponds. *Punjab Univ. J. Zool.*, 36(1): 101-110. https://dx.doi.org/10.17582/journal.pujz/2021.36.1.101.110

Introduction

Monopterus cuchia (Hamilton, 1822), locally recognized as cuchia (*synbranchidae*), is a freshwater eel species that is air-breathing in nature and prefers muddy habitat, and it usually dwells in the rice fields or swamp areas (Rosen and Greemwood, 1976; Munshi *et al*., 1989). It commonly occurs in the freshwater passages in Bangladesh, Pakistan, Northern and Northeastern India, Myanmar, and Nepal (Jingran and Talwar, 1991). However, it is

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presently reflected as a highly vulnerable fish species in Bangladesh due to the rapid loss of most preferred habitat areas, habitat alterations, and overexploitation (IUCN, 2000). Generally, it has been reported as a prevalent fish in the mud holes of shallow beels (lake-like wetland) and boros (large-sized), which are prevalently the paddy fields scattered across Bangladesh, predominantly Sylhet, Mymensing, and Tangail regions (Rahman, 1989, 2005; Bhuiyan, 1964). This eel species has recently been reported from Chalan Beel (one of the most extensive wetlands in the lower Atrai basin, Bangladesh), which is the recipient of more than 47 rivers and waterways (Galib *et al*., 2009).

This fish prefers ponds, canals, rivers, beels, and shallow water bodies that are relatively rich in aquatic plants and flooded rice fields (Shafi and Quddus, 1982). In the drought conditions and lack of food, the swamp eel can survive prolonged drought periods by burrowing in moist soils and muddy areas (Campbell and Reece, 2005). *Monopterus cuchia* is recognized as the rapacious eater showing a general predator's characteristics that feed at night and target the small-bodied fishes, amphibians, and crustaceans echinoderms, insect larvae, as well as other aquatic invertebrates (Sultana, 2008). They also target the living biota, including fish fingerlings, insect pupae, earthworms, aquatic insects, tubifex, snails, and the slaughterhouse's waste for feeding purposes. *Monopterus cuchia* manifested a significantly higher growth rate when feasting on the dead, small fish, and the lowest growth displayed with pelleted fish feed (Khan, 2008).

This species is delectable, nutritionally satisfying, medicinally valuable, has enormous export potential, tolerant to environmental changes, and is pollution resistant (Mishra *et al*., 1977). On average, we can obtain a protein content of 14 g per 100 g of eel, while the caloric value could be equal to 303 kcal/100g compared with 110 kcal/100g in the locally popular other fish species (Khan, 2008; Hasan *et al*., 2012). It can put up moderately productive aquaculture when combined with growing crops such as swamp cabbage (Nasar, 1997). Besides, it has tremendous medicinal benefits as certain ethnic tribes use it as a healing agent against few diseases (Jamir and Lal, 2005; Lohani, 2012). The eel aquaculture is relatively an economic culture system compared to the other small-scale fish culture operations and is recognized as a small investment initiative for the local fish farmers. The production does not practically demand abundant waters, and expensively formulated fish feeds. Raising is easy and fetches more profit than other fish culture activities (Lu *et al*., 2005; FAO, 2001).

Additionally, it could be quickly grown in smaller fish tanks or aquaria as well as the intensive culture systems as it can adjust well in captivity. The swamp eel is a high-value export-oriented fish species, although, in Bangladesh, very few communities prefer eating this fish species. However, it is a famous delicacy in several countries with different recipes. Its market has tremendously expanded to countries like Malaysia, Singapore, Taiwan, Japan, Korea, China, Thailand, Hongkong, New Zealand, Australia, Europe, and the USA (Herbst *et al*., 2001; Hasan *et al*., 2012).

Nowadays, the mud eel has emerged as a marketable fish species in Bangladesh (Zaher and Mazid, 1993), having genuine potential for aquaculture and research. Unfortunately, no satisfactory methods have been described yet and executed to develop reliable cultural techniques for cuchia. Although a few studies on the effect of different feed types by Narejo *et al*. (2003), rearing and production performance by using other feeding rations by Miah *et al*. (2015), the role of shelters by Narejo *et al*. (2003), the impact of temperature on growth, survival, and production by Rahman *et al*. (2005), co-management by Chakraborty *et al*. (2010), larval and grow out practices by Khanh and Ngan (2010) were studied. However, most of these investigations were carried out in cemented cisterns, tanks, ditches, rice fields, and very few in ponds using different feeds such as live and dead fish, pelleted feed in Bangladesh and Vietnam. Nevertheless, no adequate methodologies have yet been documented about the advanced culture technique at a commercial scale under different stocking densities.

Our literature study emphasized that investigations on the commercial-scale farming of mud eel under different stocking densities in ponds have immense potential and regional to global scale implications. Hence, the research underlining the impacts of varying stocking densities on the production dynamics and economic evaluations of cuchia farming in small fish ponds is essential. This species' culture can include a series of actors from culture to harvest, transportation, marketing and sales, input trading, etc. This invaluable nutrient-rich resource is rapidly declining; its culture could help make this species accessible globally and locally. Therefore, we studied the impact of varying stocking density on the net fish production as well as the economic viability of cuchia farming in fish ponds. The specific objectives included (a) monitoring of important water quality parameters; (b) evaluation of the fish growth potential and production performance estimated as the specific growth rate (SGR), final weight gain and survival rate as well as the yield; (c) appraisal of the economics of cuchia farming under different stocking densities; and (d) recommendations of suitable stocking densities for the commercial level monoculture of *M. cuchia* in ponds.

Materials and Methods

Study area location and duration

This investigation included nine earthen fishponds located in the Department of Fisheries, University of

Rajshahi, Bangladesh, for six months during July-December 2016.

Experimental design

The average size and depth of the ponds were 0.002 ha and 1.30 m, respectively. All the fishponds were rectangular designed, mainly rain-fed, and well-exposed to the daylight. Three different experimental treatments, namely T_1, T_2 and T_3 were categorized based on mud eel stocking densities; viz. 9880 cuchia/ha or 40/decimal, 14820 cuchia /ha or 60/ decimal and 19760 cuchia/ha or 80/decimal, respectively, were used and each treatment was further subdivided into three replicates. We used the different treatments to assess the impact of various feeding strategies and shelter plans to find the most suitable and plausible method for enhanced eel production.

Pond management and improvement of shelter

Before starting fish stocking in the experimental fish ponds, we carried the manual eradication of undesired aquatic weeds by eliminating undesired fish species and other predatory organisms through repeated screening. Liming in all the experimental fish ponds was performed @ 250 kg $CaC0_3$ per hectare. Three days after liming, we administered the basal fertilization using cow dung (2470 kg/ha) in all the experimental ponds. A refuge house for cuchia was developed by installing plastic-made hollow pipes (at the rate of 988 no/ha) of 90 cm length 5.5 cm diameter in all fishponds. Further, the shelter space was strengthened by providing water hyacinth (50% of pond area) above the water level (1.30 m).

Collection and stocking of cuchia

Cuchia juveniles were collected from the Bisshojit hatchery, Adamdighi, Bogra. The juveniles were transported carefully in a plastic drum with the appropriate environment for transportation, and the fishponds were stocked in the morning. During stocking, the average weight varied from 118.43±1.51 to 120.83±1.68 g.

External feeding and sampling

The cuchia eel was supplied with locally available processed poultry viscera @ 5% of the body weight. The poultry viscera were obtained mainly from the nearby station Bazar slaughterhouse and manually spread from each experimental fishpond's embankments. The feeding ration was adjusted weekly by evaluating the standing crops after each sampling event. During every sampling phase, the fish weight and length were recorded using the standard equipment types to determine the total production and other growth parameters.

Water quality assessments

We recorded some of the vital factors denoting the physicochemical water quality, including water temperature (WT), transparency in terms of Secchi disk depth (SDD), pH, dissolved oxygen (DO), ammonia-nitrogen (NH_4-N) and alkalinity daily. We used a centigrade thermometer measuring within the range of 0°C to 120°C to record the WT, while water transparency was estimated by Secchi disc apparatus and represented as cm. The DO, pH, alkalinity, and NH_4-N were determined using a Hach kit (FF-2, USA), and obtained values were articulated in milligram per liter (mg/L).

Monitoring of fish growth

The mud eel was tested monthly to evaluate its growth performance and the proper allocation of weekly feed rations. We used the following fish growth factors for assessing the eel growth performance in different experimental conditions.

Initial weight (g)= Weight (g) of fish at stock; Final weight (g)= Weight (g) of fish at harvest; Weight gain (g)= Mean final weight (g)- Mean initial weight (g); The SGR was calculated by using the equation by Brown (1957).

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

where bwd = body weight per day and Ln = log natural

$$Survival\ rate\ (\%) = No.\ of\ fish\ harvested / No.\ of\ fish\ stocked \times 100 \ldots(2)$$

$$Yield\ (kg/ha) = Fish\ biomass\ at\ harvest - Fish\ biomass\ at\ stocking \quad \ldots(3)$$

Harvesting and economics of cuchia farming

After six months, the experimental ponds were drained to harvest the grown crop of cuchia with local hunters and collectors' assistance. Furthermore, we conducted a simple cost-benefit analysis to examine the economic performances of the different experimental treatments. The obtained data on the fixed and variable expenses helped to conclude the total costs (BDT/ha; In 2016, 1 US $ = 76.54 BDT). The total income was supposed based on the market price expressed in BDT/ha. The net benefit was estimated by subtracting the total income from the total cost (BDT/ha). The cost-benefit ratio (CBR = net benefit/ total cost) was also determined for the present study.

Statistical analysis

All the datasets were evaluated for normality check before applying the one-way analysis of variance (ANOVA) followed by the Duncan Multiple Range Test (DMRT) to diagnose the significant variances in all the mean values of the experimental treatments. All analyzed values were then presented as Mean ± SE. We utilized the Statistical Package for Social Sciences (SPSS v.16.0) for all types of statistical evaluations.

Results and Discussion

Water quality variations during the culture period

The results indicated that all the physicochemical water quality parameters varied significantly in all treatments monthly, except water temperature (WT) consistency based on statistical significance (Table 1). The mean value of WT ranged from 25.28±0.31°C (T_2) to 25.44±0.20°C (T_3). The mean records of the Secchi disk transparency, DO, pH and alkalinity displayed slight increments during the experiment period. For most of the parameters, there was a steady decline from T_1 to T_3. The monthly variations of selected water quality parameters in each experimental treatment displayed monthly and treatment-wise variations (Figure 1). During October, the water transparency and pH exhibited a simultaneous surge and decline, respectively.

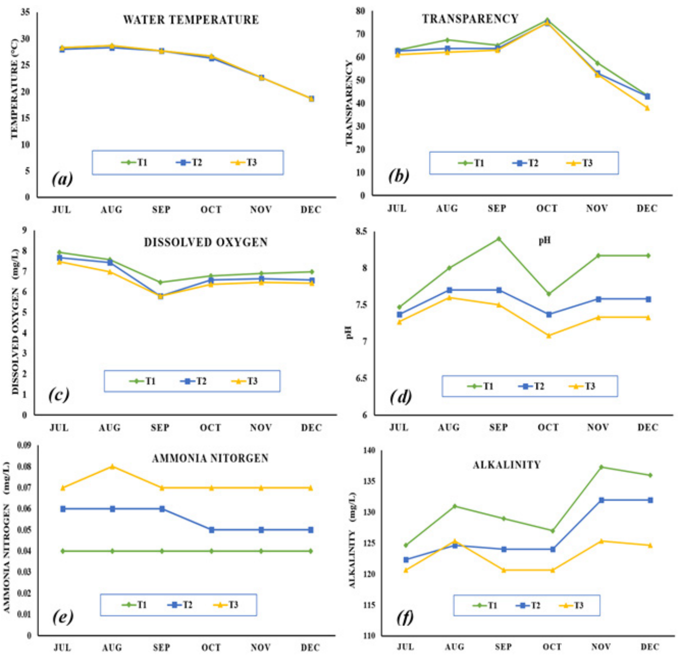

Figure 1: Monthly variations in the physicochemical water quality parameters in the three treatments of experimental ponds of Cuchia culture.

Similarly, during September, DO and pH displayed a diminished and surged, respectively. Water transparency, WT, and DO variations were similar in all three treatments and months, while pH, NH_4-N, and alkalinity differences were heterogenic among treatments and months. The maximum monthly ammonia level was registered from T_3, while maximum alkalinity was displayed in T_1.

Growth dynamics of cuchia

The overall findings on the final weight (274.53±1.93 to 349.40±1.58), weight gain (153.70±0.85 to 228.67±2.02), and SGR (0.45±0.00 to 0.58±0.00) of cuchia recorded in all the treatments indicated significant improvements during the experimental period (Table 2). The minimum values were recorded in T_3, while the maximum in T_1. The mean survival rate ranged from 76.07±0.75 to 85.14±0.51%. The minimum value was documented from T_3, whereas the maximum value was recorded with T_1. In terms of growth, the final weight in T_1 was 1.27 times higher than T_3; weight gain in T_1 was 1.49 times higher than T_3.

On the other hand, the SGR from the T_1 was recorded as 1.28 times higher than in T_3. However, the survival rate from T_1 was 9% higher than in T_3 that indicated feasible environmental conditions and sustainable stocking density in T_1. The mean value of the yield of cuchia ranged between 5878.40±40.93 to 8251.90±40.09 kg/ha/yr, where the minimum value was documented from T_1, while the maximum in T_3. Overall, a significant difference among all the experimental treatments; however, the yield in T_3 was 1.4 times higher than in T_1. The monthly variations in weight gain and SGR in the experimental treatments indicated that the weight gain and SGR gradually declined from July to December (Figure 2). There was an almost constant growth in the weight gain from July to September, which continuously decreased in the subsequent months. However, treatment 2 monthly weight gain pattern exhibited varying pattern. On the other hand, SGR decline was sharp in all three treatments from July to December.

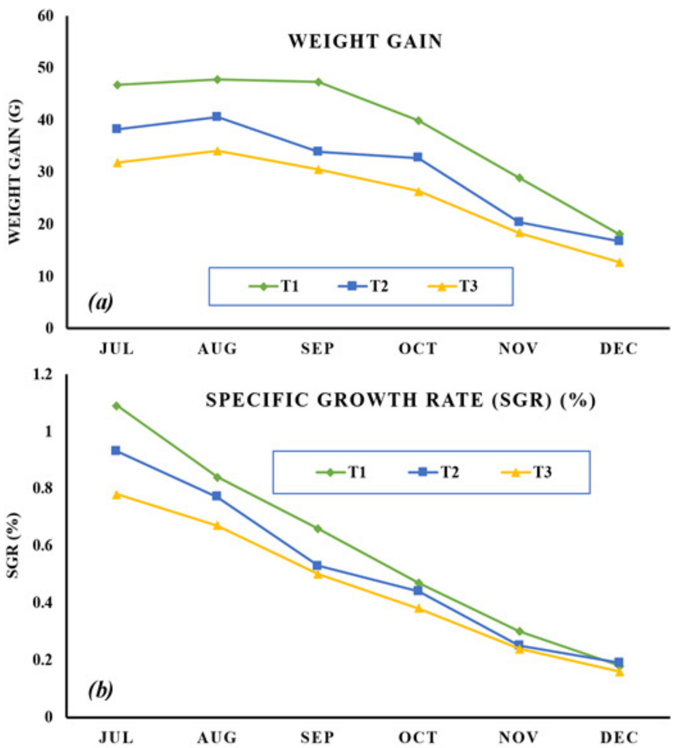

Figure 2: Monthly variations of weight gain and specific growth rate (SGR%) during the culture period.

Cuchia culture economics

Table 3 presents the specifications of expenditure incurred during the experimental culture of Cuchia eel. The land lease, fertilizer cost, liming expenses, plastic pipes for shelter, labor, and other miscellaneous expenditures remained the equivalent for all three experimental treatments. The expenses on juvenile seed and external feed source (processed poultry viscera) gradually increased from the T_1 to T_3 depending upon the stocking densities. The mean outcomes of the total culture cost (741570.00±510.26 to 1231500.00±1559.20 BDT/ha) showed significant differences like the net profit (212540.00±7847.40 to 287140.00±7647.30 BDT/ha), and the CBR (0.17±0.14 to 0.39±0.01) of cuchia culture experiment in all the experimental treatments. The lowest value was recorded from the T_1, while the highest from T_3. There was a significant difference among the three experimental treatments that could be mainly linked to the varying stocking densities. In terms of economic outputs, the total cost incurred on the T_1 was 0.60 times lower than T_3, while net profit in T_1 was 1.35 times higher than T_3, and the CBR in T_1 was 2.29 times higher than T_3.

Water quality variations

In terms of physicochemical water quality, saving WT, all the factors varied significantly in different treatments every month. It symbolized that ponds with the lowest stocking density held higher DO content, ammonia-nitrogen, and mostly alkaline water than the other two treatments. It could be linked to the lower amount of external feed source, lower fecal loads, and lesser competition for feeding. Usui (1974) reported that at approximately 12°C or below, the eels (*A. japonica*, *A. anguilla*, and *A. rostrata)* stop feeding, thereby showing no

Table 1: Variation in the mean values of water quality parameters under different treatments during the study.

Parameters	Treatments			F value
	T_1	T_2	T_3	
Temperature (°C)	25.44±0.06a	25.28±0.31a	25.44±0.20a	0.20
Transparency (cm)	62.00±0.19a	60.11±0.78ab	58.56±1.06b	5.03
DO (mg/l)	7.10±0.10a	6.78±0.04ab	6.58±0.12b	7.67
pH	7.97±0.09a	7.55±0.03b	7.35±0.01c	33.83
NH_3-N (mg/l)	0.04±0.00c	0.06±0.00b	0.07±0.00a	65.23
Alkalinity (mg/l)	130.83±0.33a	126.50±0.38b	122.89±0.87c	46.46

Figures in a row bearing similar letter(s) do not differ significantly (p<0.05).

Table 2: Variation in the mean values of growth performance of cuchia under different treatments during the study.

Parameters	Treatments			F value
	T_1	T_2	T_3	
Initial weight (g)	120.73±1.59a	118.43±1.51a	120.83±1.68a	0.73
Final weight (g)	349.40±1.58a	300.83±1.67b	274.53±1.93c	479.14
Weight gain (g)	228.67±2.02a	182.40±0.83b	153.70±0.85c	782.60
SGR (%)	0.58±0.01a	0.51±0.00b	0.45±.00c	143.37
Survival rate (%)	85.14±0.51a	78.77±0.81b	76.07±0.75c	43.81
Yield (kg/ha/6 months)	2939.20±20.46c	3512.20±51.68b	4125.90±20.05a	302.75
Yield (kg/ha/yr)	5878.40±40.93c	7023.90±103.33b	8251.90±40.09a	302.75

Figures in a row bearing similar letter(s) do not differ significantly (p<0.05).

Table 3: Economics of processed poultry viscera based cuchia culture (6 months).

Parameters	Treatments			F value
Cost	T_1	T_2	T_3	
Lease value (Tk/ha)	75000.0±0.00a	75000.0±0.00a	75000.00±0.00a	0.00
Fertilizer (Tk/ha)	6500.0±0.00a	6500.0±0.00a	6500.00±0.00a	0.00
Lime (Tk/ha)	3750.0±0.00a	3750.0±0.00a	3750.00±0.00a	0.00
Seed (Tk/ha)	375440.0±0.00c	563160.0±0.00b	750880.00±0.00a	0.00
Feed (Tk/ha)	165960.0±510.26c	222500.0±2133.10b	280490.00±1559.20a	1358.00
Plastic pipe (Tk/ha)	88920.0±0.00a	88920.0±0.00a	88920.00±0.00a	0.00
Labor (Tk/ha)	20000.0±00a	20000.0±0.00a	200000±0.00a	0.00
Others (Tk/ha)	6000±0.00a	6000±0.00a	6000±0.00a	0.00
Total cost (Tk/ha)	741570.0±510.26c	985830.00±2113.10b	1231500.0±1559.20a	24860.00
Total income (Tk/ha)	1028700.0±7162.20c	1229200.0±18084.00b	1444100.0±7016.80a	302.745
Net profit (Tk/ha)	287140.0±7647.30a	243360.0±15960.0b	212540.0±7847.40b	11.250
Cost-benefit ratio (CBR)	0.39±0.01a	0.25±0.17b	0.17±0.14c	89.463

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(In 2016, Average: 1 US $ = 76.54 BDT). Digits in a row bearing similar letter(s) do not differ significantly ($p<0.05$).

growth followed by hibernating in burrows and refuges in the mud. Our findings are also supported by Usui (1974), and Nasar (1997), that the most suitable range of WT that supports sustainable fish growth and feeding in *mud eels* lies between 20-35°C. They further claimed that this eel species might not consume the food resources well when the WT shifts away from the range. Brown (1957) and Nikolesky (1963) specified that WT modifies the standard metabolic rates and could considerably impact the fish feeding behavior and concomitant growth in poikilothermous creatures (Iqbal *et al*., 2020a, b; Jewel *et al*., 2020). Furthermore, Rahman *et al*. (2005) documented that the lowest average feeding rate occurs at the 2.9 g/kg/day at the lowest average temperature of 14.4°C and the highest average feeding rate of 12 g/kg/day at the highest average temperature 27°C. In this case, the WT was within the tolerable limit for the desired growth of cuchia.

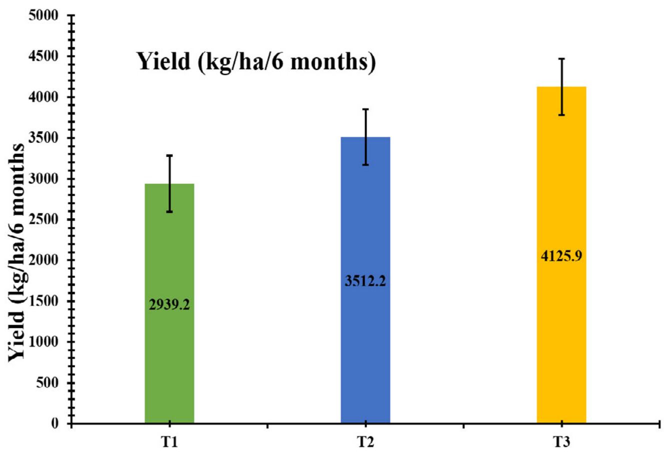

Figure 3: Treatment wise comparison of cuchia production during the study period.

The water transparency (measured in terms of Secchi disk depth) displayed significant variations in all the experimental treatments with the highest values during October and then demonstrated a steep decline. Chakraborty *et al*. (2010) recorded transparency 13.60 to 18.40 cm in earthen ponds. A comparatively higher value of water transparency was found. Boyd (1982) recommended that a transparency level of 30 to 45 cm indicated a water body's functional productivity status. Similarly, Wahab *et al*. (1995) proposed that the transparency values in the productive water bodies should be equal to or less than 40 cm. These resembling variations in pond water transparency might be linked to water depth, the plankton population's availability (Haque *et al*., 2020), and rainfall intensity (Boyd, 1979; Dewan, 1973; Atique *et al*., 2020a; Kim *et al*., 2021a, b). The significant differences in DO level corroborated with Chakraborty *et al*. (2010) conclusions that the DO levels as 3.55-6.10 mg/l. Miah *et al*. (2015) reported the DO range as 4.5 to 5.5 mg/l in the earthen ponds.

Similarly, Narejo *et al*. (2003) recorded DO (during July-December) range between 4.5-5.4 mg/l. Our study's slightly higher DO found could be linked to water hyacinth usage as a shelter and higher water depth of experimental ponds. The DO was within an acceptable range and agreed with Bhuiyan (1970), that the DO level of 5.0 to 7.0 mg/l is well inside a reasonable array for optimal fish production and other physiological functions (Atique *et al*., 2020b; Hara *et al*., 2020). However, Ali *et al*. (1982) presented the optimum DO range between 7.2-10.5 mg/l in the freshwater aquaculture ponds for good growth performance.

The pH value fluctuated between 7.08±0.08 (T_3) in October to 8.40±0.28 (T_1) in September, demonstrating significant experimental treatment variations. Chakraborty *et al*. (2010) reported the pH range between 5.88-7.40 in the earthen fish ponds, while Miah *et al*. (2015) stated the pH level as 7.30 to 7.45. On the other hand, Narejo *et al*. (2003) recorded that the pH (July-December) ranged from 7.37-7.60. Our findings firmly coordinated with Lakshman *et al*. (1971) and Swingle (1967), investigated various water quality parameters in ponds, and recorded the pH spectrum between 6.0 and 9.3, a suitable range for productive fish culture. However, these findings agree with Hossain and Bhuiyan (2007), that the water pH ranges between 6.62 to 7.85 in Bangladesh's earthen fishponds. In the present study, the alkaline pH range in all treatments symbolized moderate pH requirements for sustainable eel production.

The NH_3-N value displayed significant differences among the experimental treatments, showing a firm agreement with Alom and Zarman (2004), as the reported NH_3-N value was 0.08 mg/l. This much lower level of NH_3-N is also very suitable for sustainable fish culture, as held by Boyd (1998), suggested keeping the ammonia-nitrogen values in the fish ponds lower than 0.1 mg/l. Similarly, Milstein *et al*. (2002) registered NH_3-N values within the range of 0.09-0.99 mg/l and 0.60-0.29 mg/l, respectively. Therefore, it could be stated that the levels of NH_3-N recorded in our study stayed inside the allowable limits.

The alkalinity level also varied significantly among the experimental treatments. The literature survey exhibited that Chakraborty *et al*. (2010) recorded the total alkalinity 21.60 to 41.20 mg/l in earthen ponds, while Narejo *et al*. (2003) recorded alkalinity (July-December) range between 50-59 mg/1 at a depth of 15 cm. Our findings strongly agree with Rahman (1989), that the total alkalinity (TA) of the earthen pond water between 71-175 mg/l, and with Hossain and Bhuiyan (2007) with values of 81.25 to 147.5 mg/l. Boyd (1998) identified that a fish pond's natural fertility level grows with the growing TA up to 150 mg/l. Similar were the observations made by Alikunhi (1957) that the TA going above 100 mg/l could be recorded in highly prolific water bodies. For instance, Kohinoor (2000) and Haque *et al*. (2005) established that the average TA higher than 100 mg/l is possible, as corroborated by their findings. Therefore, it can be stated that the present results were in an acceptable range.

Growth performance and survival

The records showed that cuchia eel growth performance was primarily linked with the suitable quality and quantity of external food resources and stocking density in the semi-extensive culture system. The fish growth recorded in terms of final weight, weight gain, and SGR in *M. cuchia* exhibited significantly greater outcomes in T_1, where the used fish stocking density in the experimental fish ponds was lower contrasted to other treatments. However, the dispensed feed resources (poultry viscera) were the same as furnished to all the varying stocking destiny treatments. These findings strongly agree with Chakraborty *et al.* (2010), that comparatively higher growth performance as measured by the final weight, weight gain and SGR of *M. cuchia* at the lower stocking density 5187/ha (T_1) than higher stocking density 12866/ha (T_2) and treatment T_1 showed significantly higher growth and lower yield (cuchia 1440.0±0.0, and native fish 1122.48±9.32 kg/ha/5 months) than treatment T_2. Further, similar outcomes were published by Khanh and Ngan (2010) on the growth outcomes of *Monopterus albus* reared at varying stocking densities (0.5 kg/m^2 (T_1), 1 kg/m^2 (T_2), 2 kg/m^2 (T_3) and 3 kg/m^2 (T_4) in experimental nylon tanks for six months by feeding homemade and live feed with different ratios. They also found comparatively higher growth performance of *M. albus* in T_1, where the fish stocking density was lower than that of experimental treatment of T_2, T_3, and T_4.

The leadings reasons for such a high growth performance at lower stocking densities could include intensive competition for seeking food and shelter that could be tough to gain due to a higher density of cuchia (Islam, 2002; Rahman, 2003; Chakraborty and Mirza, 2008). It was observed during the winter that all the eel fish took refuge by burrowing in mud and PVC pipes for hibernation and overwintering. Nasar (1997) also described parallel observations in other eel species such as *A. japonica, A. anguillia A. rostrata, and A. cuchia* concerning growth performance and hibernation.

We recorded a survival rate of 85% in T_1, which firmly corroborated with the findings presented by Miah *et al.* (2015), that a survival rate of 87.5% in the earthen ponds was found. However, Narejo *et al.* (2003) observed a 70% survival rate in PVC pipe culture, while Khanh and Ngan (2010) reported a survival rate of 73.1 to 73.5% in higher stocking densities. On the other hand, our findings showed an improvement compared to Teng and Chuna (1979) study, who reported a survival rate of 93.8 to 99.1% with artificial hides. However, one reason could be ascribed to the escape of cuchia from the installed refuge holes during the rainy season. However, the lower survival rate in T_2 and T_3 could be due to the higher stocking densities producing higher competition grounds for food resources and shelter space in the treatment ponds plus possible escape during the rainy season. The other factors could be identified as the maturity size of cuchia, heavy bottom mud, and hibernation at the time of harvesting. Tripathi *et al.* (1979) and Chakraborty *et al.* (2003) have also reported comparable outcomes in some carp and barb species.

One of the unique factors that could have promoted higher growth performance in our study could be the fusion of natural (Mud and water hyacinth) and artificial shelter (plastic pipes) provision for cuchia. The production (2939.20±20.46 to 4125.90±20.05 kg/ha/6 months) performance of cuchia eel during our study proved better than reported by Chakraborty *et al.* (2010), who obtained 1440.0±0.0 to 2681.5±24.55 kg/ha/5 months. Narejo *et al.* (2002) obtained 116.83 kg/acre/6 months in snake eel, while, Narejo *et al.* (2003) illustrated 0.24±0.18 to 0.62±0.06 kg/m^2/year, Narejo *et al.* (2003) obtained 0.09 ± 0.089 to 0.95 ± 0.05 kg/m^2/year, respectively.

Culture economics

The total cost of the mud eel culture system remained significantly lower in T_1 (i.e. lower stocking density) than that of T_2 (moderate stocking density) and T_3 (the highest stocking density). We stocked a lower number of juvenile fish seed and fed the lower amount of external feed that possibly minimized the total cost than the other two treatments. The net profit was also significantly higher in T_1 than that of other treatments. This could be linked to a higher mean final weight, weight gain, and lower total cost. In terms of economics, the present findings strongly agreed with Chakraborty *et al.* (2010) and Khanh and Ngan (2010). Overall, based on current results, we obtained a higher growth performance, survival, the economics of cuchia, and more suitable water quality at a density of 9980/ha, which subjected to lower stocking density than that of moderate and highest stocking density. This is becoming significantly important under the rapidly changing socioeconomic status of the fishermen communities under varying seasonal fish biodiversity (Momi *et al*., 2021)

Conclusions and Recommendations

In conclusion, among the different treatments, treatment T_1 with lower stocking density (9880/ha) performed the best in terms of water quality, growth performance, and economics. The potential habitat management could have sustained this with water hyacinth and plastic pipes for hibernation and shelter. However, detailed studies are required to establish these links. Hence, the stocking density research in ponds culturing the *M. cuchia* under a semi-intensive culture system has shown massive potential for conservation of the species, effective utilization of rain-fed water bodies, conversion of invaluable poultry waste into a high-quality protein for enhancement of fish production, food, and nutrition security and socio-economic development. This study contributes valuable and novel information on the semi-intensive culturing practice of *M. cuchia* that could establish a new candidate fish species and a valuable source of good quality eel meat in the local to international markets.

Acknowledgements

The authors are grateful to the Ministry of Science and Technology, Government of the People's Republic of Bangladesh, for providing financial support through NST (National Science and Technology) fellowship for this study (Grant No. 39.00.0000.012.002.004.16-12 dated 16.01.2017 and No. 39.00.0000.012.002.004.16-163 (753) dated 19.03.2017).

Conflict of interest

The authors have declared no conflict of interest.

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