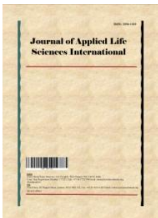

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Population Dynamics of Five Important Commercial Fish Species in the Sundarbans Ecosystem of Bangladesh

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aims: To determine the population dynamics and assess the exploitation level of *Mystus gulio, Acanthopagrus latus, Chelon parsia, Otolithoides pama* and *Lates calcarifer* in the Sundarbans ecosystem of Bangladesh.

Study Design: Monthly length-frequency data of five fish species were collected from the Sundarbans ecosystem. The lengths of five fish species were recorded to the nearest one cm intervals in each month.

Place and Duration of Study: The study was conducted from January to December 2011 in the Sundarbans ecosystem in Bangladesh.

Methodology: The FAO-ICLARM Fish Stock Assessment Tools (FiSAT II) software was used to estimate the von Bertalanffy growth parameters (L_∞ and K), mortality coefficients (Z, M and F), probability of capture, recruitment pattern and Yield/Biomass-per-recruit for five commercially important fish species caught by fishers in the Sundarbans ecosystem of Bangladesh.

Results: In the Sundarbans ecosystem of Bangladesh area the values of asymptotic length (L_∞) for *Mystus gulio, Acanthopagrus latus, Chelon parsia, Otolithoides pama and Lates calcarifer* were

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found to be 23.0 cm, 33.6 cm, 30.0 cm, 32.5 cm and 55.0 cm respectively while the growth co-efficient (K) were 0.75, 0.85, 1.1, 0.8 and 0.5 respectively. The estimates for L∝ (23.00 – 55.0 cm) and K (0.5-1.1 year^{-1}) obtained were consistent with those available in the literature. Relatively high K and low L∝ values, typical of short-lived tropical fishes, were obtained for *Mystus gulio, Acanthopagrus latus, Chelon parsia* and *Otolithoides pama*. The length growth performance index (ϕ') of the Pauly and Munro's function was in the range of 2.599 – 3.180. Natural mortality, fishing mortality and total mortality were in the range of 0.956-1.89, 0.55-1.58 and 1.52-3.3 respectively. Estimates for total mortality (Z) and natural mortality (M) imply low annual rates of survival and high turnover rates. The recruitment pattern suggested one main pulse of annual recruitment. The exploitation rate was estimated to be between 27% and 47% and the length at first capture was estimated to be approximately 19-54% of L∝. The exploitation rate obtained for five fish species are relatively lower compared to other available studies in the coastal areas of Bangladesh. The growth and exploitation rates obtained were compared with available estimates to evaluate the consistency of the results with current knowledge about the species in the region.

Conclusion: The study indicated that the length-at-first-capture/L∝ seem to be a simple parameter, which could be used to make a rapid assessment of the status of the stocks. All together, the present study reveals that the population of these five studied species attains acceptable sustainability levels in the Sundarbans ecosystem and scope for a slight increase in catch efforts.

Keywords: Population dynamics; growth parameters; mortality coefficients; exploitation rate; Sundarbans; Bangladesh.

1. INTRODUCTION

Fisheries play critical to Bangladesh economy, it constitutes to 3.61% of GDP, and it is the second largest export [1]. In 2016-17, Bangladesh fish and shellfish production reached a record 4.13 million tons and more than 11% of the total population of Bangladesh is employed either directly or indirectly in the fishery [1]. Marine fisheries, inland open water or capture fisheries and closed water fisheries provide an important source of livelihood for tens of thousands of poor people and supply a significant portion of their protein intake [2,3,4]. Fisheries constitute an important occupation for poor people in the southwest coastal region of Bangladesh, and they supply a significant portion of protein for millions [5]. Tiger shrimp *Penaeus monodon* make an important contribution to the economy of the southwest coastal region [6].

The Sundarbans located in the south-west of Bangladesh, is the largest mangrove forest and consisting of a group of plants, coastal waters, fishes, shellfish and crustaceans. The Sundarbans ecosystem supports rich fisheries diversity and constituents of 177 species of fishes [7]. A 4-year forecasting on yield of Sundarbans fisheries (based on landed data) shows marked decline of white fish, *Scylla serrate* and fry catch [8]. Sundarbans fishing communities in Bangladesh are at greater threat due to frequent natural disasters, which damages natural resources systems. Information on population dynamics on different fish and shrimp of the Bay of Bengal are available, based on length-frequency data [9,10,11,12,13,14,15]. Considering the importance of these five species, efforts have been made to get knowledge about the population dynamics of the Sundarbans fishery.

An attempt was made to analyze the asymptotic length (L∝), growth-coefficient (K), growth performance index (ϕ'), natural mortality (M), fishing mortality (F), total mortality (Z), selection pattern (Lc), recruitment pattern, exploitation rate (E), and yield/biomass-per-recruit (Y/R and B/R) of *Mystus gulio, Chelon parsia, Acanthopagus latus, Otolithoides pama* and *Lates calcarifer* in the Sundarbans ecosystem of Bangladesh.

Time series of length frequencies are the most common data type collected for population dynamics analysis. The lengths are grouped with a constant interval of 1 cm for *Mystus gulio* (Long whiskers catfish), *Acanthopagus latus* (Yellowfin seabream), *Chelon parsia* (Gold-spot mullet), *Otolithoides pama* (Pama croaker) *and Lates calcarifer* (Barramundi). This paper attempts to contribute by analyzing the length-frequency data to estimate growth parameters, mortality, exploitation rates and recruitment pattern for the sustainable management of five commercial species in the Sundarbans ecosystem.

2. MATERIALS AND METHODS

The study was conducted from January to December 2011 under Integrated Protected Area Co-management (IPAC) project in the Sundarbans ecosystem. Monthly length-frequency data were collected from the Sundarbans ecosystems (Fig. 1). The lengths of five fish species in the catch were recorded to the nearest one cm intervals in each month. For each sample the gear type and mesh size were recorded. All length-frequency data for each month were pooled across species and gear type.

2.1 Length-frequency Data Analysis

For the estimation of the growth rates, only samples from non-selective gears were used and aggregated in monthly periods. Population parameters were estimated using the FAO-FISAT software [16]. In Bangladesh, fish growth exhibits a distinct seasonal pattern with high growth during the monsoon and low growth during winter [17,18,19]. A seasonal version of the Von Bertalanffy Growth Function (VBGF) was therefore fitted to the data which has the following form:

$$Lt = L\propto (1 - \exp(-K(t-t_0) + S_{ts} - St_0)$$

where,

$S_{ts} = (CK/2\pi)_* \sin(2\pi(t-ts))$;
$S_{t0} = (CK/2\pi)_* \sin(2\pi(t_0-ts))$; and,
Lt is the length at time t.

$$Lt = L\infty * \left(1 - e^{-k*(t-to)-(CK/2\pi)*[\sin 2\pi(t-ts) - \sin 2\pi(to-ts)]}\right)$$

where:

- $L\propto$ = L infinity is the mean length the fish of a given stock would reach if they were to grow indefinitely,
- K = growth coefficient parameter, or the rate at which $L\infty$ is approached,
- t0 = T-zero, or the "age of the fish at zero length" if it had always grown in a manner described by the equation,
- Ts = the onset of the first oscillation relative to t=0; and,
- C = the intensity of the (sinusoid) growth oscillations.

For this model, the winter point (WP) or period with the slowest growth, was set at 1 or December/January (WP=ts+0.5) as this is the month with the lowest water temperature. The instantaneous total annual mortality rate (Z) was estimated using a length converted catch curve incorporating seasonal growth [20]. The natural mortality (M) was estimated using the empirical relationship derived by Pauly [21] where the mean annual water temperature was set at 28ºC.

The exploitation ratio, E was estimated as: E = F/Z = F/(F+M). Length at first capture (L_c or L_{50}) was estimated following the method of Pauly [22] while longevity was calculated as 3/K.

The probabilities of capture by length [22] were estimated by calculating the ration between the points of extrapolated descending arm and the corresponding ascending arm of the length converted catch curve. Relative yield-per-recruit (Y/R) and biomass-per-recruit (B/R) were obtained from the estimated growth parameters and probabilities of capture by length [23].

The recruitment pattern was also derived using the program [24].

3. RESULTS

3.1 Population Dynamics Parameters for *Mystus gulio*

The Long whiskers catfish, *Mystus gulio*, belongs to the family Bagridae, locally known as *tengra* in Bangladesh. *Mystus gulio* is a commercially important catfish that occurs along the entire Sundarbans ecosystems, and are traditionally caught by artisanal fishermen. The growth parameters, $L\propto$ (asymptotic length) and K (growth co-efficient) of the *Mystus gulio* were found to be 23.0 cm and 0.75 $year^{-1}$. The growth curves of those parameters are shown over its restructured length-frequency distribution in Fig. 2a. In the present study, the peak spawning takes place in May. The three different mortality rates M (natural mortality), F (fishing mortality) and Z (total mortality) were found to be 1.591, 1.42 and 3.01 respectively. Fig. 3a represents the catch curve utilized in the estimation of Z (total mortality). Probable length at first capture (L_c) was found to be 8.53 cm. The knife edge procedure for the yield-per-recruit were found to be 0.62, 0.52 and 0.32 for E_{max}, E_{10} and E_{50} respectively. Two dimensional relative yield/biomass-per-recruit prediction is given in Fig. 4a. Estimated growth performance index (ϕ') and exploitation ratio (E) values for *Mystus gulio* was found to be 2.599 and 0.47 respectively. It appears that the stock of *Mystus gulio* of the

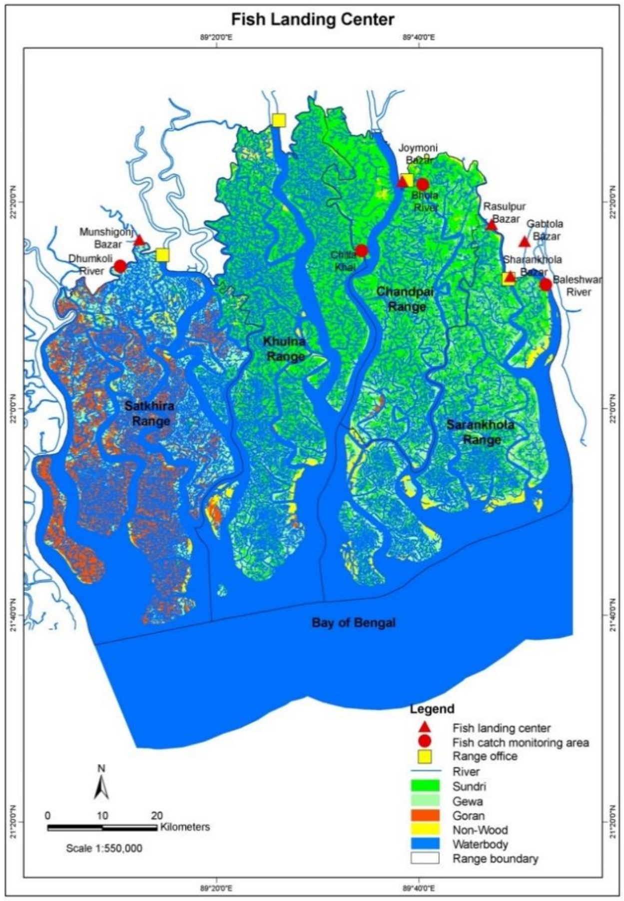

Fig. 1. Study area

Sundarbans ecosystems is not over-exploited. However, recruitment over fishing observed. So, mesh size of gears should be increased by 15% (at 50% escapement factor). Recruitment pattern of length-frequency data correlate with the length of spawning season and a growth co-efficient (K). A recruitment pattern suggested one seasonal pulse from March to August (Fig. 5a). The computed growth curve suggests that the approximate life span of *Mystus gulio* was found to be 4 years in the Sundarban ecosystem.

3.2 Population Dynamics Parameters for *Acanthopagrus latus*

The yellow fin sea bream, *Acanthopagrus latus*, belongs to the family Sparidae, locally known as *datney* in Bangladesh. *Acanthopagrus latus* form an important part of the coastal fisheries production of Bangladesh, and are traditionally caught by artisanal fishermen. The growth parameters, $L\infty$ and K of the *Acanthopagrus latus* were found to be 33.6 cm and 0.85 $year^{-1}$. The growth curves are shown in Fig. 2b. The peak spawning takes place in May. The three different mortality rates M, F and Z were found to be 1.553, 0.95 and 2.5 respectively. Fig. 3 presents the catch curve utilized in the estimation of Z. Probable length at first capture (L_c) was found to be 9.50 cm. The knife age procedure for the yield-per-recruit were found to be 0.51, 0.42 and 0.31 for E_{max}, E_{10} and E_{50} respectively. Two dimensional relative yield/biomass-per-recruit prediction is given in Fig. 4b. Estimated growth performance index (ϕ') and exploitation ratio (E) values for *Acanthopagrus latus* was found to be 2.982 and 0.38 respectively. It appears that the stock of *Acanthopagrus latus* in the Sundarban ecosystems is not over-exploited. However, recruitment over fishing observed. So, mesh size of the gears should be increased by 17% (at 50% escapement factor). Recruitment pattern of length-frequency data correlate with the length of spawning season and a growth co-efficient (K). A recruitment pattern suggested one seasonal pulse from May to October (Fig. 5b). The computed growth curve suggests that the approximate life span of *Aconthopagrus latus* was found to be 3 and half years in the Sundarban ecosystem.

3.3 Population Dynamics Parameters for *Chelon parsia*

The Gola-spot mullet, *Chelon parsia*, belongs to the family Mugilidae, locally known as pashey in Bangladesh. *Chelon parsia* is one of the most commercially important species in Bangladesh coastal waters, and are traditionally exploited by artisanal fishermen. The growth parameters, $L\infty$ (asymptotic length) and K (growth co-efficient) were found to be 30 cm and 1.1 $year^{-1}$. The growth curves of those parameters are shown over its restructured length-frequency distribution in Fig. 2c. In the present study, the peak spawning takes place in April. The three different mortality rates M, F and Z were found to be 1.89, 1.4 and 3.3 respectively. Fig. 2c represents the catch curve utilized in the estimation of Z. Probable length at first capture (L_c) was found to be 7.71 cm. The knife age procedure for the yield-per-recruit were found to be 0.48, 0.41 and 0.29 for E_{max}, E_{10} and E_{50} respectively. Two dimensional relative yield/biomass-per-recruit prediction is given in Fig. 4c. Estimated growth performance index (ϕ') and exploitation rate (E) values of *Chelon parsia* was found to be 2.996 and 0.45 respectively. It appears that the stock of the *Chelon parsia* of the Sundarban ecosystem is not over-exploited. However, recruitment over fishing observed. So, gear mesh size should be increased by 20% (at 50% escapement factor). Recruitment pattern of length-frequency data correlate with the length of spawning season and a growth co-efficient (K). A recruitment pattern suggested two seasonal pulses from February to April and August to September (Fig. 5c). The computed growth curve suggests that the approximate life span of *Chelon parsia* was found to be nearly 3 years in the Sundarban ecosystem.

3.4 Population Dynamics Parameters for *Otolithoides pama*

The Pama croker, *Otolithoides pama*, belongs to the family Sciaenidae, locally known as Poa in Bangladesh. *Otolithoides pama* form an important part of the coastal fisheries production of Bangladesh, and are traditionally caught by trawlers and artisanal fishermen. The growth parameters, $L\infty$ and K of the *Otolithoides pama* were found to be 32.5 cm and 0.8 $year^{-1}$. The growth curves of those parameters are shown over its restructured length-frequency distribution in Fig. 2d. In this study, the peak spawning takes place in July-Aug. The three different mortality rates M, F and Z were found to be 1.507, 0.55 and 2.06 respectively. Fig. 3d represents the catch curve utilized in the estimation of Z. Probable length at first capture (L_c) was found to be 13.13 cm. The knife age procedure for the yield-per-recruit were found to be 0.63, 0.50 and 0.33 for E_{max}, E_{10} and E_{50} respectively. Two dimensional relative yield/biomass-per-recruit prediction is given in Fig. 4d. Estimated growth performance index (ϕ') for *Otolithoides pama* was found to be 2.927. The exploitation rate (E) was calculated as 0.27 indicating that pama croker was not fully exploited in the Sundarbans ecosystem. It appears that the stock of *Otolithoides pama* in the Sundarban ecosystems is not over exploited. However, recruitment over fishing observed. So, gear mesh size should be increased by 17% (at 50% escapement factor). A recruitment pattern suggested two uneven seasonal pulses from March-July and September-October (Fig. 5d). The computed growth curve suggests that the approximate life span of *Otolithoides pama* was found to be more than 3 years in the Sundarbans ecosystem.

3.5 Population Dynamics Parameters for *Lates calcarifer*

The Barramundi, *Lates calcarifer*, belongs to the family Latidae, locally known as *vetki* in Bangladesh. *Lates calcarifer* form an important part of the estuarine and coastal fisheries production of Bangladesh, and are traditionally caught by artisanal fishermen. The growth parameters, $L\infty$ (asymptotic length) and K (growth co-efficient) of the *Lates calcarifer* were found to be 55 cm and 0.5 $year^{-1}$. The growth curves of those parameters are shown over its restructured length-frequency distribution in Fig. 2e. In the present study, the peak spawning takes place in April. The three different mortality rates M (natural mortality), F (fishing mortality) and Z (total mortality) were found to be 0.956, 0.56 and 1.52 respectively. Fig. 3e represents the catch curve utilized in the estimation of Z (total mortality). Probable length at first capture (L_c) was found to be 18.2 cm. The knife age procedure for the yield-per-recruit were found to be 0.55, 0.47 and 0.31 for $E_{max,}$ E_{10} and E_{50} respectively. Two dimensional relative yield/biomass-per-recruit prediction is given in Fig. 4e. Estimated growth performance index (ϕ') and exploitation ratio (E) values for *Lates*

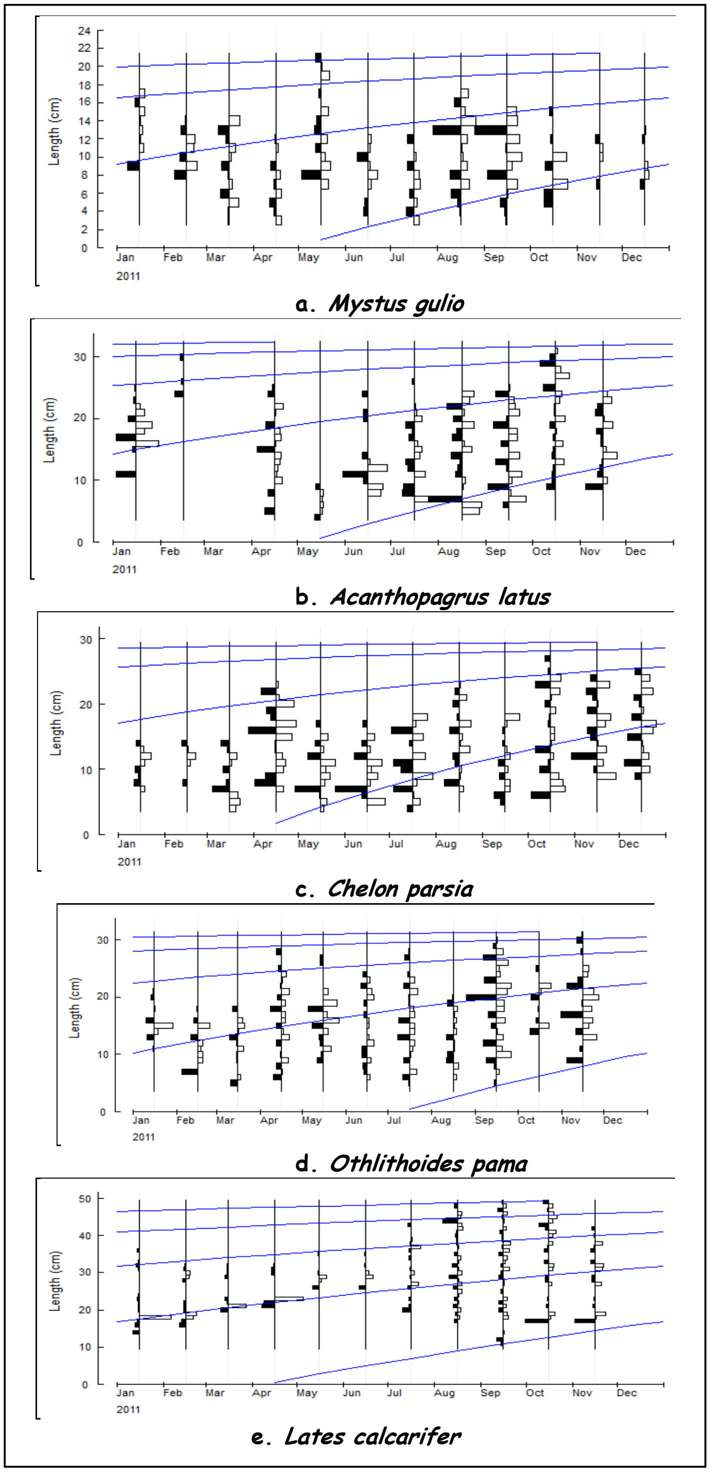

Fig. 2. Growth curve of a) *Mystus gulio,* b) *Acanthopagrus latus,* c) *Chelon parsia,* d) *Othlithoides pama and e) Lates calcarifer*

calcarifer was found to be 3.18 and 0.37 respectively. It appears that the stock of *Lates calcarifer* of the Sundarbans ecosystem is not over-exploited and recruitment over fishing also not observed (at 50% escapement factor). Recruitment pattern of length-frequency data correlates with the length of spawning season and a growth co-efficient (K). A recruitment pattern suggested two uneven seasonal pulses from March to July and October to November (Fig. 5e). The computed growth curve suggests that the approximate life span of *Lates calcarifer* was found to be 6 years in the Sundarbans ecosystem.

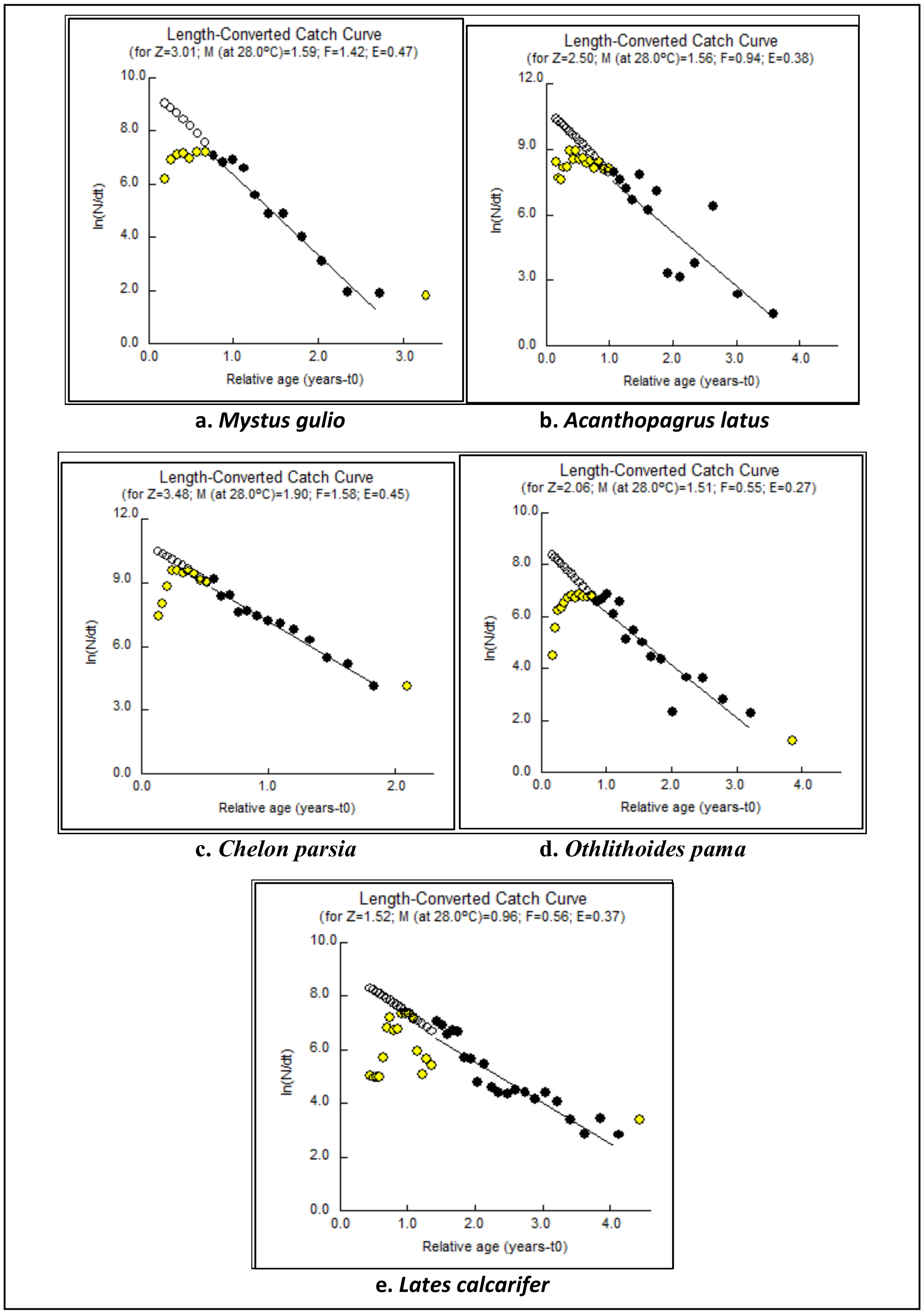

Fig. 3. Length converted catch curve of a) *Mystus gulio,* b) *Acanthopagrus latus,* c) *Chelon parsia,* d) *Otolithoides pama* and e) *Lates calcarifer* caught in the Sundarbans ecosystem (darkened circles represents length groups that are fully recruited into the fishery and used in the analysis)

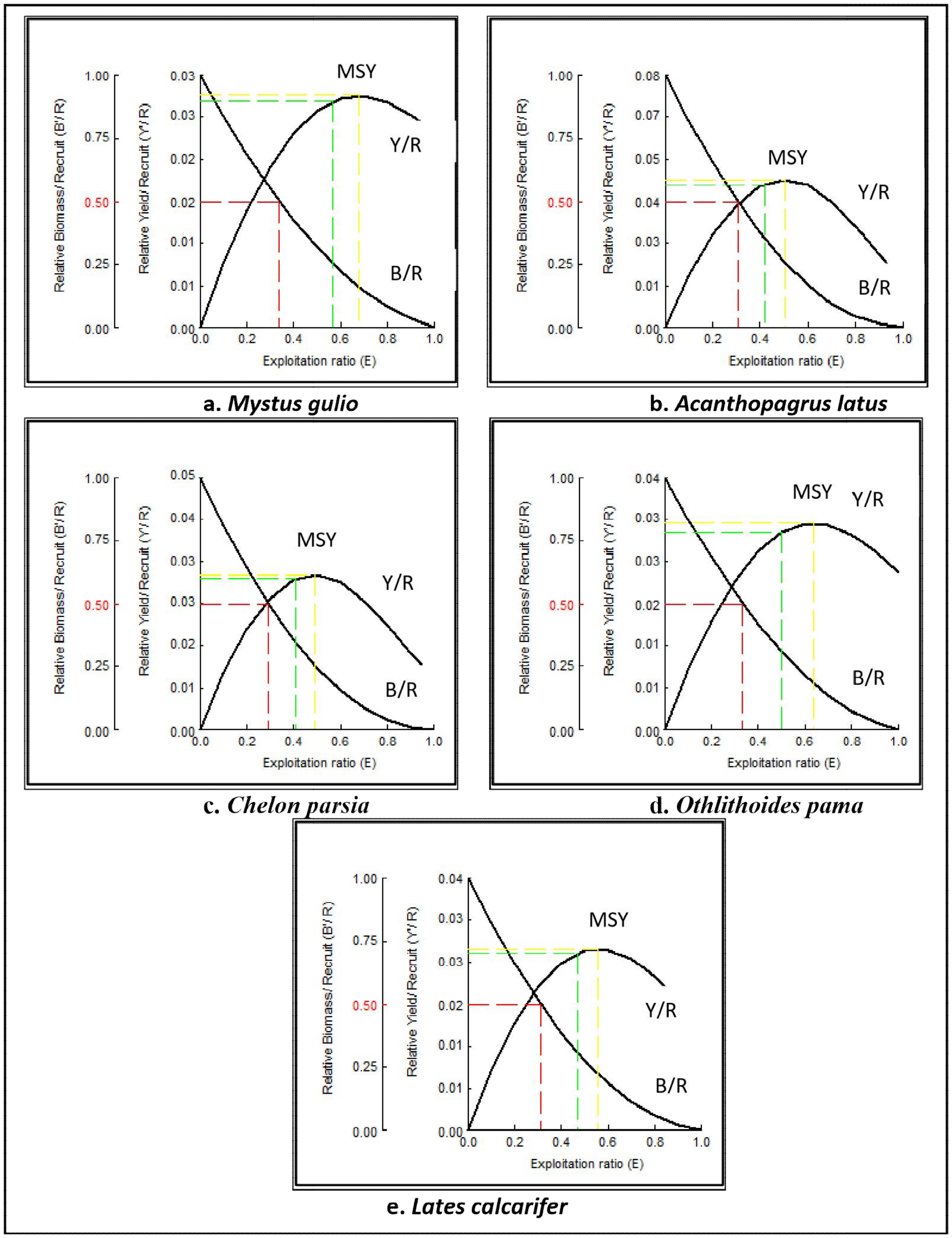

Fig. 4. Relative Yield-per-Recruit (Y/R) and Biomass-per-Recruit (B/R) of a) *Mystus gulio,* b) *Acanthopagrus latus,* c) *Chelon parsia,* d) *Otolithoides pama* and e) *Lates calcarifer* caught in the Sundarbans ecosystem

The estimated growth parameters, mortality rates and exploitation ratio for the five major species in the Sundarbans ecosystem are given in Table 1. The estimates of growth performance index (ϕ') varied between 2.599 (*Mystus gulio*) and 3.427 (*Otolithoides pama*). Simultaneously estimates of exploitation rates (E) varied between 0.27 (*Otolithoides pama*) and 0.47 (*Mystus gulio*) with mean E values equal to 0.41. The estimates of E_{max} varied between 0.48 (*Chelon parsia*) and 0.63 (*Otolithoides pama*). The computed current exploitation rate (E) for five studied species are lower than the predicted E_{max} for the five studied species in the Sundarbans ecosystem. The implication is that the stock of five studied species is not overexploited. This assumption is based on [25] theory which stated that a suitable yield is optimized when F=M, and when E is more than 0.50 the stock is generally supposed to be over-fished. The results of the study showed that exploitation of *Mystus gulio*, *Acanthopagrus latus*, *Chelon parsia*, *Otolithoides pama* and *Lates calcarifer* in the Sundarbans ecosystem is below the optimum level indicating sustainable management of fisheries and scope for a slight increase in catch efforts.

4. DISCUSSION

The specific objectives of this study were to determine the population parameters and assess the exploitation level of the Sundarbans

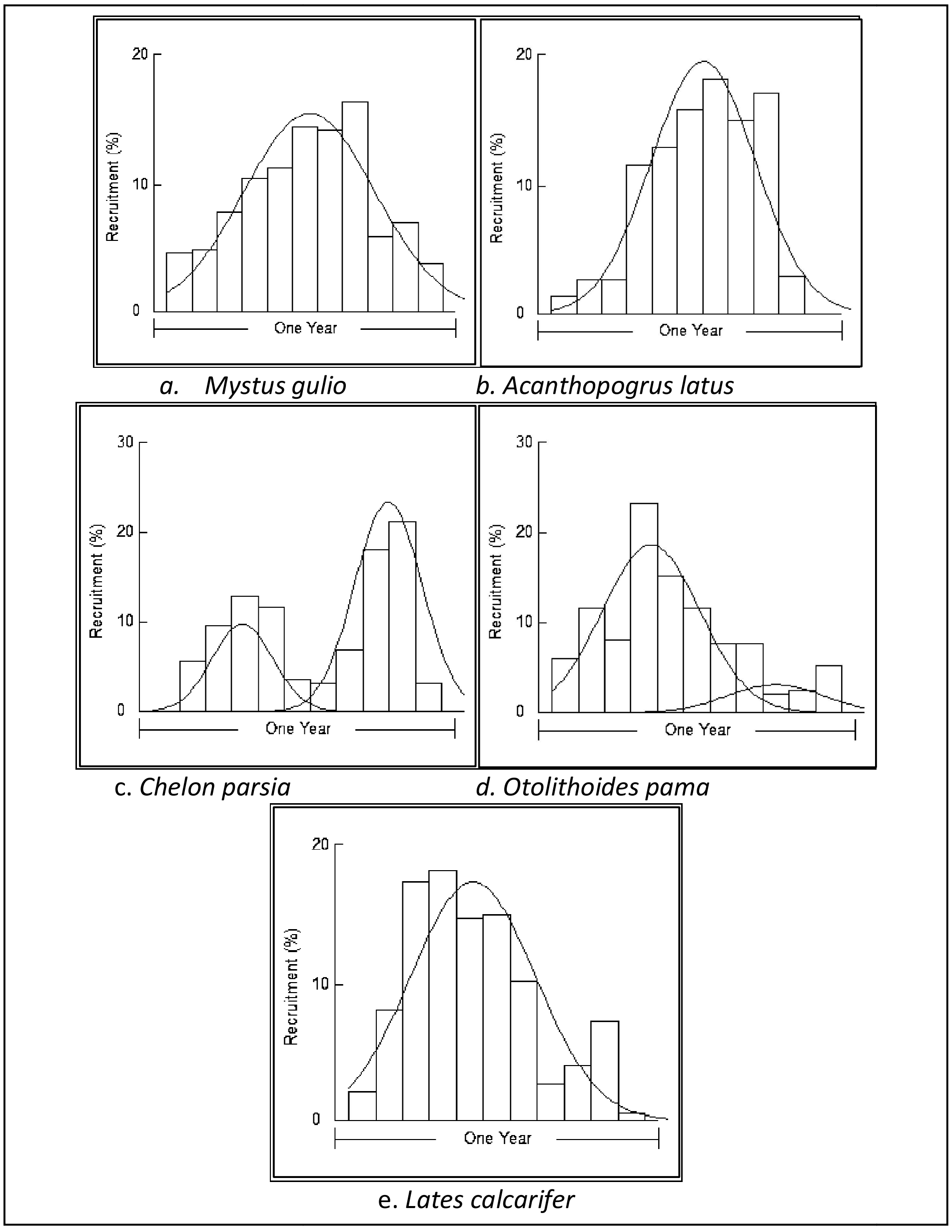

Fig. 5. Recruitment pattern of a) *Mystus gulio,* b) *Acanthopagrus latus,* c) *Chelon parsia,* d) *Otolithoides pama* and e) *Lates calcarifer* in the Sundarban ecosystem

Table 1. Growth parameters (L∝, K and Phi (ϕ')), natural mortality (M), fishing mortality (F), total mortality (Z), Length at first capture (Lc), exploitation rate (E), Maximum exploitation rate (E_{max}) and age estimated for five key species in the Sundarbans ecosystem

Family	Scientific name	Common name	Bengali name	L∝ (cm)	K	Phi (ϕ')	M	F	Z	Lc	E	E_{max}	Age
Bagridae	*Mystus gulio*	Long whiskers catfish	Tengra	23.0	0.75	2.599	1.591	1.42	3.01	8.53	0.47	0.62	4.0
Sparidae	*Acanthopagrus latus*	Yellow fin seabream	Datney	33.6	0.85	2.982	1.553	0.95	2.50	9.50	0.38	0.51	3.5
Mugilidae	*Chelon parsia*	Gold-spot mullet	Parshe bata	30.0	1.1	2.996	1.89	1.58	3.48	7.71	0.45	0.48	2.73
Sciaenidae	*Otolithoides pama*	Pama croaker	Poa	32.5	0.8	2.927	1.507	0.55	2.06	13.1	0.27	0.63	3.75
Latidae	*Lates calcarifer*	Barramundi	Vetki	55.0	0.50	3.18	0.956	0.56	1.52	18.2	0.37	0.55	6.0

ecosystem managed by the department of forest and co-management committees. In Bangladesh population dynamics study for *Mystus gulio, Acanthopagrus latua, Chelon parsia* and *Otolithoides pama* are primary attempt in the Sundarbans ecosystem. The exploitation rate (E) estimates are consistent with those reported by Chantarasri [26] and Smith [27] for *Lates calcarifer, Pomadasys hasta, Johnius argentus, Pangasius pangasius* and *Plotosus canius* in the Sundarban ecosystem. The growth rate (K) estimates are consistent with those reported by Zafar et al. [28] for *Johnius argentatus*; [12] for *Ilisha filigera*; [29] for *Lepturacanthus savala*; [30] for *Saurida tumbil*; [10] for *Pomadasys hasta*; [11] for *Harpodon nehereus*; [31] for *Rastreliger kanagurta;* [32] *Megalaspis cordyla* in the coastal waters of Bangladesh. The value of the asymptotic length of *Acanthopagrus latus* and *Lates calcarifer* calculated in the present study are considerably lower than the maximum length recorded in other regions. Growth rates of K (growth co-efficient) and $L\infty$ (asymptotic length) of the *Acanthopagrus latus* found 0.23 yr^{-1} and 50.4 cm respectively in the Persian Gulf, south part of Iran [33]. Besides, growth rates of K (growth co-efficient) and $L\infty$ (asymptotic length) of the *Lates calcarifer* in western Papua were found 0.128 and 138 cm [34]. The Sundarbans ecosystem is the nursery ground and the maximum length of *Acanthopagrus latus* and *Lates calcarifer* were found to be 32 and 49 cm respectively, which indicates higher growth co-efficient and lower asymptotic length. Growth rates of K (growth co-efficient), $L\infty$ (asymptotic length) and the maximum age (t_{max}) of the *Chelon parsia* found 0.98yr^{-1}, 32.1 cm and 3+ years respectively in Chilika Lake, Odisha state, India [35]. Growth rates of K (growth co-efficient), $L\infty$ (asymptotic length) and the maximum age (t_{max}) of the *Otolithoides pama* were found 0.98 yr^{-1}, 40.9 cm and 3.06 years respectively in Thanlwin River mouth, Mon State, Myanmar [36]. The exploitation rates obtained for these five species are relatively lower comparing to other available studies in the coastal waters of Bangladesh. A previous study conducted by Chantarasri [26] for *Lates calcarifer* showed the exploitation rate was 0.35 in the Sundarban ecosystem. A study conducted by Panahibazaz et al. [37] for *Acanthopagrus latus* in the coastal waters of Hormozgan Province, Iran and growth parameters was found to be $L\infty$ = 43.5 cm, K=0.29 $year^{-1}$ while the exploitation rate was 0.41 and similarly with the present study. Concurrently a study conducted by Mojgan et al. [38] for *Otolithes ruber* commonly called croakers in the Khoozestan Province of South Iran, and growth parameters were found to be $L\infty$=64.58 cm, K=0.4 $year^{-1}$ while the exploitation rate was 0.64.

The present study indicated that it was not easy to compare the multi-species multi-gear fisheries with fish population dynamics method so, the best option would be to convince all stakeholders to expand the mesh size of the gear. Consistently the present study reveals that the population of these five studied species attains adequate sustainability levels in the Sundarbans ecosystem. The exploitation rate for these five species was found at optimum level and suggests that the populations are not over exploited in the Sundarbans eco-system. However, the decision making on Sundarbans fisheries management cannot practice only biologically information; thus, socio-economic condition of poor people should be considered to remain sustainable management.

5. CONSLUSION

The study indicated that the length-at-first-capture/$L\infty$ seem to be a simple parameter, which could be used to make a rapid assessment of the status of the stocks. All together, the present study reveals that the population of these five studied species attains acceptable sustainability levels in the Sundarbans ecosystem and scope for a slight increase in appears warranted to confirm the exploitation rate of the most commercial species in the Sundarbans.

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COMPETING INTERESTS

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge.

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