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Research article

Assessing stocks of *Mystus tengara* (Hamilton, 1822) from three different management systems in *Baors* (Oxbow lake) of southwest Bangladesh: Implications for sustainable management

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A R T I C L E I N F O

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A B S T R A C T

This study was conducted to observe the stock assessments of *Tengara (Mystus tengara)* in three different management systems of *Baors* (Oxbow lake) such as System-1, System-2, and System-3. In this study, 1806 specimens were sampled using traditional fishing nets to observe growth pattern, population structure, growth parameters, natural mortality (*M*), fishing mortality (*F*), total mortality (*Z*), recruitment pattern, exploitation rate (*E*), relative yield per-recruit (*Y'/R*), optimum catchable length, length at first capture, steady state biomass (*SSB*), and maximum sustainable yield (*MSY*) from January to December 2021. Digital slide calipers and a digital balance were used to measure each individual's total length (*TL*) and body weight (*BW*), respectively. An empirical maximum length-based model was used to calculate size at first sexual maturity (L_m), and optimum catchable length (L_{opt}) was calculated based on asymptotic length (L_∞). The least square linear regression equation was used to determine the regression parameters. The value of regression parameter, '*b*' was 3.01 for system-1, 2.78 for system-2, and 2.70 for system-3, indicating that growth pattern of *Tengara* is isometric in system-1, but negative allometric growth in system-2 and system-3. The highest asymptotic length (L_∞) and weight (W_∞) of *Tengara* were found in system-1 (11.19 cm and 13.67 g) in comparison with system-2, (10.98 cm and 12.49 g) and system-3 (9.09 cm and 6.96 g) respectively. The growth coefficient (*K*) of the von Bertalanffy growth function (VBGF) was 0.72 year^{-1}, 0.72 year^{-1}, and 0.73 year^{-1} for system-1, system-2 and system-3, respectively. The calculated *M, F, Z* were 1.72, 1.28, and 3.00 year^{-1} for system-1, 1.11, 0.67 and 1.78 year^{-1} for system-2 and 1.12, 0.84 and 1.96 year^{-1} for system-3 respectively. The calculated life span (t_{max}) was found 4.19 years for system-1, 4.15 years for system-2 and 4.12 years for system-3. The recruitment patterns showed that the highest relative percentage of recruits were found in July, June and September for system-1, system-2 and system-3 respectively, with the major recruitment peak occurring from April to June for system-1, May to June for system-2 and June to July for system-3. One minor recruitment peak also occurred from August to September in system-1. The exploitation rate was more or less same in all three systems indicating that *Tengara* is under exploited from all the *Baors*. The significantly highest *SSB* and *MSY* were found in system-1 (22.65 and 12.11 metric tons), compared to system-

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2 (16.16 and 10.28 metric tons) and system-3 (5.55 and 5.49 metric tons), respectively. Considering the values of regression parameters, recruitment pattern, *SSB* and *MSY*, system-1 was found more suitable for *Tengara* compared to system-2 and system-3 management practices of *Baors*. Finally, these findings will turn out to be paradigm for the impregnable management of *Tengara* in *Baors* of southwest Bangladesh.

1. Introduction

In Bangladesh, Oxbow lake is commonly known as *Baor* which is a dead river arm in the Moribund Delta. It appears as a depression with a saucer shape. There are over 600 *Baors* in southwest Bangladesh, covering an area of 5488 ha, and majority of them concentrated in the multiple greater districts such as Jashore, Kustia and Faridpur, with their highest concentrations in greater Jashore district [1]. *Baor* has a diverse range of fisheries resources, and a large number of local community members depend solely on the *Baor* fisheries for their livelihood. Small indigenous fish species (SIFS) and some major cultivable fishes are mostly available in the *Baors* of Bangladesh. Nonetheless, due to overfishing, using harmful fishing techniques, the loss and destruction of fish habitats, the siltation of water bodies by natural processes, and industrial and agrochemical water pollution, the majority of *Baor* fisheries have now lost their fashionable characteristics [2].

In Bangladesh, *Baors* are mainly managed by the following three systems: system-1 [3], system-2 [4], and system-3 [5]. There are some key differences among the three management systems which are given in Table 1. In system-1, fingerlings are stocked by Department of Fisheries (DoF), while in system-2 and system-3; fingerlings are stocked by fishermen groups who are mainly involved in the management system. Sanctuary establishment and no use of feeds, fertilizers, and chemicals are major features of the system-1. Besides, local communities catch small indigenous fish throughout the year from *Baors*, whereas nets with minimum 2.0 cm mesh size are allowed for harvesting in the system-1, but in system-2 and system-3, there are no restrictions.

The order Siluriformes, is an important component of the ichthyofauna in all types of aquatic ecosystems [6]. There are 35 families of Siluriformes that are found all over the world. Catfishes are a diverse group of freshwater fishes that comprise the order Siluriformes. The catfish are remarkably popular fish in our country because of their flesh feature, high nutritional value with high protein and mineral content [7,8] and it is critical to the local food supply. *Mystus tengara* is one of the most popular catfish and locally known as '*Tengara*,' and it is mostly available in Bangladesh, Nepal, Pakistan, India and Afghanistan. This fish is naturally found in lakes, rivers, canals, haors, *Baors*, ponds, paddy fields and streams. During the rainy season, this species is commonly found in weedy, sandy, and muddy areas of pools, streams, and rivers [9]. It is omnivorous and feeds upon plankton, algae, protozoa, shrimp, insects, worms, and other tiny fishes. This species is declining, according to a study conducted in southwestern Bengal [10]. As a result, managing guidelines are desperately required for ensuring their permanence and production. Information regarding population structures, growth patterns, maturity, and mortality of this fish are critical to understanding for sustainable management because they provide a complete picture of the fish.

Fishery management aims to balance fishermen's economic and social needs with ensuring that long-term fish stock captures are ecologically sustainable [11,12]. Fisheries conservation strategies enhance management practices that protect aquatic ecosystems, prevent species extinction, and boost the number of threatened fish stocks [13]. Stock assessments are fundamental management techniques that help in understanding fish populations, recruitment pattern, mortality rate, maximum sustainable yield, and also exploitation ratio [14]. Because of their meaningful and significant characteristics, they can provide a key concept about the condition of the fish stock [15].

Table 1
Major characteristics of three different systems practiced for *Baor* management in southwest Bangladesh.

Characteristics	System-1 (S-1)	System-2 (S-2)	System-3 (S-3)
	1. *Baor* directly supervised by Department of Fisheries (DoF).	1. *Baor* partially supervised by Department of Fisheries (DoF).	1. *Baor* supervised by local administration.
	2. *Baor* operated by *Baor* communities and Department of Fisheries (DoF).	2. *Baor* operated by *Baor* communities and Department of Fisheries (DoF).	2. *Baor* operated by a group of influenced person through leasing system.
	3. Production costs borne by DoF.	3. Production cost borne by *Baor* communities.	3. Production costs borne by lessee people.
	4. Feed, fertilizers and chemicals not used.	4. Feed, fertilizers and chemicals partially used.	4. Feed, fertilizers and chemicals highly used.
	5. Fish sanctuary established.	5. Sanctuary rarely established.	5. Sanctuary not established.
	6. DoF highly benefitted.	6. DoF moderately benefitted.	6. DoF not benefitted, lessee people highly benefitted.
	7. *Baor* communities moderately benefitted.	7. *Baor* communities highly benefitted.	7. *Baor* communities not benefitted.
	8. Biodiversity not affected.	8. Biodiversity partially affected.	8. Biodiversity highly affected.
	9. Fishing gear restricted for small indigenous fish species (SIFS).	9. Fishing gear partially restricted for SIFS.	9. Fishing gear not restricted for SIFS.
	10. Traditional culture practice used.	10. Improved traditional culture practice used.	10. Semi-intensive culture practice used.
References	[3]	[4]	[5]

A fish species' biometric indices from a particular body of water provide information about the health of fish, the ecology, and whether or not the water body is suitable for their survival [16–18]. The characteristics include growth pattern, the volume of offspring, size and gender balance of offspring, seasonal fluctuation in breeding, age and dimension of mature fish groups, growth pattern, and natural mortality, all of which are interrelated [19]. Calculating length-weight relationships (LWRs) and fish growth characteristics are the most important part of the biometric evaluation. LWRs are extremely important in fisheries for predicting length distributions into masses for biomass estimation [20]. The distribution of species inside a fish population may be impacted by fish size classes [21]. Understanding growth characteristics like the von Bertalanffy growth coefficient (K), size at reproductive age (L_m), age at zero length (t_0), asymptotic length (L_∞), maximum reported age (t_{max}), and natural mortality (M) is necessary for creating ecosystem models [22]. Furthermore, the size at first sexual maturity (L_m) are important management parameters for establishing whether there are enough mature juveniles in a gathered population to reproduce [23]. A specific stock's optimum catchable length (L_{opt}) is characterized as the in-between length class, when each individual's regular weight attained its highest level [24]. Length at first capture (L_c) is the length at which 50% fish are caught, indicating whether the stock is over or under fishing pressure [25].

Earlier researchers had investigated different aspects such as reproductive biology [26,27], fecundity estimation [8], food and feeding habit [28], feeding ecology [29,30], and growth and prey preference [30] of *Tengara* in India and Bangladesh. Prior to our present study, few researchers had studied the length-weight relationships and condition factors of *Tengara*. The relations between length, weight and relative condition factor of *Tengara* were investigated in the Lechia Pavomari beel (wetland) of Dhemaji district, Assam, India [31]. Length-weight relationships of *Tengara* were reported from Baruipur, South 24 Paraganas, West Bengal, India [32]. Recently seasonal length-weight relationships and condition factors were also investigated in two districts, Paschim Medinipur and Jhargram of West Bengal, India [33]. However, no thorough investigation into different *Baor* management systems' effects on growth pattern, growth parameters, mortality, recruitment pattern, steady state biomass, maximum sustainable yield and overall stock assessment of *Tengara* has not yet been studied. Therefore, our present study is the first report to look in depth stock assessments of *Tengara* from *Baors* under three different management systems practiced by different authorities in the greater Jashore district of southwest Bangladesh.

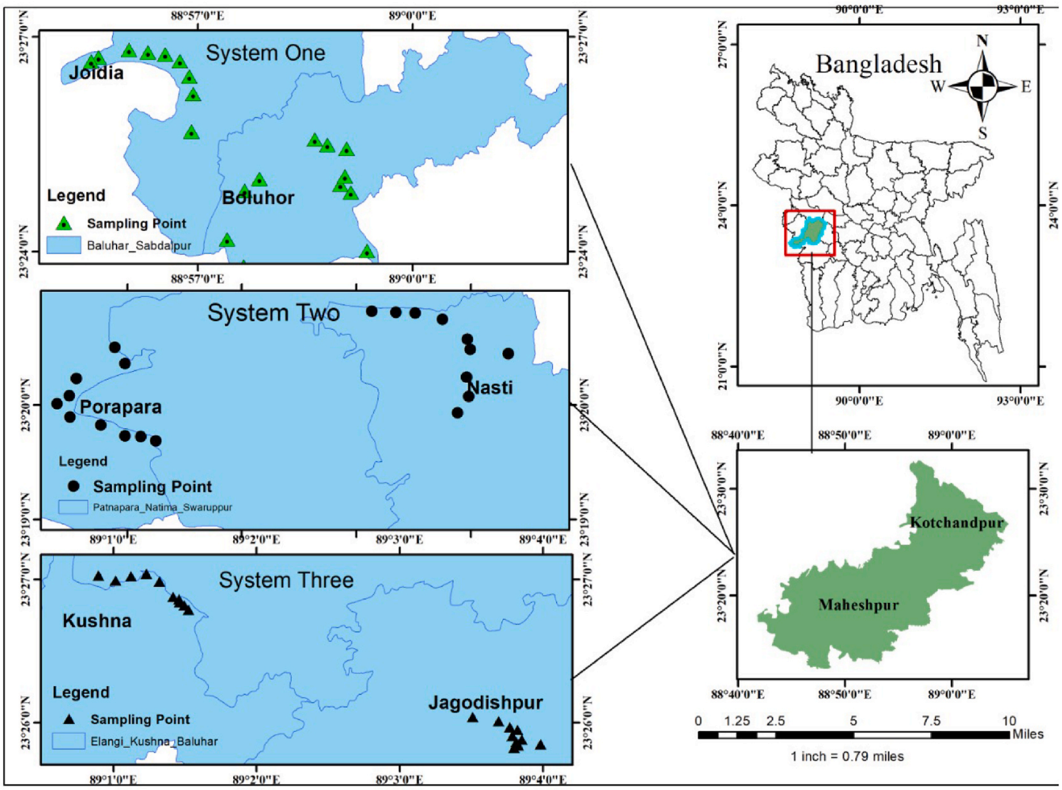

Fig. 1. Map showing the study sites (*Baors*) located southwestern Bangladesh, from where *Mystus tengara* were collected (S-1=System-1, S-2=System-2, S-3=System-3).

2. Materials and methods

2.1. Sampling location

The authors sampled 1806 *Tengara* specimens from six *Baors* under three different management systems through the fishers' catch from January to December 2021. System-1 [3] includes Boluhor and Joidia *Baors*, System-2 [4] includes Nasti and Porapara *Baors*, and System-3 [5] includes Kushna and Jagodishpur *Baors* (Fig. 1). Fish were sampled monthly from fishers' catch using only three traditional fishing nets: push net, cast net and gill net. Push net and cast net having the mesh sizes of 1.0–2.0 cm and gill nets having mesh sizes of 1.5–2.5 cm were used to catch the experimental fish. These three fishing nets were used monthly at the same location within a 0.5 km area of each *Baor* to ensure that the catch included all the number of specimens from the same study sites. The collected specimens were chilled and preserved with 10% alcohol solution and stored in the Fisheries Laboratory of Jashore University of Science and Technology (JUST), Bangladesh.

2.2. Fish measurement

In the JUST laboratory, the total length (TL, cm) and total body weight (BW, g) were computed with an accuracy of 0.01 cm and 0.01 g, correspondingly, using modern slide calipers and weight scale. Furthermore, TL was taken into account for the stock assessment study by FAO-ICLARM approved tools (FiSAT-II).

2.3. Growth pattern

Following the formula $BW = a^*(TL)^b$ allowed for the identification of growth outlines. With the help of length and weight of fish body, the least square linear regression equation, $\ln (BW) = \ln (a) + b^*\ln (TL)$, is used to estimate natural logarithms as well as determine the value of the constant, *a*, and slope, *b*. The regression analysis did not include extreme outliers [34]. In order to observe the growth types, isometric and allometric, significant deviations from the b values are observed by a *t*-test [35].

2.4. Growth parameters

FAO-ICLARM Stock Assessment Tools (FiSAT-II) is a program package designed primarily for the study of monthly length-frequency data, but it also supports related studies such as size-at-age, catch-at-age, selection, and other analyses. Length-frequency distributions (LFDs) were constructed using 1.0 cm class intervals of total length (TL). The Powell-Wetherall process [36,37], which was further improved [38], to analyze the LFD. The initial L_∞ and Z/K were accounted by s/b and $-(1+b)/b$, respectively using $\bar{L}\text{-}L' = a+bL'$ equation, where, L' is the cut off length; $\bar{L}$ is the mean length of all fish ($\geq L'$) [36–38].

The empirical formula, $\log (L_m) = -0.1189 + 0.9157 * \log (L_{max})$, where L_{max} is the observed maximal TL [39], was used to calculate the L_m for *Tengara*. L_{opt} was calculated as $\log L_{opt} = 1.0421*\log (L_\infty)\text{-}0.2742$ [40]. The age at first maturity (t_m) was calculated using the age at length equation: $t_m = \text{-}(1/K)*\ln (1\text{-}L_m/L_\infty) + t_o$, where L_m is the length at first sexual maturity [41].

The ELEFAN 1 (electronic frequency analysis) procedure was applied to analyze the growth parameters [42]. Capture probabilities were used to adjust the impacts of gear selectivity. The von Bertalanffy Growth Function (VBGF) was obtained based on the growth coefficient (K) and asymptotic length (L_∞).

The preliminary estimates resulted in the catch curve from length. The gear means selection curve was computed using the left portion (ascending) of the length-converted catch curve. Using this assortment curve, the length-frequency records for small fish gear selections were adjusted [43,44]. Using the FiSAT-II software, K and L_∞ values were obtained by the modified LFD analysis [45].

$\text{Log } t_{max} = 0.5496 + 0.957*\log (t_m)$ [40] was used to compute the maximum life span (t_{max}), where t_m is age at sexual maturity (year). The average age for zero length (t_0) was calculated by the equation, $\text{Log } (\text{-}t_0) = -0.3922 - 0.2752 \text{ Log } L_\infty - 1.038 \text{ Log } K$ [43]. Growth performance indicator was created using the formula, $\varnothing = \log K + 2 \log L_\infty$ [46].

2.5. Probabilities of capture

The catch-curve technique for quantifying the likelihood of capture was developed by projecting the number (n) that would have been projected if there had been no selectivity [47].

2.6. Recruitment pattern

The backward projection of the regularity into the time alignment of a collection of samples across time, with a trajectory given by the VBGF, using the growth factors L_∞, K, C, and WP as inputs, produced charts showing periodic arrays of recruitment. Exercises were conducted using reenacted samples [48].

2.7. Stock assessment

To determine the immediate overall mortality, the length-converted catch curve procedure [45] was applied (Z). Following the Pauly equation, $\log M = -0.0066 - 0.279 \log L_\infty + 0.6543 \log K + 0.4634 \log T$ [43], M was calculated, where T represents the middling heat of the ecosystem. Instantaneous fishing mortality (F) was estimated as $F = Z - M$ [49]. The E was calculated by means of formula $E = F/Z = F/(F + M)$ [50]. The E_{max} (exploitation rate generating highest yield), $E_{0.1}$ (exploitation rate upon which the secondary rise of Y'/R is 10 percent of its virgin biomass) and $E_{0.5}$ (the exploitation rate at which half its virgin biomass of stock is reduced) were determined [23].

2.8. Maximum sustainable yield (MSY)

The yield per recruit (Y'/R) was assessed using FiSAT-II software through modified model [51]. The procedure produce a Y'/R vs. $E=(F/Z)$ and a relative biomass per recruit (B'/R) vs. E.

The steady state biomass (SSB) was determined through virtual population analysis (VPA) as metric ton using the length-weight relationship criterion. The MSY of *Tengara* was estimated using Gulland's equation [52], which was later amended as $MSY = 0.5 \times SSB \times Z$ [53].

2.9. Statistical analyses

Data processing and statistical analyses were performed with Microsoft® Excel-add-in-DDXL software and *t*-test [35]. The least squares regression method was used to estimate natural logarithms as well as to determine the regression parameters.

3. Results

3.1. Length frequency distribution (LFD)

The samples of *Tengara* were collected from fishers' catch at distinctive parts of the three different management systems. The sample sizes (n) of three different systems, system-1, system-2 and system-3 were 571, 635, and 600, respectively (Table 2). The restructured length frequency distribution (LFD) showed that the biggest and the smallest individuals of *Tengara* were 10.50 and 5.00 cm for system-1, 10.30 and 4.00 cm for system-2 and 8.50 and 4.50 cm for system-3, correspondingly (Fig. 2).

Fig. 3 and Table 3 showed the length and weight relationships among *Tengara* fish. The length and weight data, as well as the relationship between length and weight, were used to calculate the parameters a and b of *Tengara* fish. For *Tengara* fish, the TL vs. BW relationship suggested negative allometric growth for system-2 and system-3 but isometric growth for system-1. We converted length to weight after measuring *Tengara*'s SSB.

3.2. Growth parameters

The Powell-Wetherall method was used to generate the seed values L_∞ and Z/K of *Tengara* fish, which were 9.04 cm and 0.290 for system-1, 9.09 cm and 0.799 for system-2, and 7.64 cm and 0.364 for system-3 using month to month frequency data (Fig. 4). The K-scan strategy characterized an L_∞ of 11.19 cm TL and K value of 0.62 year^{-1} for system-1, L_∞ of 10.98 cm TL and K value of 0.87 year^{-1} for system-2 and L_∞ of 9.09 cm TL and K value of 1.10 year^{-1} for system-3 of *Tengara* fish to the initial information set (Fig. 5 and Table 4). The growth coefficients (K) of the VBGF were 0.72 year^{-1} for system-1, 0.72 year^{-1} for system-2 and 0.73 year^{-1} for system-3 of *Tengara* fish. The growth performance indices ($\varnothing$) were calculated by the von Bertalanffy growth parameters, L_∞ and K, as $\varnothing = 1.95$ for system-1, $\varnothing = 1.94$ for system-2 and $\varnothing = 1.78$ for system-3 of *Tengara* species. Fig. 2 illustrated the histograms of length–frequency as well as the VBGC (von Bertalanffy Growth Curve). The length–frequency histograms were superimposed on these growth curves. The starting extreme length value was utilized in the ELEFAN-I program (Fig. 6), which is part of the FiSAT-II package, to generate the best growth curve. The Life span (t_{max}) and age at zero length (t_0) were found 4.19 and 0.037 year for system-1, 4.15 and 0.038 year for system-2 and 4.12 and 0.039 year for system-3 of *Tengara* fish (Table 4).

Table 2
Monthly sample size (n) of *Mystus tengara* from three different management systems practiced for *Baors* in southwest Bangladesh.

Months	System-1 (n)	System-2(n)	System-3(n)
January	50	50	50
February	50	50	50
March	47	**60**	57
April	53	60	50
May	51	45	50
June	50	50	43
July	50	50	50
August	50	50	52
September	50	50	48
October	49	54	50
November	32	56	51
December	39	60	49
Total	**571**	**635**	**600**

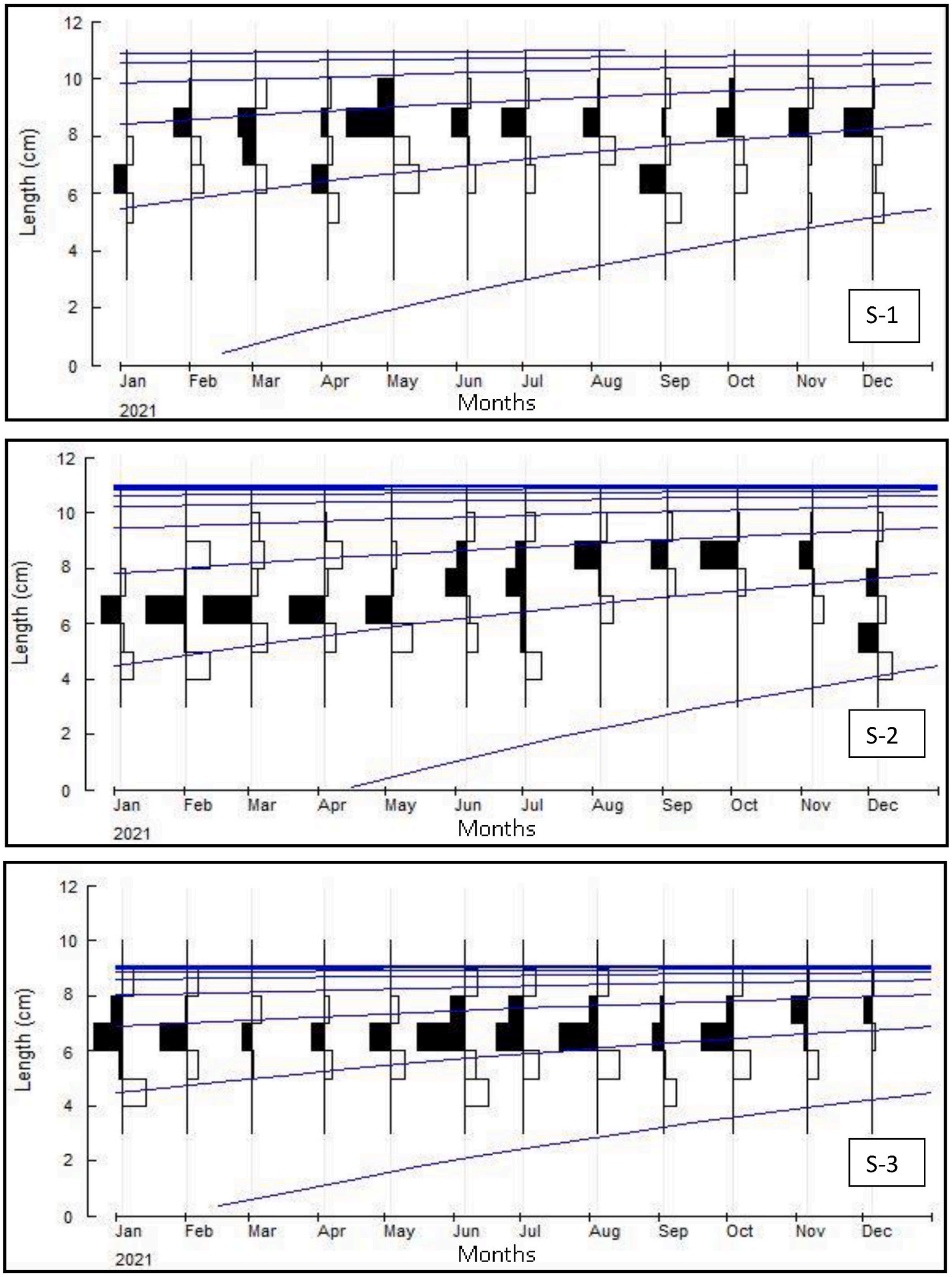

Fig. 2. von Bertalanffy growth curve of *Mystus tengara* as superimposed on the restructured total length-frequency histogram from three different systems (S-1=System-1, S-2=System-2, S-3=System-3) practiced for *Baor* management in southwest Bangladesh.

3.3. Fishing gear selection

The various patterns were discovered in the probability of capture for different length classes using a logistic regression analysis based on the length-converted catch curve. The probability of capture is specifically connected with system-2 and system-3 within the 6.5–7.5 cm group. However, as group lengths increase from 7.5 to 8.5 cm, the risk of capture is connected to system-1. This shows a

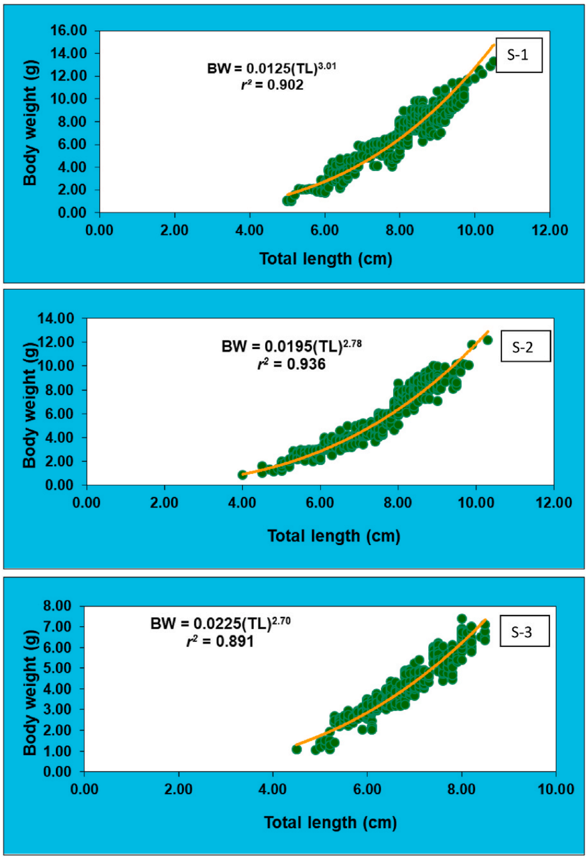

Fig. 3. Length-weight relationships of *Mystus tengara* from three different systems practiced for *Baor* management in southwest Bangladesh.

Table 3
Total length, body weight, regression parameters (*a* and *b*), confidence limits (CL) of mean values, coefficient of determination (r^2), and growth types of *Mystus tengara* from three different management systems practiced for *Baors* in southwest Bangladesh.

Growth parameter	TL (cm)	BW (g)	*a*	95% CL of a	*b*	95% CL of *b*	r^2	Growth type
System-1	5.0–10.5	1.02–13.28	0.0125	0.011–0.015	3.01	2.93–3.09	0.902	I
System-2	4.0–10.3	0.87–12.17	0.0195	0.017–0.022	2.78	2.73–2.84	0.936	-A
System-3	4.5–8.5	1.05–7.38	0.0225	0.019–0.026	2.70	2.63–2.78	0.891	-A

(I, Isometric Growth and -A, Negative Allometric Growth).

shift in capture dynamics between these two length groups, with distinct systems influencing capture probability at various size ranges (Fig. 7).

3.4. Recruitment pattern

The recruitment patterns of *Tengara* were shown in Fig. 8. The histogram showed the relative percentage of recruits per month. The highest monthly relative percentage of recruits were found in July for system-1, June for system-2 and September for system-3, with the major recruitment peak occurring from April to June for system-1, from May to June for system-2 and from June to July for system-3. In case of system-1, a minor recruitment peak was also found from August to September for *Tengara*.

3.5. Assessments of stock

Fig. 9 showed the slope *Z* value of catch curve from length for *Tengara*. The average temperature at three systems was calculated around 28 °C. The assessed catch curve from length was put to get the instantaneous rate of *M*, *F* and *Z* values and were estimated as 1.72, 1.28, and 3.00 year^{-1} for system-1, 1.11, 0.67 and 1.78 year^{-1} for system-2 and 1.12, 0.84 and 1.96 year^{-1} for system-3 of *Tengara* fish. The rate of exploitation was calculated as $E = 0.43$ for system-1, 0.38 for system-2 and 0.43 for system-3 of *Tengara* fish based on instant fishing and overall mortality (Table 4). It indicated that all the three systems were under exploitation for *Tengara* fish.

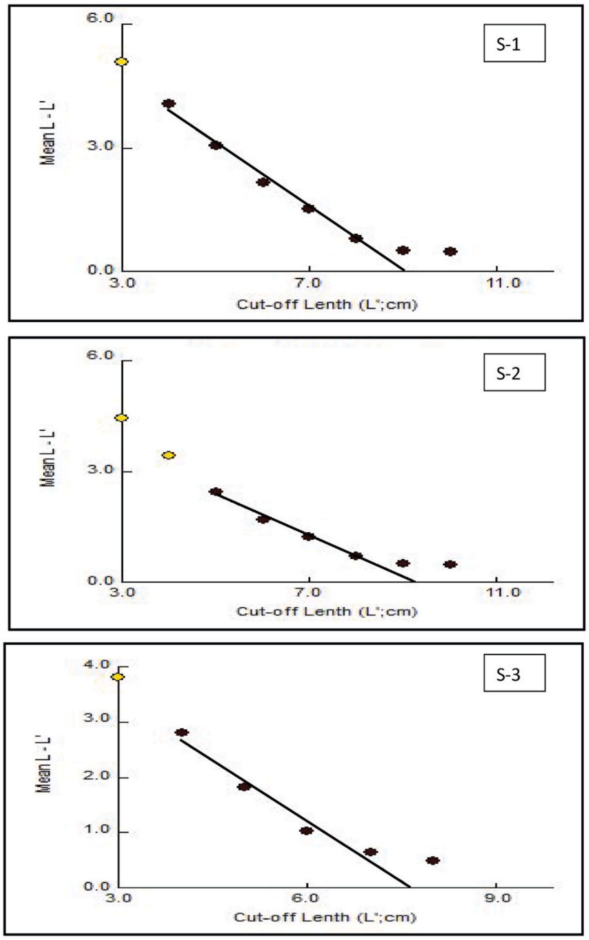

Fig. 4. Powel-Wetherall plot for the length frequency data of *Mystus tengara* from three different systems (S-1=System-1, S-2=System-2, S-3=System-3) practiced for *Baor* management in southwest Bangladesh suggests that values of (L_{mean} - L_{prime}) plotted against a series of cut-off points, L_{prime} as a straight line. Solid black symbols are exploited samples.

3.6. Estimation of maximum sustainable yield (MSY)

The maximum Y'/R value was attained at $E_{\max} = 0.421$ for all systems, when the biomass-per-recruit (B'/R) and relative yield-per-recruit (Y'/R) plotted against the exploitation rate (E) of *Tengara* for all systems (Fig. 10). The values obtained for $E_{0.1}$ and $E_{0.5}$ were 0.36 and 0.278 for all systems. The preference of the knife edge assumes that individuals smaller than L_c will avoid the net. The L_c/L_∞ measurement was performed as 0.050 for all systems, which is a requirement for constructing a yield isopleth figure. The yield isopleth diagram revealed that fishing at $E = 0.40$ and $L_c/L_\infty = 0.050$ is possible (Fig. 11). According to the relative yield per recruit, the maximum yield is found at E of 0.43. Furthermore, the intended E is around 0.40, indicating that the *Tengara* is under exploited from all the *Baors*. The estimated total *SSB* through using FiSAT-II procedure of length-structured virtual population analysis (VPA) were 22.65 metric tons for system-1, 16.16 metric tons for system-2 and 5.55 metric tons for system-3 of *Tengara* fish (Fig. 12). The *MSY* were 12.11 metric tons for system-1, 10.28 metric tons for system-2 and 5.49 metric tons for system-3 of *Tengara* fish if the suggested length ($L_c = 7.5$) at the first capture is followed.

4. Discussion

A dynamic cycle of management designed to protect fisheries resources includes stock assessments as a key component. The main foundation of effective policy formulation for fisheries resources is based on the findings of stock assessments and provides potential future directions for its fishery [54]. Many stock assessment models need a lot of data [55], which eventually limit their application to only desirable species and stocks [56]. Other species are, however, less taken into consideration [57].

Numerous specimens of varying lengths were captured for our study by conventional fishing nets from the six *Baors* during the whole year. The TL of Tengara usually ranges from 5.10 to 10.50 cm for system-1, 4.00–10.30 cm for system-2, and 4.50–8.50 cm for system-3 (Fig. 2). During the study period, the slightly bigger fishes were caught in system-1, whereas the smaller fishes were caught in

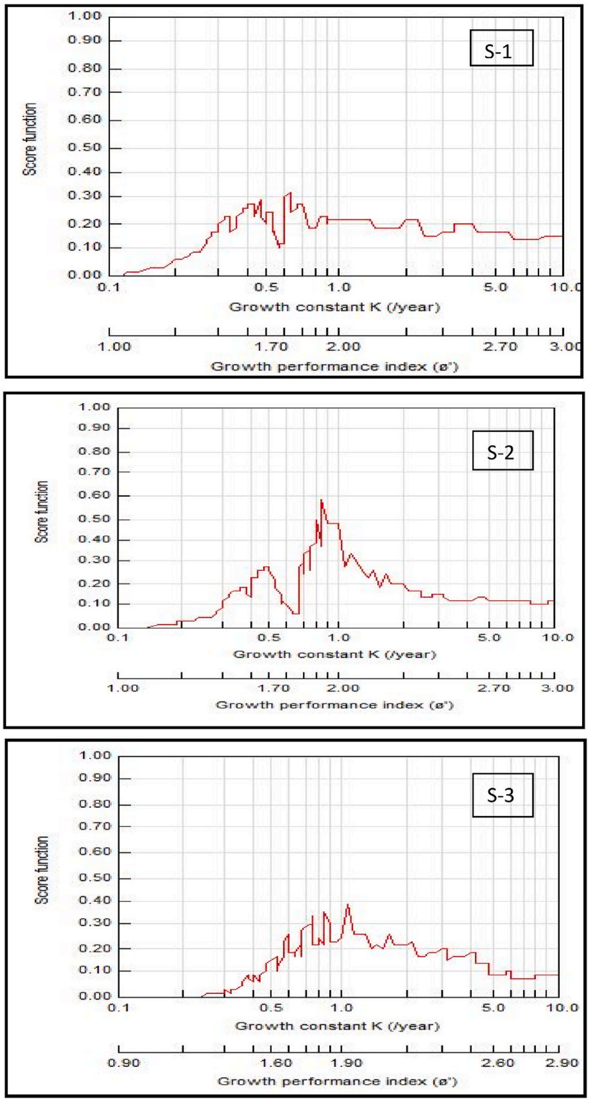

Fig. 5. K-scan routine for determining best growth curvature giving best value of asymptotic length with growth performance indices of *Mystus tengara* from three different systems (S-1=System-1, S-2=System-2, S-3=System-3) practiced for *Baor* management in southwest Bangladesh.

system-3 on the basis of TL. Though the same types of nets with similar mesh sizes were used for fishing in all three systems, it was not possible to catch fishes smaller than 5.10 cm in system-1 whereas smaller fishes (4.0–4.5 cm) were found in system-2 and system-3. It is indicating that growth performance of *Tengara* was slightly higher in system-1 compared to system-2 and system-3 in respect of TL. These TL differences may be influenced by water temperatures and other environmental factors that influence fish growth [58]. In system-1, fertilizer and chemicals are not used, as well as biodiversity may not be affected, as a result, natural environment and food supply may be favourable for growth of *Tengara*. Moreover, fishing gear for catching small indigenous fish species (SIFS) are very much restricted in system-1 that will be helpful for *Tengara* growth. On the other hand, fishing gears are not restricted and biodiversity are affected by using fertilizer and chemicals, which may hinders the growth of *Tengara* in system-2 and system-3. The maximum recorded length was 18.00 cm for *Tengara* in India [59], but there is no record of this length in Bangladesh. In another study, the maximum length was found 11.3 cm for male and 11.7 cm for female *Tengara* in Indian Subcontinent [32] which is more or less close to our findings.

Population parameters reveal the growth patterns, which are extremely important in fisheries research [60]. Fish growth forms differ greatly between species. When the regression parameter "*b*" value is 3, fish grow isometrically; however, when the value of *b* is significantly different from 3.0, allometric growth is either positive or negative [61]. Throughout this study, the value of 'b' was 3.01 for system-1, 2.78 for system-2, and 2.70 for system-3, shows isometric growth pattern for system-1, indicating the fish gets heavier as it grows larger, but negative allometric growth for system-2 and system-3 of *Tengara* in *Baors* of southwest Bangladesh.

In the present study, there was no change of body shape of fish that is isometric growth in system-1, whereas in system-2 and

Table 4
Growth and reproduction parameters (L_∞, t_{max}, $\emptyset$, t_0, L_m, t_m, and K), mortality (*Z, M,* and *F*) and Fishery parameters (*E*, *SSB*, and MSY) of *Mystus tengara* from the three different management systems practiced for *Baors* in southwest Bangladesh.

Growth parameter	System-1	System-2	System-3
Asymptotic length (L_∞) (cm)	11.19	10.98	9.09
Asymptotic weight (W_∞) (g)	13.67	12.49	6.96
Optimum catchable length (L_{opt}) (cm)	6.59	6.46	5.31
Size at first sexual maturity (L_m) (cm)	7.74	7.60	6.28
Age at first sexual maturity (t_m) (year)	1.19	1.18	1.17
Longevity (t_{max}) (year)	4.19	4.15	4.12
Growth coefficient (k) ($year^{-1}$)	0.72	0.72	0.73
Age at zero length (t_0) (year)	0.037	0.038	0.039
Fishing mortality (F) ($year^{-1}$)	1.28	0.67	0.84
Natural mortality (M) ($year^{-1}$)	1.72	1.11	1.12
Total mortality (Z) ($year^{-1}$)	3.00	1.78	1.96
Exploitation (E)	0.43	0.38	0.43
Growth performance indexes (Ø)	1.95	1.94	1.78
Steady state biomass (*SSB*) (mt)	22.65	16.16	5.55
Maximum sustainable yield (*MSY*) (mt)	12.11	10.28	5.49

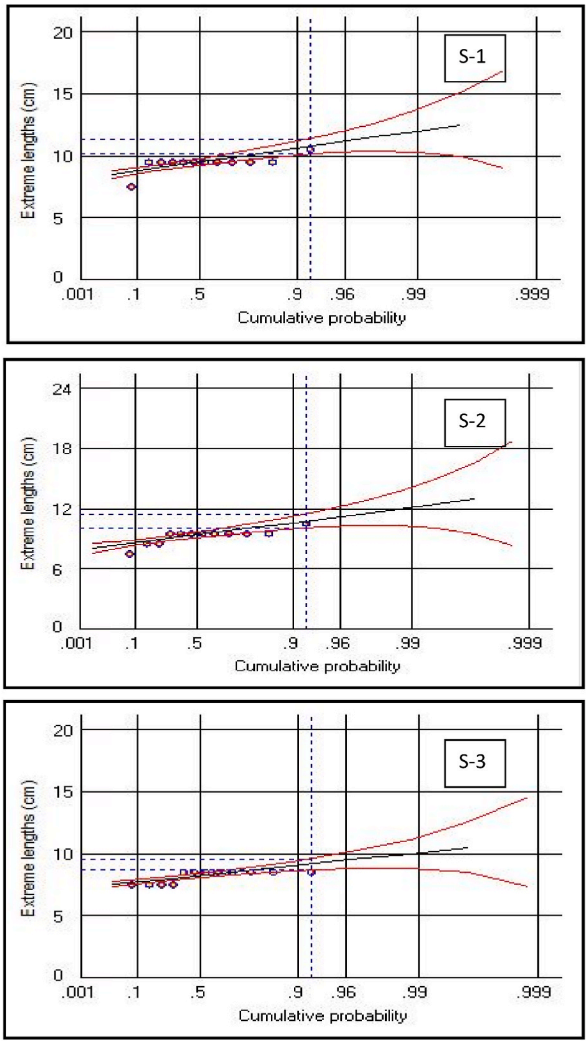

Fig. 6. Predicted maximum length of *Mystus tengara* based on extreme value theory with a 95% confidence interval, obtained from the intersection of overall maximum length.

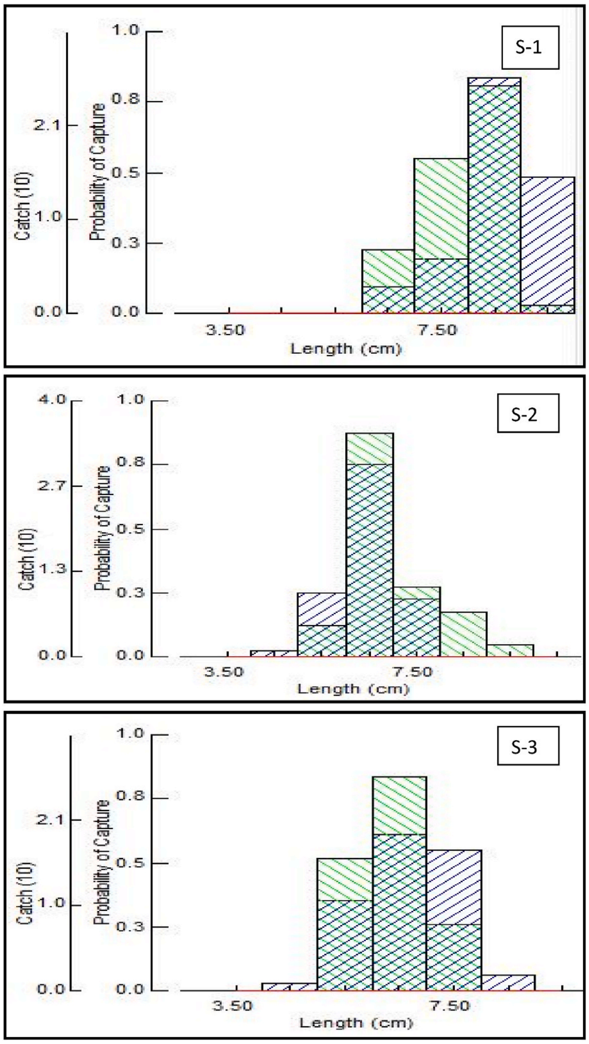

Fig. 7. Gill net selection of *Mystus tengara* from three different systems (S-1=System-1, S-2=System-2, S-3=System-3) practiced for *Baor* management in southwest Bangladesh.

system-3, the fishes were found more or less slender in body shape due to negative allometric growth. As the pesticides and chemicals are not used in *Baors* of system-1, there was no change of biodiversity and natural environment of fish habitat that may not cause any harm to change in growth pattern, population structure and suitability of natural food availability [62]. In the present study, minimum b values were found in *Baors* of system-2 and system-3. If the fish are not feeding well enough or if their environment, such as their physicochemical characteristics and their breeding season, is not conducive to their growth, b values become minimum and negative allometric growth is observed [63,64]. The b value for similar species varies due to changes in observed fish length, environmental stresses (such as water quality parameters), and biological characteristics (such as microbiological and parasitic infections on the host) [65]. Another study in West Bengal, India [32] shows that the *b* values were 2.94 for male, 3.12 for female and 3.07 for combined sex of *Tengara,* which are more or less closer with our findings.

In the current study, regression analyses show that values of coefficient of determination are found $r^2 = 0.902$ in system-1, $r^2 = 0.936$ in system-2 and $r^2 = 0.891$ in system-3 of *Baor* managements (Fig. 3 and Table 3). The present study reveals that growth performance in *Tengara* is quite high since the values of 'r^2'show that length and weight are positively and strongly correlated in three different management systems of *Baors*, but with negative allometric growth in system-2 and system-3 which may be due to lower natural feed availability and/or the environmental condition including physicochemical parameters. Since in system-2 and system-3, supplementary feed, fertilizer and chemicals are frequently used that may result in hindering the growth and production of natural feeds like plankton, algae, protozoa, insects, worms, etc. which are the major feed for *Tengara*. In all three management systems (system-1, 2 and 3) of *Baors*, physicochemical parameters such as temperature, DO and pH are almost same throughout the year, as a result, these parameters may not be responsible for negative allometric growth of Tengara in system-2 and system-3. In System-1, supplementary feed, fertilizer and chemicals are not used and natural environment remains unchanged for Tengara that may result

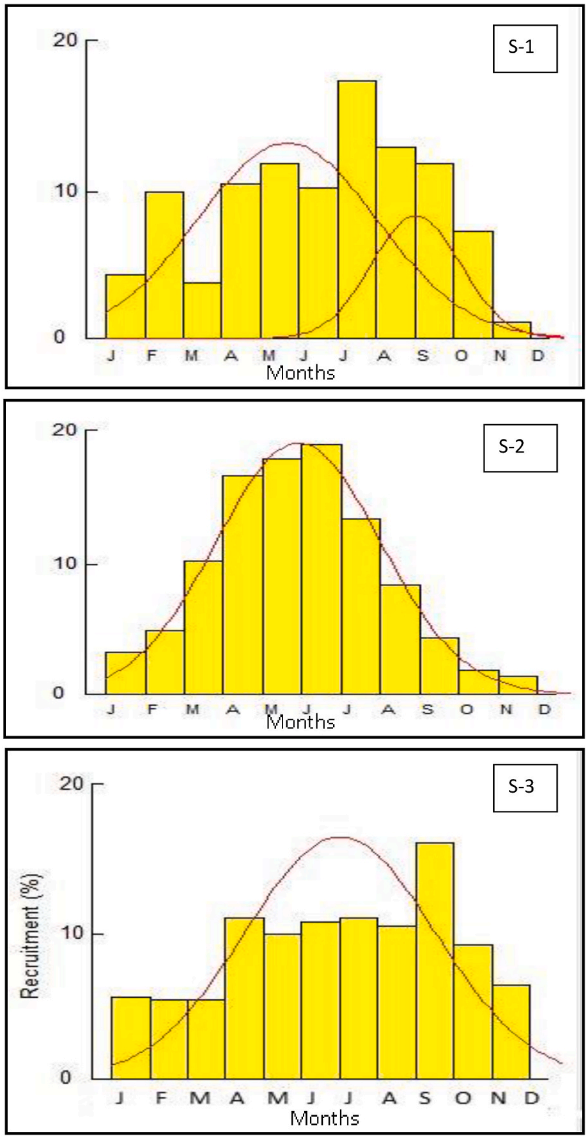

Fig. 8. Recruitment pattern of *Mystus tengara* from three different systems (S-1=System-1, S-2=System-2, S-3=System-3) practiced for *Baor* management in southwest Bangladesh. The histogram shows relative percentage of recruits per month whereas bell shaped curves show the recruitment peak.

in isometric growth.

The von Bertalanffy model is a good description of fish growth patterns and is most frequently used in fishery biology [66]. In the present study, value of asymptotic length ($L_{\infty,}$ cm) is higher in system-1 (11.19 cm) compared to system-2 (10.98 cm) and system-3 (9.09 cm). But longevity (t_{max}, year) and growth coefficient (K, year^{-1}) were more and less same in all three different management systems of *Baors*. Another study in northern Bangladesh shows that the calculated values of L_∞ (cm), K (year^{-1}), and t_{max} (year) of *Tengara* were 16.0, 0.9 and 3.3 in Ashura and Dikshi Beel, and 16.0, 1.0 and 3.0 in Medi Beel, respectively [67] and the values of L_∞ (cm) and K (year-1) were higher, but the value of t_{max} (year) was smaller than that in our present study.

Natural mortality is the removal of fish from the stock due to causes not associated with fishing. Natural mortality is an essential consideration in fisheries management and stock assessment because it reflects the overall dynamics of the fish population, including those factors not directly influenced by human fishing activities. Disease, competition, cannibalism, old age, predation, pollution, or any other natural event that cause fish death is an example of such causes. Furthermore, several of these variables are stock/location dependent such as growth variations, environmental conditions, and the prevalence of carnivores that can significantly influence the anticipated mortality rates within the stock [68]. In this study, natural mortality (M) is more or less same in all three management systems (1.12–1.72 year^{-1}), but fishing mortality (F) is significantly greater in system-1 (1.28 year^{-1}) compared to system-2 (0.67 year^{-1}) and system-3 (0.84 year^{-1}). Due to higher fishing mortality, total mortality (Z) is also much higher in system-1 (3.00 year^{-1})

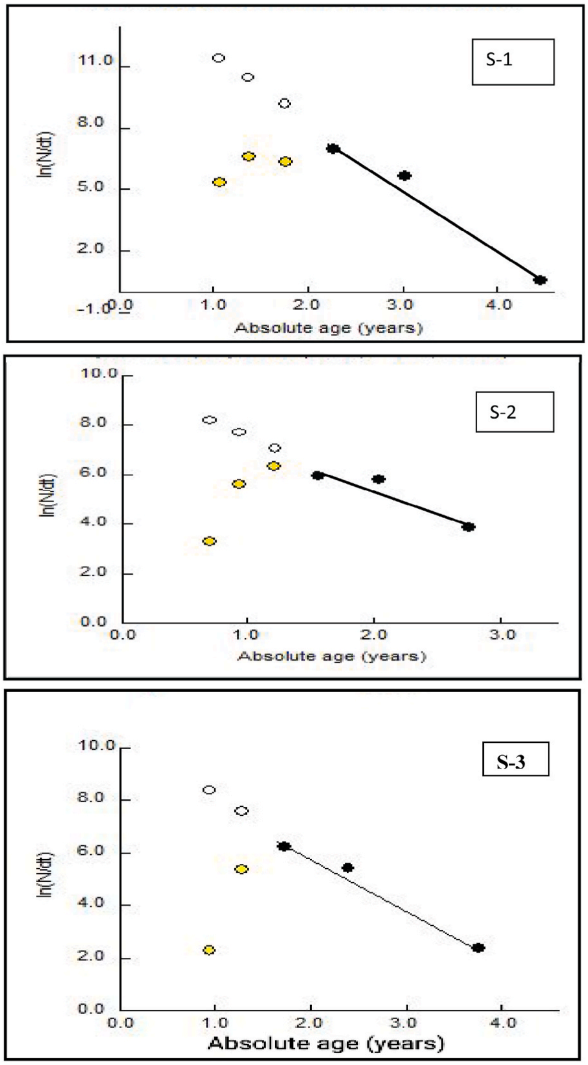

Fig. 9. Length-converted catch curve of *Mystus tengara* from three different systems (S-1=System-1, S-2=System-2, S-3=System-3) practiced for *Baor* management in southwest Bangladesh. Data included in the regression are shown as black solid points.

than in system-2 (1.78 year^{-1}) and system-3 (1.96 year^{-1}). In system-1, fishing gears are highly restricted to catch an optimum catchable size of fish. As a result, smaller sizes of fish get chance to be recruited easily to that particular size. Due to availability of enough smaller fish, recruitment and then catching happen repeatedly that result in the increase of fishing mortality (*F*) as well as maximum sustainable yield (MSY) in this system. As the fishing gears are not well restricted in system-2 and system-3, different sizes of fish are caught by different fishing gears which result in the unavailability of recruitable fish which is the ultimate reason of lower fishing mortality as well as lower MSY in these systems. Previous study in different Beels of northern Bangladesh shows that the values of *M*, *F*, and *Z* of *Tengara* were 1.98, 4.31 and 6.29 in Ashura Beel and 1.98, 4.45 and 6.43 in Dikshi Beel which are much higher than in our present study, but 1.76, 1.21 and 2.97 in Mara Beel and 2.12, 1.14 and 3.26 in Medi Beel, respectively [67] which are more or less similar with our present results. The natural mortality rate in fish varies with maturity and predator frequency [43].

In the present study, the values of exploitation rate (*E*) of *Tengara* were almost same ($E = 0.43$, 0.38, and 0.43) in all three management systems of *Baors* indicating that *Tengara* is under exploited from all these *Baors*. In northern Bangladesh [67], the status of this fish is under exploitation in Mara Beel ($E = 0.41$) and Medi Beel ($E = 0.35$) which is similar to our findings in *Baor* systems. But in Ashura Beel ($E = 0.69$) and Dikshi Beel (E = 0.69), *Tengara* is found to be over exploited which is just opposite to our results.

From this study, optimum catchable length (L_{opt}) is found almost same in system-1 (6.59 cm) and system-2 (6.46 cm), but slightly lower in system-3 (5.31 cm). Similarly, fish sizes at first sexual maturity (L_m) are observed higher in system-1 (7.74 cm) and system-2 (7.60 cm) but comparatively lower in system-3 (6.28 cm). In previous works of *Tengara* [31–33], methods of data analysis are more or less different so it is really difficult to relate these findings with previous data. Fish ages at first sexual maturity (t_m) and zero length (t_0) are found almost same in all three management systems, (1.17–1.19 year) and (0.037–0.039 year) respectively. Growth performance indexes ($\varnothing$) are observed higher in system-1 (1.95) and system-2 (1.94), but somewhat lower in system-3 (1.78). However, till now, no

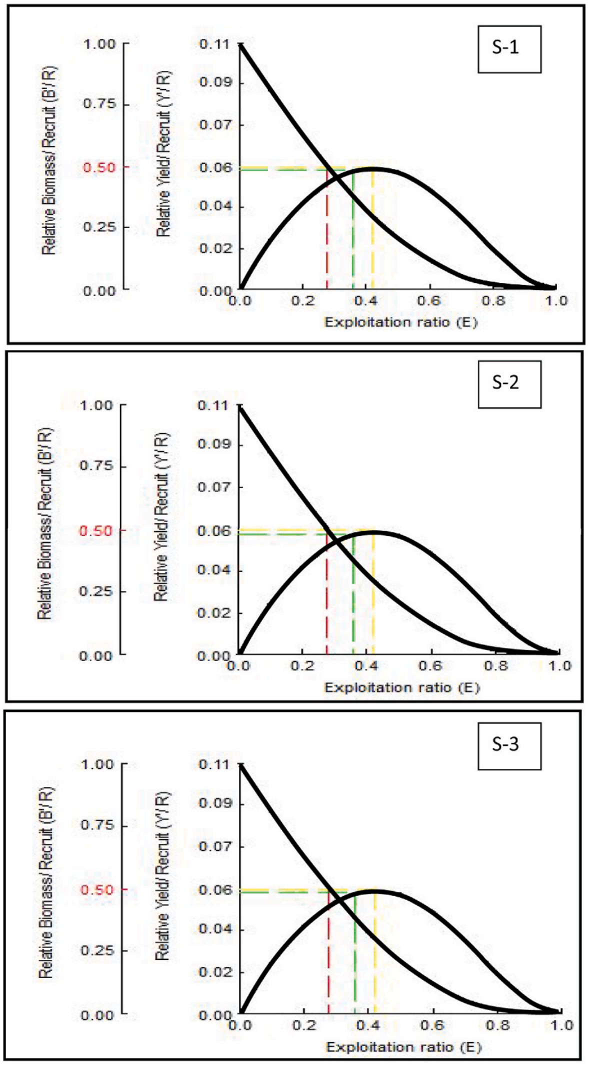

Fig. 10. Yield-per-recruit and average biomass per recruit models, showing levels of yield index of *Mystus tengara* from three different systems (S-1=System-1, S-2=System-2, S-3=System-3) practiced for *Baor* management in southwest Bangladesh.

information has been available about the above indices of *Tengara* in different management based systems of *Baor.* Therefore, it is quite impossible to comprehensively contrast the present findings with the previous results.

There was no previous study on the steady state biomass (*SSB*) and maximum sustainable yield (*MSY*) of this species, so it is not possible to compare the present results with other findings in *Tengara*. In this study, *SSB* and *MSY* of system-1 (22.65 mt and 12.11 mt) were much greater in comparison with that in system-2 (16.16 mt and 10.28 mt) and system-3 (5.55 mt and 5.49 mt), the higher values of *SSB* and *MSY* in system-1 may be due to the presence of sanctuary, restriction on mesh sizes of fishing nets, no use of fertilizer and chemicals as well as other management practices. The presence of fish sanctuary in water bodies has great role on fish production and socio-economic competence, so the annual fish production became almost doubled as a result of establishing sanctuaries in Halti Beel during the year, 2012–2013 [69].

This present effort will facilitate in the development of management policies as well as the introduction of adequate fishing regulations for enhanced fish conservation for this species in *Baors* of Bangladesh. Though this study only considers biological characteristics, it is endorsed that the environmental and socioeconomic characteristics may be studied in future as well. Generally, the months of May, June and July are the major spawning season for the most fish species due to heavy rains in Bangladesh. The month of April is the early-spawning season, and August–September is the late-spawning season. In *Baor* management system-2 and system-3, the recruitment peaks of *Tengara* occurred only in the major spawning season, whereas in system-1, the recruitment peaks occurred in both early- and late-spawning seasons in addition to major spawning season, indicating that enough mature fish are available for longer period in this system. In the present study of *Tengara,* the '*b*' value is found 3.01 in system-1 which shows isometric growth which may be due to effect of ovary weight and state of maturity [70], and developmental stages of gonads [64]. As a result, minor peak during August–September is justified in system-1 due to availability of mature fish with developed gonads. Moreover, if mature

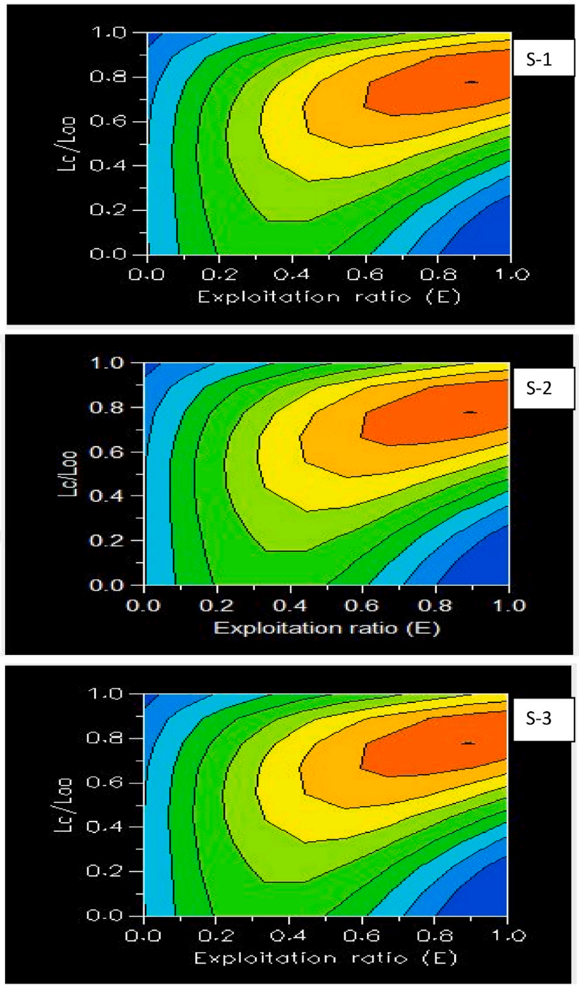

Fig. 11. Yield Isopleths, showing optimum fishing activity both in terms of fishing effort and size of first capture of *Mystus tengara* from three different systems (S-1=System-1, S-2=System-2, S-3=System-3) practiced for *Baor* management in southwest Bangladesh.

fish are available, it may occur sometimes due to heavy rain in August–September. However, it is our inability to discuss properly the current results due to limitation of enough recruitment-related literatures in this species. However, it is recommended that the management guidance of system-1 may be followed in *Baors* and other nearby habitats for *Tengara* in Bangladesh.

5. Conclusion

The present study can be concluded that the growth pattern of *Tengara* is isometric in the *Baors* of management system-1. In this system, natural aquatic environment is maintained by establishing the sanctuary, inhibiting the use of artificial feed, fertilizers, and chemical, and restricting the mesh sizes of fishing gears in the water bodies. As a result, fish can get chances to grow properly, be healthy and reproductively mature that result in two peaks of recruitment, one in May–June and another in August–September. Contrarily, application of supplementary feed, fertilizer and chemicals, the unavailability of sanctuary, and no restriction of fishing gears that may result in declining the growth and production of natural feed which may be responsible for negative allometric growth of *Tengara* in the *Baor*s of management system-2 and system-3 affecting the health condition, steady-state biomass and maximum sustainable yield. The findings of this study will be a great source of information for sustainable management of *Baors* accepting fishing regulation, restricting the mesh sizes of nets, and numbers of fishing gears and crafts. However, further investigation is needed to study the natural food availability and aquatic environmental parameters that may have influence on the overall condition of growth and maturity of *Tengara* fish in the present *Baor* management systems.

Ethical statement

Following the guidelines of ethical review committee of the Faculty of Biological Science and Technology, Jashore University of

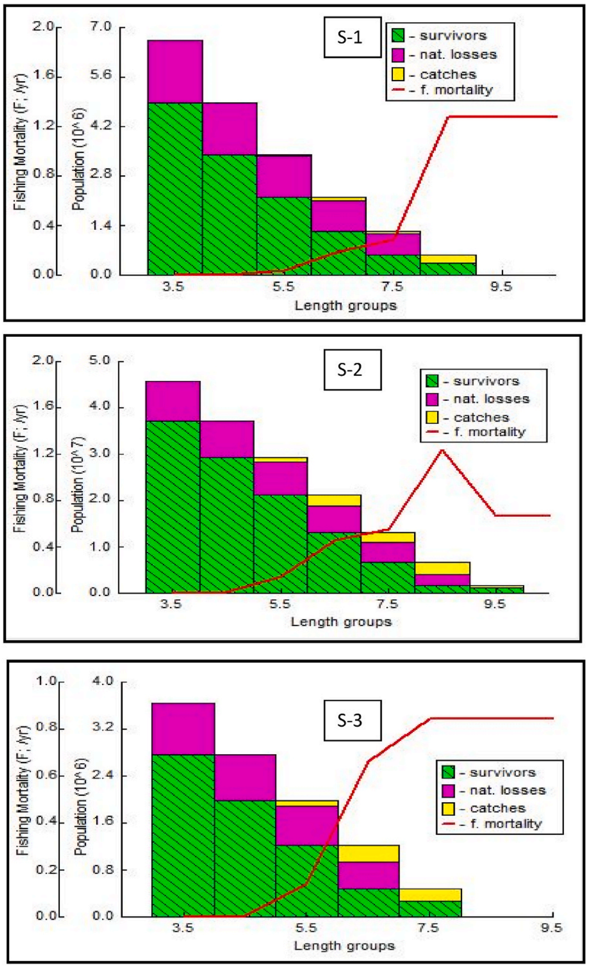

Fig. 12. Length-structured virtual population analysis of *Mystus tengara* from three different systems (S-1=System-1, S-2=System-2, S-3=System-3) practiced for *Baor* management in southwest Bangladesh.

Science and Technology, Bangladesh, this research work was conducted.

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Additional information

No additional information is available for this study.

Data availability statement

Research data of this study will be made available on request.

CRediT authorship contribution statement

Md Monzurul Islam: Writing – review & editing, Writing – original draft, Visualization, Software, Resources, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Md Habibur Rahman:** Writing – review & editing, Formal analysis, Data curation. **Mst Afia Sultana:** Writing – review & editing, Writing – original draft, Software, Methodology, Formal analysis, Data curation. **Md Ataur Rahman:** Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Md Yeamin Hossain:** Writing – review & editing, Supervision, Methodology, Investigation. **Moumita Choudhury:** Writing – review & editing, Supervision. **Md Anisur Rahman:** Writing – review & editing, Visualization, Validation, Supervision, Software, Methodology, Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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