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Stock Assessment of Six Sciaenidae Species in the Bay of Bengal, Bangladesh Water Using a Length-Based Bayesian Biomass (LBB) Method

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Abstract: Six most abundant and commercially valuable croakers (Scianidae) stocks in the coastal water of Bangladesh were evaluated using a length-based Bayesian Biomass (LBB) approach. The ratios B/B_0 (current relative biomass) were smaller than the B_{MSY}/B_0 in five of the six stocks. For the six estimated populations, two (*Otolithes ruber* and *Pterotolithus maculatus*) are grossly overfished, one (*Otolithoides pama*) is overfished, two (*Johnius belangerii* and *Panna heterolepis*) are slightly overfished, and only donkey croaker (*Pennahia anea*) is in the healthy (B/B_0 > B_{MSY}/B_0) status. Furthermore, the optimal length at first capture (*Lc_opt*) was higher than the length at first capture (*Lc*) in four populations, indicating growth overfishing, suggesting that increasing mesh size would benefit the catch and biomass. Findings from the present study confirm the declining trend of fisheries resources, particularly the croaker species in the BoB, Bangladesh coastal water. Management strategies (such as effort control, choosing the appropriate mesh size, total allowable catch limit, identify and enhance protection of the feeding, breeding, and nursery ground, etc.) should be taken for the sustainable management and recovery of the country's marine fishing resources, particularly the valuable croaker species.

Keywords: fish stock assessment; data limited assessment; LBB; Sciaenidae; Bay of Bengal

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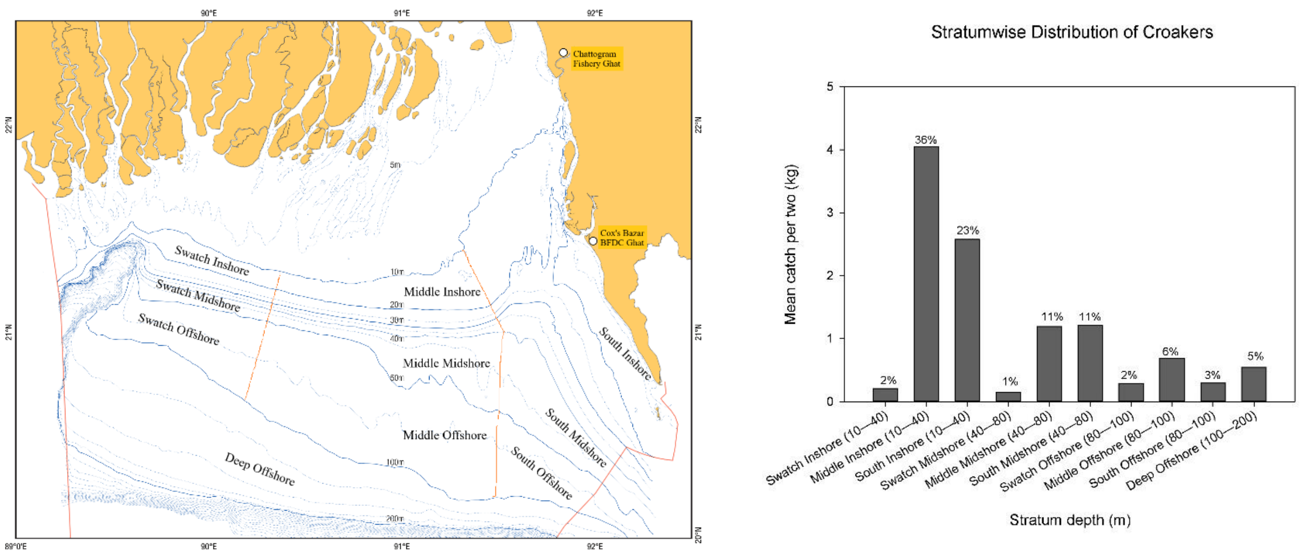
1. Introduction

Effective fish stock assessments can provide the condition of fish stocks and the effect on these stocks of the actions being contemplated [1], which will facilitate the sustainable use of the fisheries resources [2,3]. However, for the data poor fisheries, fish stock assessment is a challenging task, and only about 12% of the world's fisheries are correctly managed as a consequence of stock assessments [3–5]. Due to a lack of data for estimating abundance and fishing mortality of the stocks, the majority of commercially harvested fish and shellfish stocks in the world do not have a proper stock assessment [6,7]. Fisheries with only catch and/or length frequency (LFQ) data, referred to as data limited fisheries, require a unique set of models [8]. Croakers (Sciaenidae) are widely distributed throughout the world and can be categorized as data-limited fisheries in the Bay of Bengal (BoB), Bangladesh coastal water, which have only the catch and LFQ data available.

The Croakers or Jewfishes are locally called 'Poa mach' and belong to the largest family, 'Sciaenidae', under Perciformes. Jewfishes are usually found in the shallow water [9], and more than 70% of biomass distribution by depth strata of this group is found in the inshore (10–40 m) area of BoB, Bangladesh (Figure 1B) [9,10]. In the Sciaenidae family, 32 species of marine, brackish, and freshwater under 15 different genera have been reported by [11]. Besides, 19 species under 11 genera have been reported by [10], from the Bangladesh marine water, where *Johnius* was the most dominant genus. The most abundant with maximum occurrence species in the trawl were *Pennahia anea* (Donkey croaker), *Johnius belangerii* (Belanger's croaker), *Otolithes ruber* (Tiger-tooth croaker), *Otolithoides pama* (Pama croaker), *Protonibea diacanthus* (Blackspotted croaker), *Panna heterolepis* (Hooghly croaker), *J. elongates* (Spindle croaker), and *Pterotolithus maculatus* (Blotched tiger-toothed croaker), which have a significant contribution to the national economy of Bangladesh [10,12].



(**A**) (**B**)

Figure 1. (**A**). Bay of Bengal, Bangladesh coastal map showing the different stratum. (**B**). Stratum wise distribution (%) of Croakers.

Jewfish is the most abundant group, representing 12.8% of the total demersal biomass [9] in the coastal area of Bangladesh. It is caught by industrial and artisanal trawlers, with a total production of 41,943 MT in 2019–2020 [13], accounting for 6.25% of the country's total marine catch. For value-added items, the larger fishes are used, and the smaller ones are dried naturally in the sun. Approximately 86 per cent of the total harvested jewfish is dried and exported to the different South and Southeast Asian countries like Singapore, Japan, China, South Korea, etc. [14,15]. Due to its high demand in national and international markets, continuous fishing pressure has increased since 1985. Moreover, indiscriminate and illegal use of the Set bag net (SBN) and other fishing gears in the coastal areas is depleting the stocks of both pelagic and demersal fisheries in this region [12], resulting in the croaker having been overexploited for decades in the BoB Bangladesh water. Hence, reliable fish stock assessment should be taken for the sustainable management and effective rebuilding of these valuable fisheries resources in the Bangladesh coast.

In this context, due to the lack of data and expertise, minimal studies have been done on the single-stock estimation of jewfish resources in Bangladesh marine water. However, few studies on the growth pattern, mortality, exploitation rate, length-weight relationships, and stock status of some Jewfishes have been done, but no species wise inclusive information on the valuable croaker stocks in the BoB, Bangladesh water, is available [10,16–20].

Recently, two different methodologies for estimating fisheries resources in Bangladesh and other Asian nations have been applied. The surplus production model is one of them, where the maximum sustainable yield (MSY) was estimated using time series of catch and effort/abundance index data [12,21,22]. Length-based Bayesian Biomass (LBB) method is another one, where the stock status of single fisheries were estimated using only the length frequency (LF) data [3,5,22–25].

In this study, we used the LBB approach on six (6) commercially valuable Sciaenidae species to investigate their current stock status in the BoB Bangladesh water and give potential management choices for sustainable harvesting policies.

2. Materials and Methods

2.1. Data Sources and Sampling Procedure

The commercial fishing sector in Bangladesh's coastal and marine water is broadly categorized as industrial and artisanal. Industrial trawlers are typically 20–40 m long and use marine diesel engines having 350–1450 horsepower (HP), while mechanized fishing boats have 20–75 horsepower (HP) marine diesel engines [13,26]. Jew fishes are usually harvested by both categories of fishing fleets in the coastal water of Bangladesh. The monthly length-frequency data for these six croaker species were collected from January 2020 to December 2021 from the "Fishery Ghat" in Chattogram (22°19′42″ N, 91°50′48″ E) (Figure 1A), where more than 90% of industrial trawlers and a large number of artisanal boats landed their fish. Moreover, the LF data were also collected from the artisanal boats from another larger fish landing center named BFDC fish harbor in Cox's Bazar Sadar (21°27′06″ N, 91°58′05″ E).

The length-frequency (LF) data of six valuable croaker species were collected from the BoB, Bangladesh coast (Figure 1A). Trawlers were routinely visited to ensure a better representation and quality of the LF data. LF data of 5578 individuals were randomly taken as mixed fish samples from them. Fifteen industrial and mechanized fishing fleets were visited at random each month (without June and July due to the fishing ban period) for the collection of samples, representing roughly 5% and 0.03% of the entire industrial and mechanized fleets, respectively. Total length (TL) and weight data for each fish in the sample were measured onboard the vessel using a metric scale closest to mm and g. A few obtained samples were taken to the laboratory of the marine fishery survey management unit, Department of Fisheries (DoF), Chattogram, for taxonomic confirmation, and species names were confirmed using FishBase [27].

The LF data for this study were collected from industrial and artisanal fishing vessels at the landing centers despite the financing inefficiencies. The sampling process' may compromise the accuracy of the data and cause LF data to be interpreted incorrectly [3]. We have tried our best to collect the representative sample data in LBB analysis to confirm the maximum representation of LFQ data and least data error.

The R-codes (LBB 33a.R) were used in the R statistical environment to analyze the LF data along with a New User Guide, which is available http://oceanrep.Geomar.de/44832/ (accessed on 20 March 2022).

2.2. Description of the LBB Method

The length-based Bayesian Biomass estimation approach (LBB) was developed to analyze the *LF* data from the commercial fisheries [5,23,25]. For species that grow throughout their lives, such as the most economically important fish and invertebrates, the LBB model is appropriate with only length-frequency data required [25]. It calculates the asymptotic length (L_∞), length at first capture (L_c), relative natural mortality to growth rate (M/K), and relative fishing mortality to natural mortality (F/M). If a reasonable estimation L_∞ is available from an independent study, the user can introduce this value to reduce the uncertainty in the findings of LBB [25]. LBB determines the ratio of depletion (B/B_0) or currently developed biomass to undeveloped biomass using the classic equation of fishery [28,29]. Here, only the fundamental formulas are given. More complete and details information regarding the LBB method can be obtained in the recent studies [25,30].

LBB [25] makes the assumption that length growth complies with von Bertalanffy's growth [28] equation (Equation (1)).

$$L_t = L_{inf}[1 - e^{-k(t-t_0)}] \tag{1}$$

where the length at age t is symbolized by L_t, L_{inf} denotes the asymptotic length, growth coefficient (year^{-1}) is denoted by K, and t_0 indicates the hypothetical age at zero length.

When the fish are entirely selected by the particular fishing gear, the curvature of the right side of caught fish depends on total mortality (Z =M + F) in relation to K (Equation (2)). Equation (3) assumes the selection curves for fishing gears, to avoid catching extremely young fish. Equations (1)–(3) can be combined and rearranged to create Equations (4) and (5), which can determine L_{inf}, L_c, $\frac{M}{K}$, $\frac{F}{K}$, and at the same time α (alpha). Equation (6) was used to predict the L_{opt} (size of fish at which cohort biomass reaches the greatest) using the provided L_{inf} and $\frac{M}{K}$ [31]. Based on Equation (6) and $\frac{F}{M}$, Equation (7) was utilized to determine the length at the maximum catch and biomass (L_{c_opt}).

$$N_L = N_{L_{start}}\left(\frac{L_{inf} - L}{L_{inf} - L_{start}}\right)^{z/k} \tag{2}$$

$$S_L = \frac{1}{[1 + e^{-\alpha(L-L_c)}]} \tag{3}$$

$$N_{L_i} = N_{L_{i-1}}\left(\frac{L_{inf} - L_i}{L_{inf} - L_{i-1}}\right)^{\frac{M}{K}+\frac{F}{K}S_{L_i}} \tag{4}$$

and

$$C_{L_i} = N_{L_i} S_{L_i} \tag{5}$$

$$L_{opt} = L_{inf}\left(\frac{3}{3 + \frac{M}{K}}\right) \tag{6}$$

$$L_{c\_opt} = \frac{L_{inf}\left(2 + 3\,\frac{F}{M}\right)}{\left(1 + \frac{F}{M}\right)\left(3 + \frac{M}{K}\right)} \tag{7}$$

where N_L and $N_{L_{start}}$ are the total population numbers at length L and L_{start} respectively. The ratio of total mortality rate Z to somatic growth rate detotes the z/k. S_L is the fraction of individuals at length L that are kept in the gear, and α indicates how steep the ogive is. The number of individuals kept in the fishing gear is indicated by C.

Equations (8) and (9) derived the yield per recruit (Y′/R) and catch per unit of effort ($CPUE'/R$) respectively [32]:

$$\frac{Y'}{R} = \frac{\left(\frac{F}{M}\right)}{\left(1 + \frac{F}{M}\right)}\left(1 - \frac{L_c}{L_\infty}\right)^{\frac{M}{K}}\left(1 - \frac{3(1 - \frac{L_c}{L_\infty})}{1 + (\frac{1}{(\frac{M}{k} + \frac{F}{k})})} + \frac{3(1 - \frac{L_c}{L_\infty})^2}{1 + (\frac{2}{(\frac{M}{k} + \frac{F}{k})})} + \frac{(1 - \frac{L_c}{L_\infty})^3}{1 + (\frac{3}{(\frac{M}{k} + \frac{F}{k})})}\right) \tag{8}$$

$$\frac{CPUE\prime}{R} = \frac{\frac{Y'}{R}}{\frac{F}{M}} = \left(\frac{1}{M}\right)\left(1 - \frac{L_c}{L_\infty}\right)^{\frac{M}{K}}\left(1 - \frac{3(1 - \frac{L_c}{L_\infty})}{1 + (\frac{1}{(\frac{M}{k} + \frac{F}{k})})} + \frac{3(1 - \frac{L_c}{L_\infty})^2}{1 + (\frac{2}{(\frac{M}{k} + \frac{F}{k})})} + \frac{(1 - \frac{L_c}{L_\infty})^3}{1 + (\frac{3}{(\frac{M}{k} + \frac{F}{k})})}\right) \tag{9}$$

In the exploited phase of the population, Equation (10) computed the biomass per recruit:

$$\frac{B'_0 > L_c}{R} = \left(1 - \frac{L_c}{L_\infty}\right)^{\frac{M}{K}}\left(1 - \frac{3(1 - \frac{L_c}{L_\infty})}{1 + (\frac{1}{(\frac{M}{k} + \frac{F}{k})})} + \frac{3(1 - \frac{L_c}{L_\infty})^2}{1 + (\frac{2}{(\frac{M}{k} + \frac{F}{k})})} + \frac{(1 - \frac{L_c}{L_\infty})^3}{1 + (\frac{3}{(\frac{M}{k} + \frac{F}{k})})}\right) \tag{10}$$

where exploitable fraction (>L_c) of the unfished biomass (B_0) is denoted by $(B'_0 > L_c)$.

Finally, for the exploited population, Equation (11) was used to determine the biomass depletion (B/B_0) [32]:

$$\frac{B}{B_0} = \frac{\frac{CPUE'}{R}}{\frac{B'_0 > L_c}{R}} \quad (11)$$

Finally, rerunning Equations (8)–(11) yielded a proxy for the proportion of biomass capable of producing MSY (B_{msy}/B_0).

LBB relative biomass estimates were similar to independent estimates from comprehensive stock assessments and did not differ significantly from "actual" values in simulated data [25]. Length-frequency data of the six commercially valuable Sciaenidae species (Table 1) from the BoB Bangladesh coast were investigated in this study.

Table 1. Basic and prior information of six croaker species in BoB for the LBB approach.

Scientist Name	Common Name	Min (cm)	Max (cm)	Class Interval (cm)	Numbers	L_{inf} Prior (cm)	*Z/K* Prior	*M/K* Prior	*F/K* Prior	L_c Prior	*Alpha* Prior
Pennahia anea	Donkey croaker	8	33	1.0	794	33	2.3	1.5	0.76	13.3	13.2
Johnius belangerii	Belanger's croaker	6	32	1.0	931	32	3.1	1.5	1.64	12.8	9.91
Otolithes ruber	Tiger-tooth croaker	12	45	1.0	1169	46.6	4.6	1.5	3.13	20.9	19.9
Otolithoides pama	Pama croaker	10	33	1.0	1001	35.4	3.7	1.5	2.18	16.8	17.9
Panna heterolepis	Hooghly croaker	8	31	1.0	1063	34	2.9	1.5	1.36	16.3	18.5
Pterotolithus maculatus	Blotched tiger-toothed croaker	17	52	1.0	620	54.2	3.8	1.5	2.28	24	19

Overfishing status of the stocks is indicated by $F/M > 1$, while overfished status is indicated by $B/Bmsy < 1$. In particular, extremely low condition of the current biomass is indicated by $B/Bmsy < 0.5$. The truncated length structure and capturing of individual species that are too small is suggested if the values of the ratios L_{mean}/L_{opt} and L_c/L_{c_opt} are below unity. Likewise, at least some large fish species are still present, as is indicated when the 95th percentile length and asymptotic length L_{95th}/L_{inf} ratio are close to one (>0.9). Table 2 shows the stock status based on the estimated value of B/B_{MSY} [3,5,24,25,33].

Table 2. Definition of the stock status in the present study based on the values of B/B_{MSY}.

B/B_{MSY}	Stock Status
$\geq$1	Healthy
0.8–1.0	Slightly overfished
0.5–0.8	Overfished
0.2–0.5	Grossly overfished
$\leq$0.2	Collapsed

The estimated outputs of LBB can directly be used in the data-limited stocks management. Fishing pressure or catch should be reduced for $B/B_0 < B_{MSY}/B_0$. Fishing should start at larger sizes for $L_c < L_{c\_opt}$.

3. Results

Six croaker stocks from the BoB, Bangladesh coast, were analyzed using the LBB method. The basic information and priors (L_{inf}, L_c, Z/K, M/K, F/K, and α) of six species are in Table 1, and the results are in Figure 2 and Table 3.

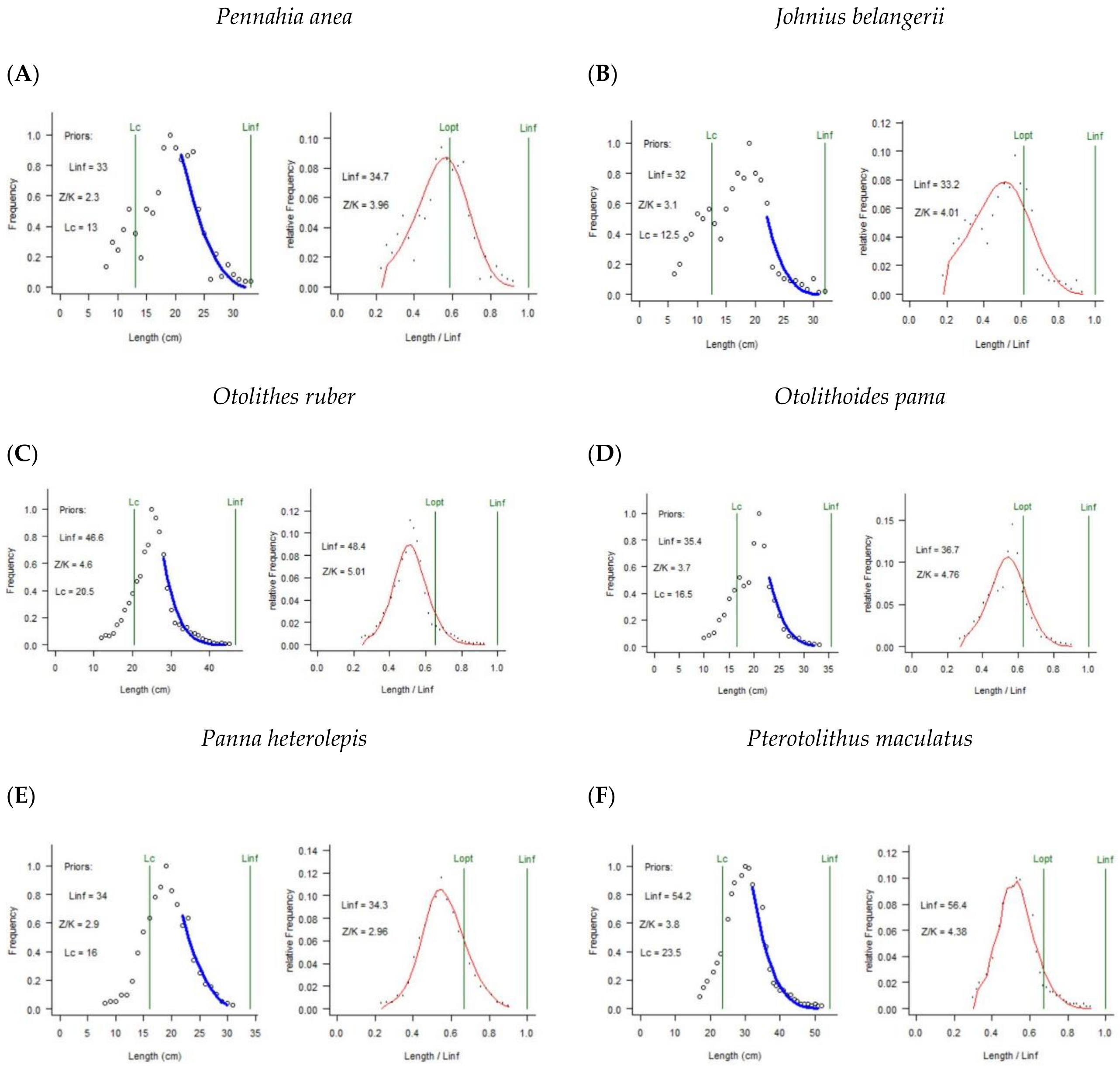


Figure 2. Graphical outputs (**A**–**F**) of LBB method for the six commercially valuable croaker species from the BoB, Bangladesh coast. Where *Lc* = length at first captured, L_{inf} = asymptotic length of this species, and L_{opt} = length at which the maximum sustainable yield is obtained. The left curve of each species output indicates the fitting of the model to the length data and the right curve shows the prediction of LBB method.

Table 3. Estimated results of Six Scianidea species in BoB by the length-based Bayesian biomass (LBB) method.

Scientist Name	L_{mean}/L_{opt}	L_c/L_{c_opt}	L_{95th}/L_{inf}	B/B_0	B/B_{MSY}	F/M	F/K	Z/K	Assessment
Pennahia anea	1.1	1.2	0.92	0.42	1.2	0.88	1.9	3.9	Healthy
Johnius belangerii	1.1	1.1	0.93	0.34	0.96	1.1	2.1	4	Slightly overfished
Otolithes ruber	0.86	0.82	0.93	0.17	0.47	2.1	3.4	5	Grossly overfished
Otolithoides pama	0.97	0.95	0.90	0.23	0.64	1.7	3.0	4.8	Overfished

Table 3. *Cont.*

Scientist Name	L_{mean}/L_{opt}	L_c/L_{c_opt}	L_{95th}/L_{inf}	B/B_0	B/B_{MSY}	F/M	F/K	Z/K	Assessment
Panna heterolepis	0.91	0.87	0.90	0.34	0.92	0.96	1.5	2.9	Slightly overfished
Pterotolithus maculatus	0.87	0.80	0.92	0.18	0.48	2	2.9	4.4	Grossly overfished

3.1. Donkey Croaker (*Pennahia anea*)

The bigeye croaker, commonly known as Donkey croaker and locally called 'Boster poa or white poa', is one of the most abundant and commercially valuable Sciaenidae species on Bangladesh's coast. The values of B/B_{MSY} = 1.2 and the B/B_0 = 0.42, along with the position of L_{opt} line on the right curve (Table 3 and Figure 2A), suggest healthy status for the species in the study area.

3.2. Belanger's Croaker (*Johnius belangerii*)

Belanger's croaker, locally known as 'Silver poa or rupali poa', is one of the most valuable croaker species in the Bangladesh coast. The values of B/B_{MSY} = 0.96, and F/M = 1.1 suggest a slightly overfished states in this study area (Table 3 and Figure 2B).

3.3. Tiger-Tooth Croaker (*Otolithes ruber*)

Tiger-tooth croaker is locally known as 'Dat poa'. The possible existence of 2 stocks of *O. ruber* were suggested on the east coast of India along the Bay of Bengal [34]. The estimated value of the F/M = 2.1 suggests the overfishing status of this species, farther, the very low current biomass status of this species is indicated by B/B_0 = 0.17. However, the presence of at least some large fishes in the stock was suggested from the estimated value of L_{95}/L_{inf} = 0.93 (Table 3 and Figure 2C).

3.4. Pama Croaker (*Otolithoides pama*)

Pama croaker is locally familiar as 'Leijja poa' and distributed in the Indo-Pacific: Pakistan to Papua New Guinea. The values of the estimated parameters B/B_{MSY} = 0.64 and F/M = 1.7, along with the L_{opt} line position on the right curve, suggest overfished status in this study area (Table 3 and Figure 2D). However, the presence of at least some large fish in the stock was suggested by L_{95th}/L_{inf} > 0.9.

3.5. Hooghly Croaker (*Panna heterolepis*)

Hooghly croaker is locally known as 'Chotta lambu poa'. It is distributed in the Indian Ocean: Coast of Bangladesh, India, Sri Lanka, and Myanmar. The estimated values of B/B_{MSY} = 0.92 and B/B_0 = 0.34 suggest the slightly overfished status of *P. heterolepis* resource on the coast of Bangladesh (Table 3 and Figure 2E).

3.6. Blotched Tiger-toothed Croaker (*Pterotolithus maculatus*)

P. maculatus is locally called 'Guti poa', a famous and highly valued croaker species, distributed in the Indo-Pacific, Sri Lanka, around the Bay of Bengal to Borneo. The estimated values (F/M = 2.0) and (B/B_0 = 0.18) indicate the high fishing intensity (Table 3 and Figure 2F) and low biomass of this species. Similarly, the estimated values of L_{mean}/L_{opt} =0.87 and L_c/L_{c_opt} = 0.80, which are below unity indicating overfishing.

4. Discussion

LBB could be particularly effective in the management of data-poor stocks with erratic or missing catch data. Representative length-frequency samples from the primary fishing gear or the main landing site may be sufficient to provide a preliminary estimate of stock size in relation to MSY levels. LBB also compares the present length at first capture *Lc* to the one (*Lc_opt*) that would maximize catch and biomass for the given fishing pressure [25,31].

Based on this knowledge, management can recommend modifications in lengths at first capture and fishing effort until the relative biomass projected by LF data exceeds the approximate MSY level.

In the current study, the LBB method was used using the LF data to assess the resource status of Six Sciaenidae species in the BoB Bangladesh water. The estimated ratios L_{mean}/L_{opt} were below one in four stocks out of the six; similar outcomes from the ratios L_c/L_{c_opt} indicate truncated length structure and capture of undersized individuals. However, in the four stocks out of six, the estimated values of L_{95th}/L_{inf} were close to unity (>0.9), suggesting the existence of at least some large fishes. In the current study, estimated smaller ratios of B/B_0 in six stocks, except in *P. anea* and B_{MSY}/B_0, indicates the overfishing status of five stocks. Where two species were grossly overfished, two were slightly overfished, one was overfished, and one was healthy status.

Most of the previous studies were consistent with the present study. However, no report was found for the *O. ruber* and *P. maculatus* on the BoB Bangladesh coast. The current study estimated the healthy stock status of *P. anea* in the BoB Bangladesh water (Table 3), which consists of the findings of [10], where the not-overexploited status of this species was estimated through the Biomass dynamics model. In addition, [35] reported the optimally exploited status of this species on India's northeast coast, which further justifies the present study's findings. The croakers overall are in decline in the catch and appear to be decreasing in biomass [10], which complies with the findings of slightly overfished status for the *J. belangerii* in the study area (Table 3). However, using the LBB method [4], we reported the healthy status of this species in the Beibu Gulf in China.

The *O. ruber* stock was slightly overexploited from the Tamil Nadu coast, India [36], which is somewhat consistent with the grossly overfished status of this species in the study area (Table 3). The present study found the overfished status of *O. pama* species (Table 3) similar to the over-exploited status reported by [37]. However, [16] reported a not-overexploited status for this stock on the Bangladesh coast, which might be due to the data sources from the different ecosystems or different samples. More research is needed.

Present study found the slightly overfished status of the Hooghly croaker (*P. heterolepis*) in the BoB, Bangladesh coastal water (Table 3). Similar findings (slightly overexploited) for this species were reported by [19] in the Sundarbans ecosystem in Bangladesh, which is consistent with the present study. There is no recent information on the stock status of the Blotched tiger-toothed croaker (*Pterotolithus maculatus*) in the BoB Bangladesh coast. The present study estimated the grossly overfished status of *P. maculatus* species in the study area. Large and more valuable croakers may be severely depleted in the Bangladesh marine water, and recovery will require significant reductions in fishing mortality and may be quite slow [10], which strongly complies with the grossly overfished status of *P. maculatus* in the BoB, Bangladesh coast (Table 3).

The LBB approach requires only LFQ data. It is a data-poor method which is especially useful in the fisheries in Bangladesh. However, the LBB method relies on high quality data, which demands extra caution in data collection. Computer simulation analysis can be used to study the possible biases, where the true values are known. We hope to conduct such analysis in the near future. In addition, comparisons with the other data-poor methods, such as TropFishR, can also be helpful in understanding the fisheries in Bangladesh.

5. Conclusions

The six most abundant and valuable Sciaenidae stocks in the coastal water of Bangladesh were assessed using the LBB approach. The estimated findings indicate that only donkey croaker (*P. anea*) is in the healthy status, whereas two species, belonger's croaker (*J. belangerii*) and Hooghly croaker (*P. heterolepis*), are slightly overfished, two species, tiger-tooth croaker (*O. ruber*) and blotched tiger-toothed croaker (*P. maculatus*), are grossly overfished, and pama croaker (*O. pama*) is overfished. Besides, the present findings ($L_c < L_{c\_opt}$) in four out of six populations suggest increasing the mesh size for benefitting the catch and biomass. Hence, we recommend reducing the fishing intensity in the coastal water of

Bangladesh by implementing the mesh size regulation, close season and total allowable catch (TAC), and controlling the expansion of fishing fleets.

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