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Research Article

Population biology and exploitation status of four commercially important marine fishes of the northern Bay of Bengal, India

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Abstract

In the present paper population structure of four commercially important fishes were studied, namely *Tenualosa ilisha*, *Pampus argenteus*, *Scomberomorus guttatus* and *Osteogeneiosus militaris*, in the Sundarban Estuary of the northern Bay of Bengal from June 2011 to March 2012. However, a thorough understanding of life history based on length and weight data of these four fishes (617 *T. ilisha*, 485 *P. argenteus*, 351 *S. guttatus* and 416 *O. militaris*) would be immensely important. Results of such studies would be important for sustainable management of these highly economic biological resources. The analysis of life history parameters of these four species, such as growth, exploitation, mortality, etc. showed that their stocks in coastal waters off West Bengal were overexploited during the study period as exploitation rate of *T. ilisha, P. argenteus, S. guttatus* and *O. militaris* were 0.78, 0.62, 0.75 and 0.54 respectively. Widespread fishing of juvenile and growing fish declined the population considerably losing the economic advantage. Good governance, strong law enforcement and effective management system should be sure for actual benefit from the fish resources and improving livelihoods of dependent communities.

Keywords: Exploitation rate, Mortalities, Length–weight relationship, Condition factor, Sundarban Estuary, Bay of Bengal

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Introduction

Hilsa shad, *Tenualosa ilisha* (Hamilton, 1822), Silver pomfret, *Pampus argenteus* (Euphrasen, 1788), Indo-Pacific king mackerel, *Scomberomorus guttatus* (Bloch and Schneider, 1801) and Soilder catfish, *Osteogeneiosus militaris* (Linnaeus, 1758) are most commercially important fishes of the Bay of Bengal coast (Islam 2003, Quader, 2010; Dutta *et al*., 2012a). *T. ilisha* and *P. argenteus* are very popular in Bengali cuisine and both fishes have very high market price. *S. guttatus* is landed in fewer amounts in West Bengal coast, but is valued for its taste and thereby, has high export demand. The West Bengal coast contain the world largest mangrove ecosystem, i.e. the Sundarban estuarine ecosystem of the northern Bay of Bengal (BoB) which is a highly productive marine ecological system (Mukhopadhyay *et al*., 2006; Heileman *et al*., 2009) containing a wide range of highly valuable, species-rich and diverse ecological structures. The Bay of Bengal is one of unique and at-risk marine ecological systems (Dwivedi 1993; De *et al*., 2011) in the world, when evaluated based on the confluence of these features. The northern part of the Bay of Bengal includes the Ganges-Brahmaputra-Meghna delta, one of the largest deltas in the world (Islam and Gnauck 2008).

Population dynamics of economically important fish species are dependent on their distribution, habitat quality, life history characteristics, market demand and the amount of harvest. King and McFarlane (2003) point out the effects of indiscriminate capture fishery and environmental forcing on the population attributes of marine fish species. The study of life history of marine fish species is a fundamental tool for their conservation and management (Foster and Vincent, 2004). Life history theory offered a promising framework for building bridges between demography and fundamental aspects of species biology (Goodwin *et al*., 2006). Begg *et al*. (1999) described the importance of life history attributes for stock assessment. The urgency to collect such biological data for management planning has contributed greatly towards our current understanding of the biology of many exploited species and formulation of current management strategies for sustainable fisheries and ecosystems (Marriott *et al*., 2007). While studying the natural population it is important to know the size frequency distribution of any fish to understand the status of the fish population structure (Nurul Amin *et al*., 2005). Besides length and weight, data provide quantitative cornerstones in the foundation of fisheries research and management (Anderson and Neumann, 1996). Length-weight relationship (LWR) is an important parameter to understand growth dynamics of the fish population; hence, it is important for its management. Mortality is also a key characteristic to study fish population dynamics. In the present scenario anthropogenic activities threaten marine ecosystems (Schipper *et al*., 2008), that increases fishing mortality trends. Further, Claiborne *et al*. (2014) reported that anthropogenic and natural inherent causes are often leave similar impacts on marine fish populations. Therefore, collecting comprehensive data on population attributes of natural marine fish population is a hard task. The underlying causes of mortality are difficult to ascertain during critical life stages of fish. Successful management of a fishery is often defined in terms of biological, socio-economic and political objectives (Beddington *et al*., 2007).

The main objective of this paper is to study the population biology of four species aiming at their sustainable exploitation and long-term conservation efforts. Large schools of *T. ilisha* are reported throughout its geographical range, by fishermen at various times of the year in coastal waters, however, the origin and movement of these fish have never been investigated (Rahman and Naevdal, 2000). Literature survey showed that several authors (Gulati *et al*., 1996; Raje, 2006; Rashid *et al*., 2010; Narges *et al*., 2011; Dutta *et al*., 2012b; Panhwar and Liu, 2013) published their findings on population dynamics of these four species from different marine situations, however, a few studies are conducted in the Sundarban Estuary of the Bay of Bengal (BoB) (De and Dutta, 1990; Bhaumik and Sharma, 2012; Nurul Amin *et al*., 2004, 2005). No detailed information on population attributes of these four fish species are on record at the northern Bay of Bengal. Therefore, an in-depth study on the population biology of these four fish species is initiated in view of the sustainable management. In this paper, we focus on the LWR and condition factor, length frequency distribution, weight frequency distribution, allometry coefficient, exploitation rate and recruitment pattern. Ecological factors, like feeding habits, trophic level and habitat are analyzed from secondary sources. Management recommendations are provided with the help of obtained results for the most uncertain climatic zone of the northern BoB (Sundarban Estuary).

Materials and methods

Study area

The present study was conducted at Fraserganj Fishing Harbour (21°34'45.91"N; 88°15'5.38"E) of the northern Bay of Bengal at West Bengal coast (Fig. 1). The coastline of the West Bengal is stretched over a total of 168 km and the continental shelf comprises of an area of 17,049 km^2. It is connected with world's second largest hydrological basin that is Ganga-Brahmaputra-Meghna (GBM) river basin (Heileman *et al*., 2009). Huge sediment load from GBM system has given rise to the world's largest mangrove ecosystem, i.e. Sundarbans, shared by India and Bangladesh (Das and Ray, 2008). This portion of the BoB is extremely dynamic in nature, in both geomorphologic and biologic terms (Gomes *et al*., 2000). This region is rich in biological diversity and productivity owing to regular flushing of nutrient-rich silts and regular supplies of organic matter from mangrove litter falls (Mandal *et al*., 2012). Mangrove estuarine ecosystems are unique at the interface between land and sea in tropical and subtropical regions (Barbier *et al*., 2011). Due to the high input of nutrient and detritus in the system from its unique mangrove ecosystem, it produces large quantities of fish (Islam, 2003; Mandal *et al*., 2013). We selected the Sundarban estuarine area of the northern BoB, a part of the Bay of Bengal Large Marine Ecosystem and a nursery ground for various fish species, for the present investigation.

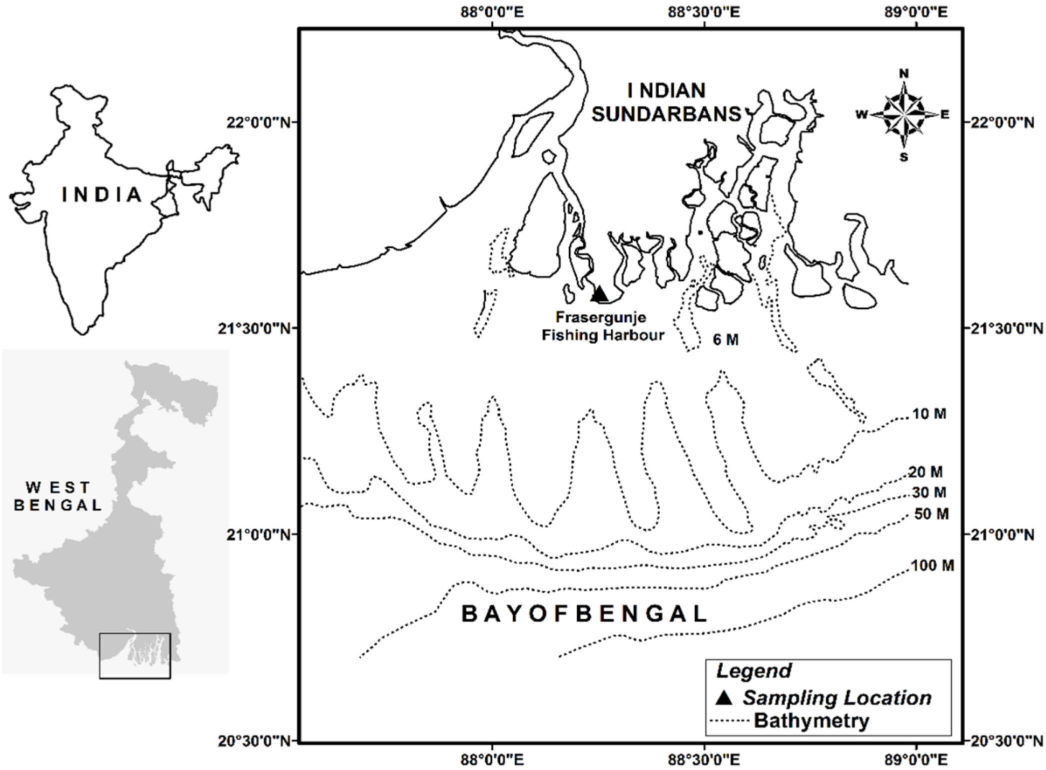

Figure 1: Figure shows the sampling location, Fraserganj Fishing Harbour of the northern Bay of Bengal of West Bengal coast.

Estimations of population parameters

A total of 617 *T. ilisha*, 485 *P. argenteus*, 351 *S. guttatus* and 416 *O. militaris* were measured during the period from June 2011 to March 2012. Sampling was not conducted between April and May, because these two months are fishing ban period. No fish samples were sexed. The fishes were caught using gill net (60-110 millimeter (mm) mesh size, 1000-2000 meter (m) net length and 12-15 m height), mostly preferred by the fishermen of the area that proved to yield sustained good catch. Pre-monsoon (February through May), monsoon (June through September) and post-monsoon (October through January) seasons were considered for field data collection in the present study. For length-weight relationship the total length (TL) was measured in millimeter from the upper jaw to the tip of the tail by laying the fish normally without stretching (Volvich and Appelbaum, 2001; Froese, 2006) using a steel metric scale and the weight was estimated using a digital weighing machine (Wensar TTB-3; max capacity 3 Kg; sensitivity 0.1 gm). Length-weight relationship was calculated following the equation proposed by Le Cren (1951),

$$W = aL^b$$

Where W is body weight of the fish in g, L is total length of the fish in mm, b is the exponent describing the rate of variation in weight with respect to length and a denotes the coefficient of length-weight relationship. The equation $W=aL^b$

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can be linearly represented as *LogW= Loga+bLogL*. The values of '*b*' and '*Log a*' in the equation were estimated using least square regression method. In order to verify whether *b* values acquired in the linear regressions were significantly different the isometric value of ±95% (α = 0.05) was applied, expressed by the equation according to Sokal and Rohlf (1987) as $t_s = (b-3) / s_b$, where t_s is the t-test value, *b* the slope and s_b the standard error of the slope (*b*). Comparison between the obtained values of t-test and the respective tabled critical values allowed for the determination of the *b* values showed their statistically significance and their inclusion in the isometric range (*b*=3) or allometric range (negative allometric; *b*<3 or positive allometric; *b*>3).

Fulton's condition factor (*C*) (Fulton, 1904) was calculated using the following formula:

$C=(W/L^3) *100$

Where W = weight of the fish in g; L = total length of the fish in mm.

We estimated length and weight variations in different age classes from von Bertalanffy growth equation.

Ford (1933) equation modified by Walford (1946) was used to estimate von Bertalanffy growth parameters considering asymptotic length ($L\infty$) and von Bertalanffy Growth Function (VBGF) growth constant (*K*),

$$L_{t+1} = L\infty(1-e^{-K}) + e^{-K} L_t$$

Where L_t and L_{t+1} were total length at age *t* and *t+1* respectively. By plotting L_t against L_{t+1}, the resulting slope, $b = e^{-K}$ and the intercept $a = L\infty(1-e^{-K})$.

Total mortality (Z) could be estimated using parameters of the VBGF as follows:

$$Z = K * \frac{L\infty - \bar{L}}{\bar{L} - L'}$$

Where K was VBGF growth constant, L_∞ was asymptotic length, $\bar{L}$ was mean length of the fish population and L' represented mean length of fish when entering into the fishery.

Natural mortality (*M*) was calculated using Pauly's *M*-empirical equation (Pauly 1980):

$$Log_{10}M = -0.0066 - 0.279Log_{10}L\infty + 0.6543Log_{10}K + 0.4634Log_{10}T$$

Considering standard deviation of log of natural mortality (SD Log_{10} *M*) = *0.245*, and mean annual variations in habitat temperature (*T*) as *27.8°C*.

Fishing mortality rate (F) was calculated as $F = Z - M$. Rate of exploitation (E) was calculated using the quotient between fishing and total mortality: $E = F / Z$ (Pauly, 1984).

The recruitment pattern was figured out by backward projection of length-frequency data, using the von Bertalanffy growth equation and estimated growth parameters (L_∞ and K, Pauly, 1982).

Relative yield-per-recruit and biomass-per-recruit were projected based on Beverton and Holt (1966) model. Relative yield-per-recruit (Y'/R) was computed from:

$$Y' / R = EU^{M/K}\left\{1 - 3U/(1+m) + 3U^2/(1+2m) - U^3/(1+3m)\right\}$$

Where $U = 1 - (L_c / L_\infty)$ and L_c is mean length of fish at first capture. In standard case L_c is taken as L_{50}, $m = (1-E)/(M/K) = (K/Z)$ and $E = F/Z$

Relative biomass-per-recruit (B'/R) was estimated from the following equation:

$B'/R = (Y'/R)/F$

Sea surface temperature (SST) was measured in $^\circ C$ unit using handheld digital thermometer Erma H-9269 and sea surface salinity was measured in ppt unit using Erma Hand Refractometer. Both the physico-chemical parameters were collected onboard at each sampling time. All data analysis and figures were prepared in Microsoft Office Excel version 2010 and RStudio (software version 1.3.959).

Results

Descriptive statistics and assessed parameters of length–weight relationship ($W=aL^b$) for combined sex of four commercially important fishes in the Bay of Bengal, India is exhibited in Table 1. Monthly length-weight variations and allometry coefficient of the four species is shown in Figure 2. Length (Shapiro-Wilk normality test W=0.96, p-value<0.001) of *T. ilisha* was higher during monsoon season (June-September, Fig. 2a). Weight (W=0.87, p-value<0.001) of *P. argenteus* was low in post monsoon season (October-January) and the allometry coefficient was high in the month of January (Fig. 2b). Length (W=0.94, p-value<0.001) of *S. guttatus* was higher than weight (W=0.90, p-value<0.001) in post-monsoon season (Fig. 2c).

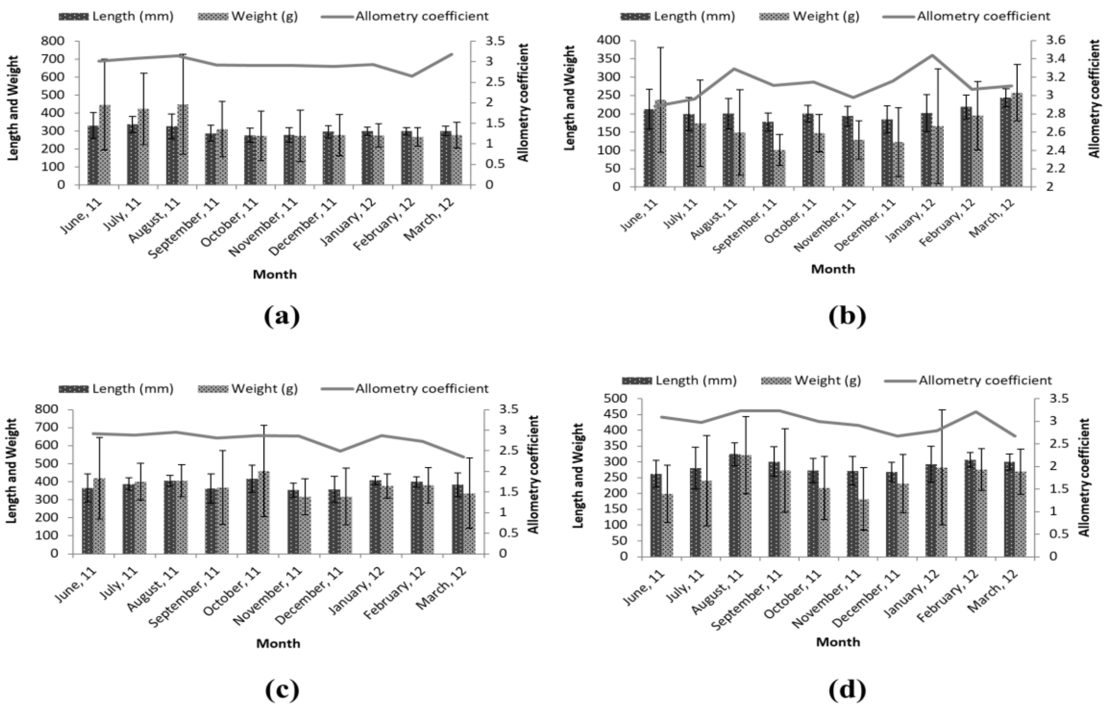

Figure 2: Month wise length and weight and allometry coefficient variation of *Tenualosa ilisha* (a), *Pampus argenteus* (b), *Scomberomorus guttatus* (c), *Osteogeneiosus militaris* (d).

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The overall length-weight relationship (LWR) of four species is depicted in Figure 3. It is to be noted that b value of *P. argenteus* was 3.12 (t=4.60, p-value<0.001) indicating a positive allometry, whereas, b value of *O. militaris* was 2.83 (t=-3.73, p-value<0.001), b value of *T. ilisha* was 2.86 (t=-4.07, p-value<0.001) and b value of *S. guttatus* was 2.53 (t=-10.55, p-value<0.001) representing a negative allometry (Fig. 3, Table 1). The most abundant length class was 308-357mm in *T. ilisha* population. In *P. argenteus* the most dominated length class was 80-130mm. While 430-478mm length class was dominated by individuals of *S. guttatus* (Fig. 4a). The dominated length class was 250-274mm for *O. militaris* population (Fig. 4d). A more or less similar pattern in the differences in length and weight at different age classes of *T. ilisha*, *P. argenteus* and *O. militaris* were apparent (Fig. 5a, b, d). However, it was interesting to note that there were no such variations between length and weight in different age classes of *S. guttatus* population (Fig. 5c).

Two main physico-chemical factors, namely SST and salinity, fluctuated during the study period (Figure 6a-d). SST was observed to be fairly low during post-monsoon season and the lowest was recorded in January (23.27±1.87^{o}C). The highest value for SST was noted in August (30.72±0.56^{o}C).

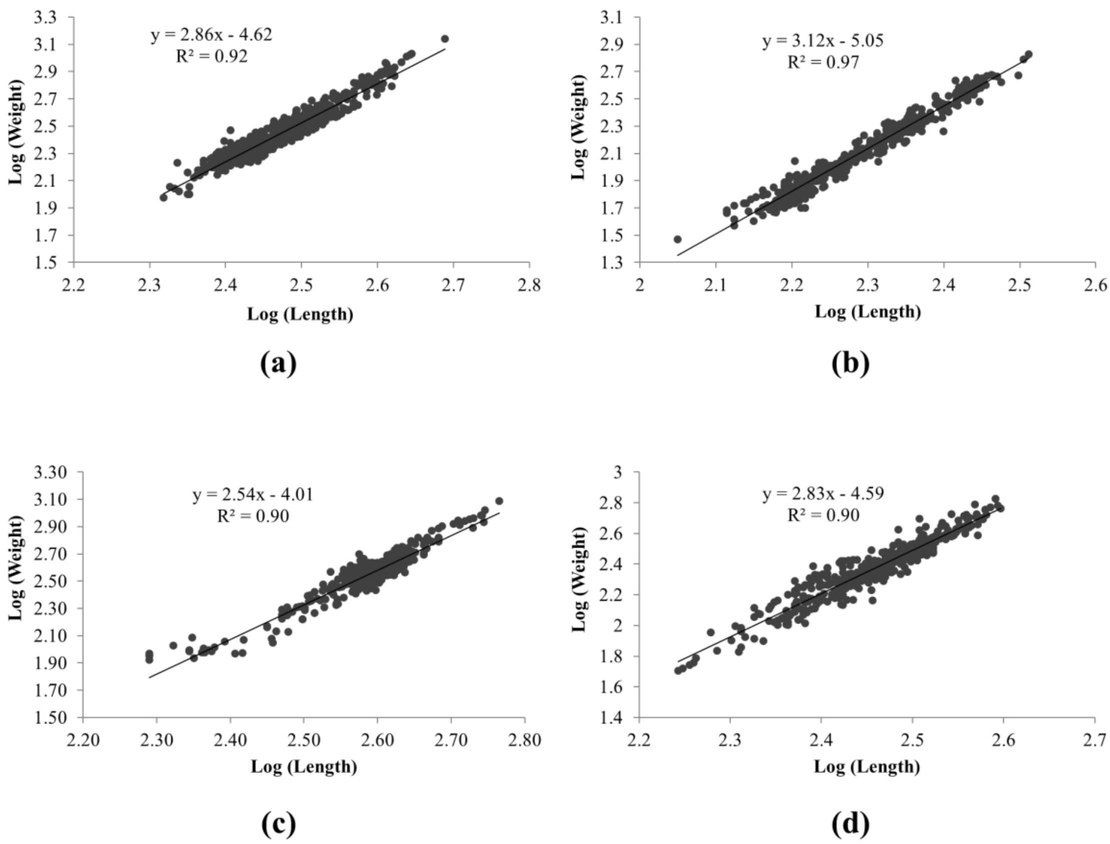

Figure 3: The figure exhibits length-weight relationship of *Tenualosa ilisha* (a), *Pampus argenteus* (b), *Scomberomorus guttatus* (c), *Osteogeneiosus militaris* (d).

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Table 1: Descriptive statistics and assessed parameters of length–weight relationship ($W=aL^b$) for combined sex of four commercially important fishes in the Bay of Bengal, India. *n*=sample size, SD=standard deviation, Min=minimum, Max=Maximum, *a*=intercept, *b*=slope, *CL*=confidence limits, r^2=coefficient of determination, t_s=t-test value, growth type: +A=positive allometric, -A=negative allometric, parentheses indicate the range of a mean value.

Species	*n*	Length (mm)			Weight (g)			Regression parameter		95% *CL* of b	r^2	t_s	Growth
		Min	Max	Mean±SD	Min	Max	Mean±SD	*a*	*b*				
Tenualosa ilisha	617	208	488	300.85± 43.96	94.1	1382.3	312.32± 160.76	0.0098	2.86	2.79 – 2.93	0.92	-4.07	-A
Pampus argenteus	485	112	325	202.81± 40.92	29.46	668.9	164.93± 108.93	0.0064	3.12	3.07 - 3.18	0.97	4.60	+A
Scomberomorus guttatus	351	195	583	385.51± 60.55	84.1	1223.4	372.67± 162.32	0.0181	2.54	2.45 – 2.62	0.90	-10.55	-A
Osteogeneiosus militaris	416	175	395	287.56± 42.42	50.90	671.4	251.81± 108.43	0.0102	2.83	2.74 – 2.92	0.90	-3.73	-A

Salinity, on the contrary, was fairly high during post-monsoon through pre-monsoon and the highest salinity was noted in March (30.80±0-1.67ppt). The lowest mean salinity was recorded in September (13.68±2.74ppt). Annual mean SST and salinity were noted as 27.5±2.55°C and 22.67±6.36ppt respectively. The condition factor of *T. ilisha* increased with decrease in salinity and increase in temperature during monsoon (Fig. 6a), while a different pattern in fluctuations of condition factors for other three fish species in relation to salinity and SST were noted (Fig. 6b-d). Comparatively lower condition factors for these three species were noted during both monsoon and pre-monsoon seasons, while an overall rise was apparent during post-monsoon.

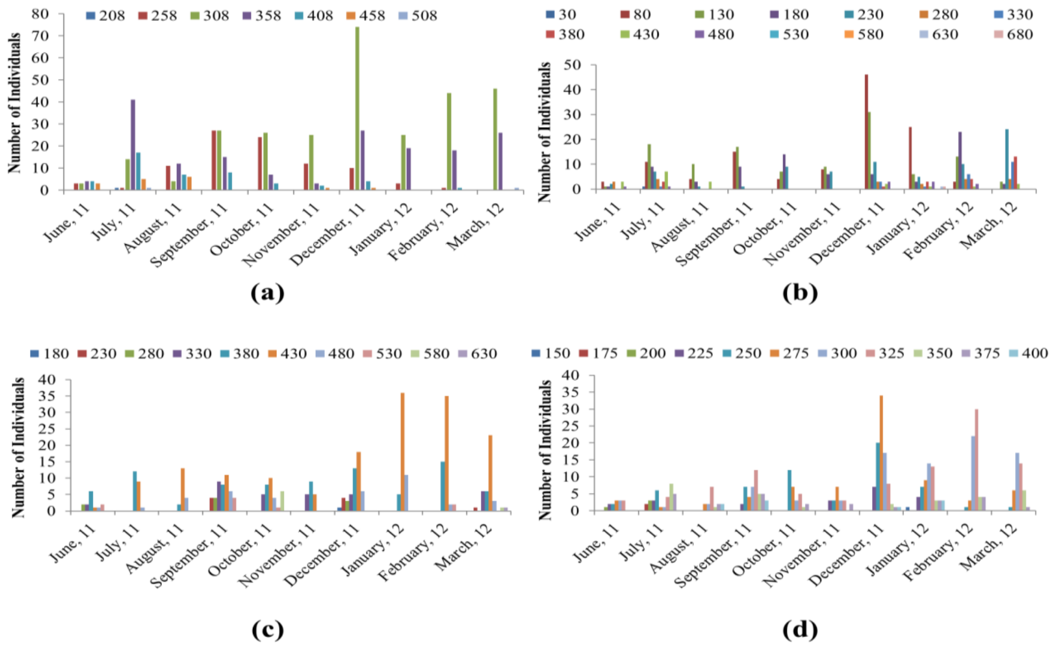

Figure 4: Months wise length-frequency distribution (length in mm in legend) of four studied species, *Tenualosa ilisha* (a), *Pampus argenteus* (b), *Scomberomorus guttatus* (c), *Osteogeneiosus militaris* (d).

Total mortality (*Z*) of *T. ilisha*, *P. argenteus*, *S. guttatus* and *O. militaris* in West Bengal coast were calculated as 3.15, 1.93, 3.39 and 1.40 respectively (Table 2). The natural mortality (*F*) in *T. ilisha*, *P. argenteus*, *S. guttatus* and *O. militaris* were estimated as 0.71, 0.74, 0.85 and 0.65 respectively. Moreover, fishing mortality (*F*) in *T. ilisha*, *P. argenteus*, *S. guttatus* and *O. militaris* were calculated as 2.44, 1.19, 2.54 and 0.75 respectively. Fishing mortality was higher than natural mortality among all four species (Fig. 7). Fishing mortality was observed to reduce survival to between 10 and 75%. Fishing induced highest reduction in survival age was noted for *T. ilisha* and *S. Guttatus* where natural survival age of 5 years reduced to 1.5-2.0 years (Fig. 7a, c).

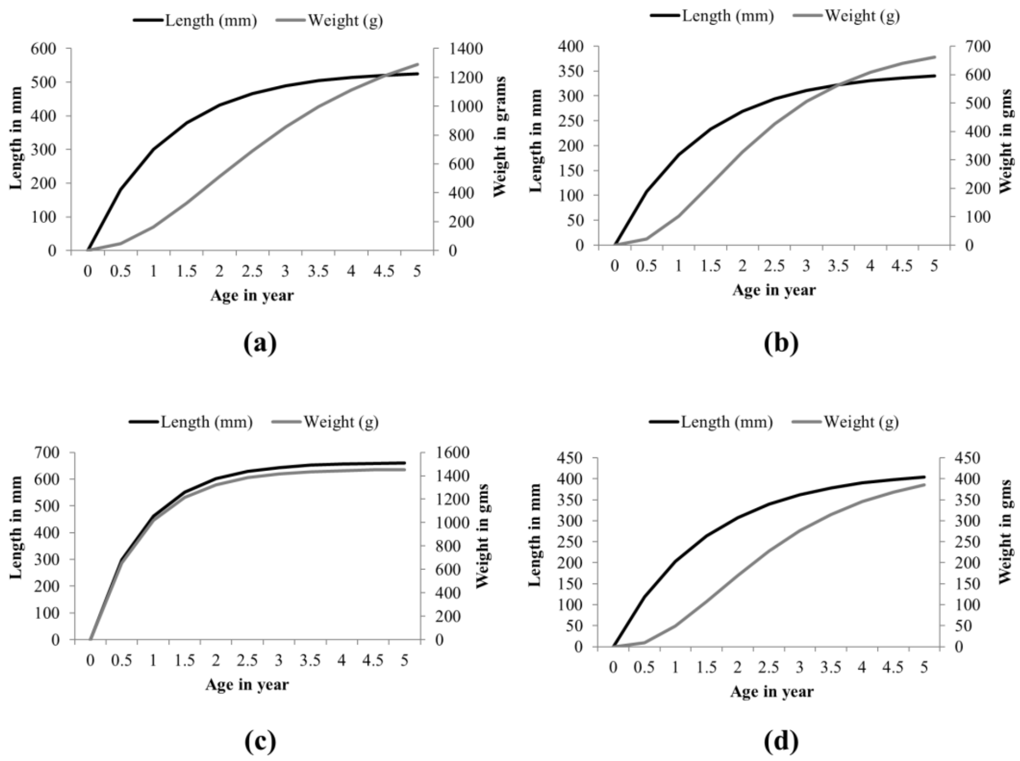

Figure 5: Age based total length and body weight of *Tenualosa ilisha* (a), *Pampus argenteus* (b), *Scomberomorus guttatus* (c), *Osteogeneiosus militaris* (d).

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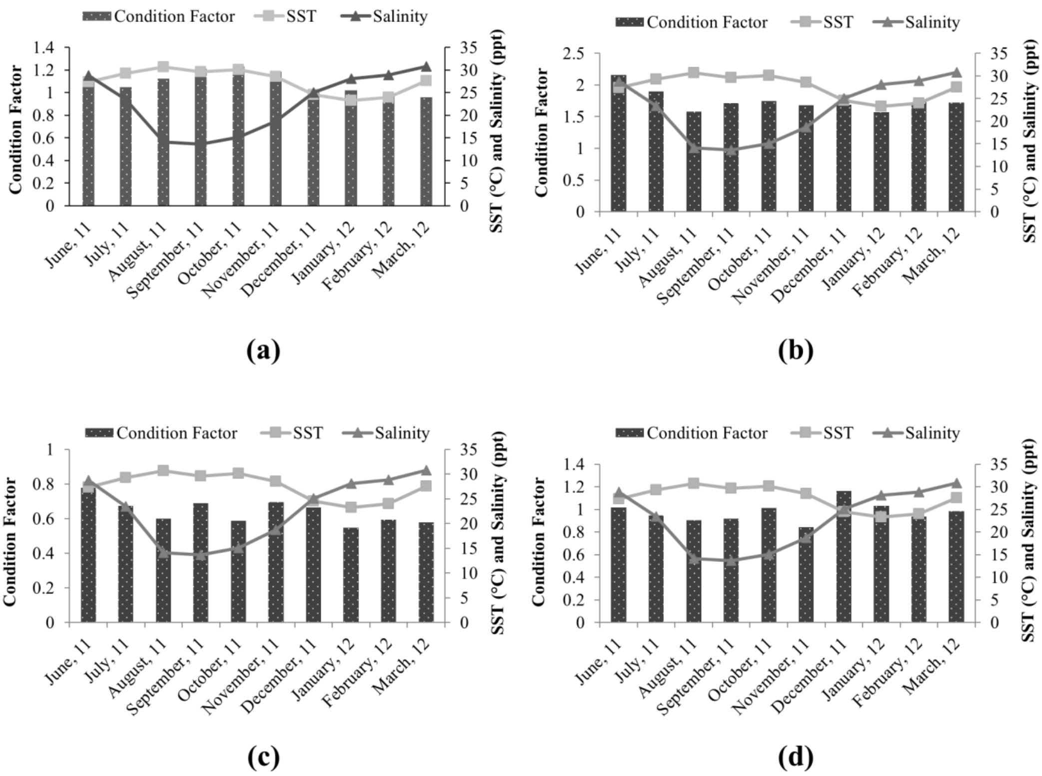

Figure 6: Month wise condition factor of the four studied species, *Tenualosa ilisha* (a), *Pampus argenteus* (b), *Scomberomorus guttatus* (c), *Osteogeneiosus militaris* (d). SST and salinity are plotted in the secondary axis.

Table 2: Population growth function and different mortality rate with rate of exploitation of four species. *L*∞=asymptotic length, *K*=growth constant, *Z*=total mortality, *F*=fishing mortality, *M*=natural mortality, *E*=exploitation rate.

Species	*L*∞ (mm)	*K* (year^{-1})	*Z* (year^{-1})	*F* (year^{-1})	*M* (year^{-1})	*E*
Tenualosa ilisha	533.4	0.83	3.15	2.44	0.71	0.78
Pampus argenteus	348.6	0.74	1.93	1.19	0.74	0.62
Scomberomorus guttatus	661.5	1.20	3.39	2.54	0.85	0.75
Osteogeneiosus militaris	420.0	0.66	1.40	0.75	0.65	0.54

For *P. argenteus* such reduction was moderate (nearly 40%; Fig. 7b), while for *O. militaris* survival was minimally influenced by fishing mortality (less than 10%; Fig. 7d). The probability of survival decreased due to high fishing pressure for all four species (Fig. 7). Total mortality (*Z*) of *T. ilisha*, *P. argenteus*, *S. guttatus* and *O. militaris* in the present study were calculated as 3.15, 1.93, 3.39 and 1.40 respectively (Table 2). The natural mortality (*F*) in *T. ilisha*, *P. argenteus*, *S. guttatus* and *O. militaris* were estimated as 0.71, 0.74, 0.85 and 0.65 respectively. In addition, fishing mortality (*F*) in *T. ilisha*, *P. argenteus*, *S. guttatus* and *O. militaris* were calculated as 2.44, 1.19, 2.54 and 0.75 respectively. Fishing mortality was higher than natural mortality among all four species (Fig. 7). Fishing mortality was

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observed to reduce survival to between 10 and 75%. Fishing induced highest reduction in survival age was noted for *T. ilisha* and *S. guttatus* where natural survival age of 5 years reduced to 1.5-2.0 years (Fig. 7a, c). For *P. argenteus* such reduction was moderate (nearly 40%; Fig. 7b), while for *O. militaris* survival was minimally influenced by fishing mortality (less than 10%; Fig. 7d). The probability of survival decreased due to high fishing pressure for all four species (Fig. 7).

Recruitment peaks of these fish species are shown in Fig. 8a-d. A general pattern of single recruitment peak was shown by *T. ilisha*, *S. guttatus* and *O. militaris* and the peaks for these three species were noted in July, August and May respectively (Fig.8a, c, d). However, *P. argenteus* showed two peaks of recruitment, one in March and the other in August (Fig. 8b).

The highest probability of capture of mid-length group is shown in Fig. 9. In *T. ilisha* population, 308mm length class showed the highest probability of catch, whereas 358mm length class had the highest fishing mortality (Fig. 9a). The 172mm size group showed the highest catch in *P. argenteus* population. Both the highest catch and highest fishing mortality were reported in 430mm size group of *S. guttatus,* whereas in *O. militaris* populations the highest catch and highest fishing mortality both were reported in 325mm size group.

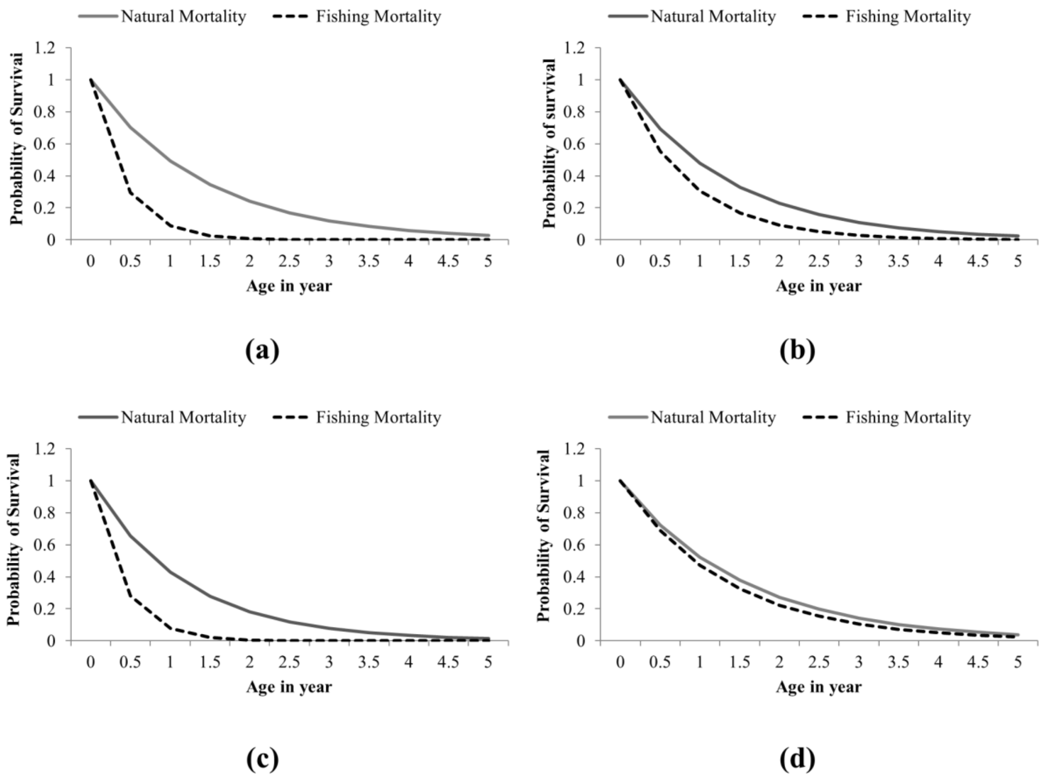

Figure 7: Probability of survival in different mortality condition at different age of *Tenualosa ilisha* (a), *Pampus argenteus* (b), *Scomberomorus guttatus* (c), *Osteogeneiosus militaris* (d).

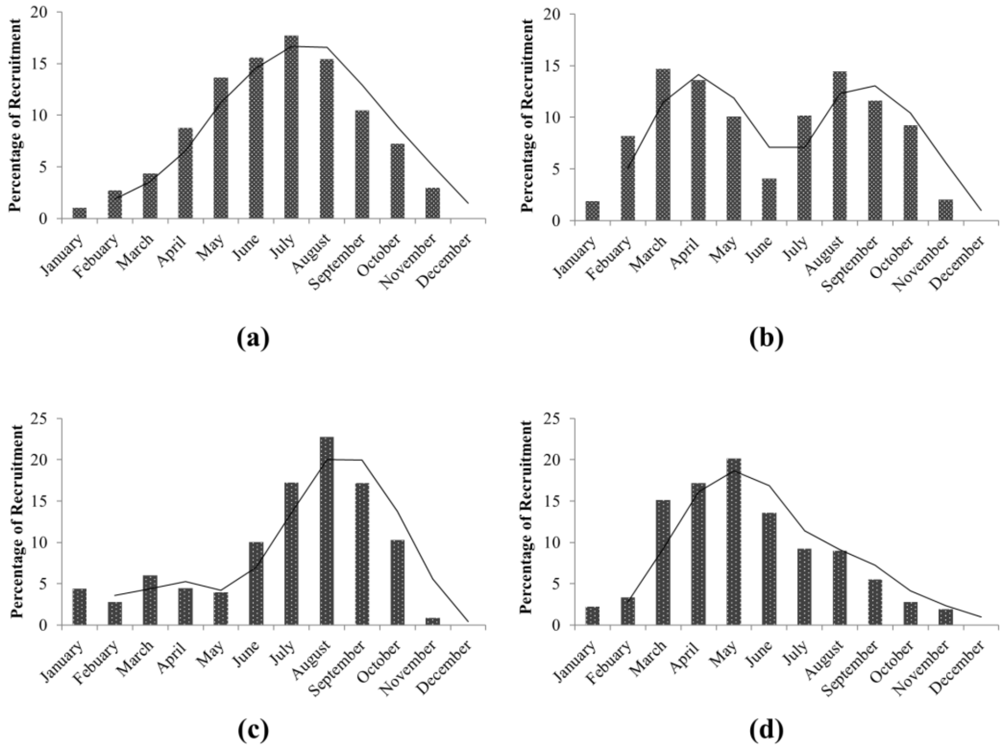

Figure 8: Recruitment structure of *Tenualosa ilisha* (a), *Pampus argenteus* (b), *Scomberomorus guttatus* (c), *Osteogeneiosus militaris* (d).

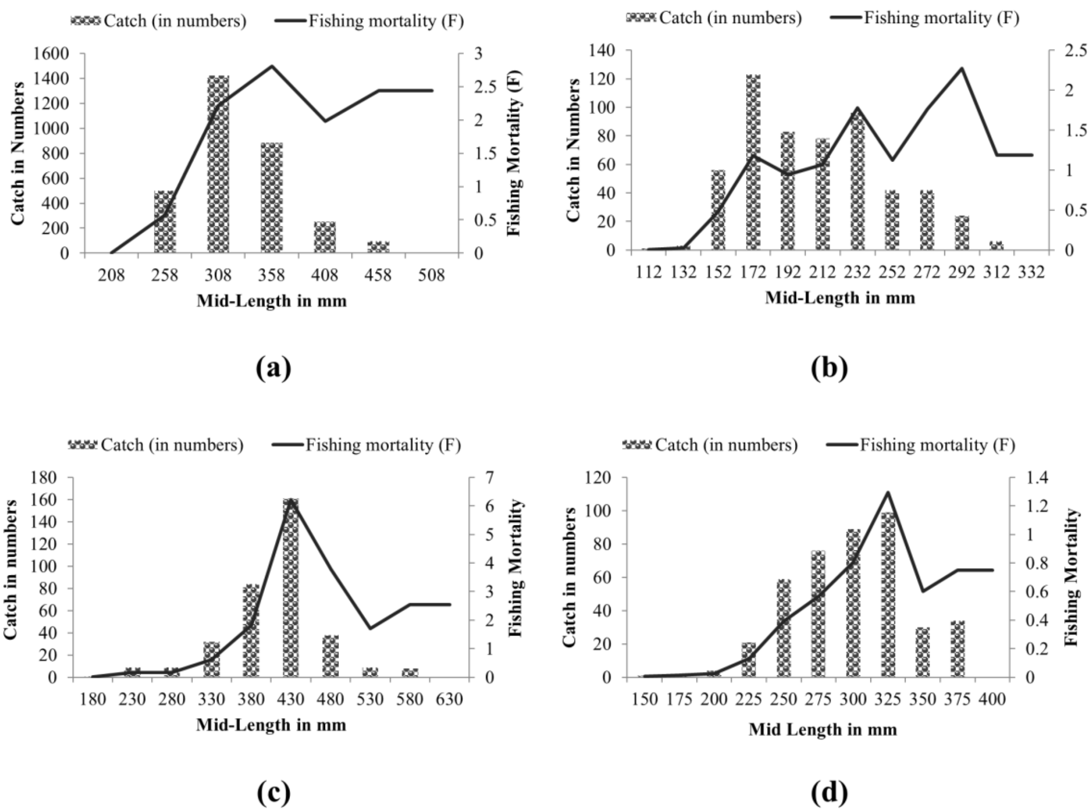

Figure 9: Length based Population Viability Analysis of four commercially important species of the northern BoB, *Tenualosa ilisha* (a), *Pampus argenteus* (b), *Scomberomorus guttatus* (c), *Osteogeneiosus militaris* (d).

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Relative yield per recruit (*Y/R*) and relative biomass per recruit (*B/R*) of four species are plotted with respect to exploitation rate (*E*) in Figure 10. In *T. ilisha* and *S. guttatus* exploitation rates were similar (0.78 and 0.75 respectively) and their *Y/R* were also similar, i.e., 0.095 and 0.119, while *B/R* were 0.038 and 0.048 respectively at the stated exploitation rates (Fig. 10a, c). In case of *P. argenteus* and *O. militaris* exploitation rates were 0.62 and 0.54 respectively and *Y/R* ratios were also similar i.e., 0.082 and 0.072 and *B/R* were calculated as 0.068 and 0.132 respectively (Fig. 10b, d). It was noticeable in Figure 10 that relative yield increased with increasing rate of exploitation up to a certain limit indicating the level of maximum sustainable yield (MSY).

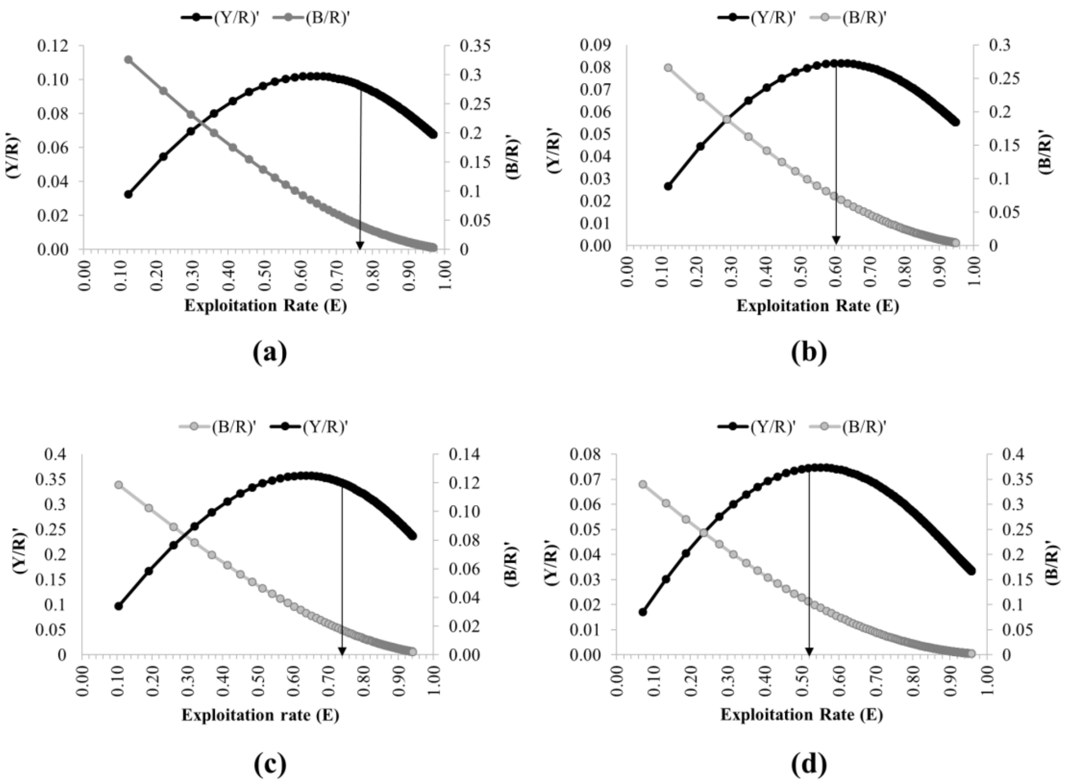

Figure 10: Relative yield per recruit and biomass per recruit plotted against exploitation rate of *Tenualosa ilisha* (a), *Pampus argenteus* (b), *Scomberomorus guttatus* (c), *Osteogeneiosus militaris* (d). Arrow indicates current exploitation rate.

Discussion

In the present study, allometry growth of *T. ilisha* was negative as '*b*' value was 2.86. Roomian and Jamili (2011) also pointed out negative allometry growth (*b*=2.97) for *T. ilisha* population in Iran. However, there was a positive allometry growth (*b*=3.381) in *T. ilisha* population in Bangladesh waters (Nurul Amin *et al*., 2005). Similarly, Dutta *et al*. (2012a) showed positive allometric growth in *T. ilisha* in West Bengal coast. The length weight relationship of *P. argenteus* in the present study was W=0.0064$L^{3.12}$, that indicates the positive allometric growth in *P. argenteus*. Pati (1981) found isometric growth (W=0.00362$L^{3.0051}$) in *P. argenteus* combined sex from the Bay of Bengal region. Ghosh *et al*., (2009) also illustrated isometric growth (b=3.0504) in *P. argenteus* combined sex from Veraval coast. Whereas, Dutta *et al*. (2012a) exhibited a negative allometric growth in *P. argenteus* in the same study region. In present study, it was observed that growth of *S. guttatus* was negative allometric (b=2.54). Rashid *et al*. (2010) estimated the total length and body weight relationship in *S. guttatus*, suggesting that the growth rate was negative allometric (b=2.86). Devaraj (1981) also found a negative allometric growth rate for *S. guttatus* (b = 2.86) from south and south-west India. The LWR of *O. militaris* was negative allometric (b=2.83) during the study period in the northern Bay of Bengal. Raje (2006) and Dutta *et al*. (2012a) reported that the LWR in *O. militaris* was negative allometric (b=2.923 and b=2.954 respectively), however, b values were very closer to values recorded in the present study. Therefore, length and weight were not observed to increase in *O. militaris* proportionately. Dutta *et al*. (2012a) concluded that these four species maintained their length-weight relationship consistently throughout their size classes.

Within-species variance in weight-length relationships could be substantial, depending on season, population, or annual differences in environmental conditions (Froese, 2006). There was a good seasonal variation in length-weight among the four species. Seasonal changes in body length and weight were essential to know the health of the population and the growth stage. Essentially, fish condition is known to differ in response to a variety of exogenous and endogenous factors, such as temperature, food availability, stage of maturity and sex. Environmental parameters (salinity and SST) had a good impact on the condition factor of these fish species. It was noted that all these four species were salinity and SST sensitive, especially *T. ilisha* was highly salinity sensitive species. Considering monthly variations in condition factor, it might be indicated that *T. ilisha* were well fed during post-monsoon months, whereas, condition factor of *T. ilisha* was low during pre-monsoon and monsoon periods indicating lower consumption. The reason behind the good condition factor in post-monsoon period was food availability. Narejo *et al*. (2005) also reported the availability of good number of phytoplankton and zooplankton in post-monsoon period in the river system when anadromous *T. ilisha* swim downstream to reach their oceanic habitat. During the monsoon period *T. ilisha* stopped feeding while migrating upstream for spawning in river waters of greatly reduced salinity for variety of physiological reasons (Dutta *et al*., 2014; Ghobeishavi *et al*., 2016). However, these factors (diet, food habits) were not considered in present study and need to further investigation, but the results of condition factor could be explained by diet and food habit information. Dadzie *et al*. (2000) concluded that *P. argenteus* is characterized by a high condition factor during spawning and characterized by a low condition factor during the offbreeding season. Tarigan *et al*. (2019) illustrated that condition factor for *S. guttatus* is relatively good during August and September in Pangandaran waters of West Java, Indonesia. Dutta *et al*. (2012a) concluded that condition factor of *S. guttatus* was 0.649±0.003 that means fish growth was poor and weight was not increasing with length, which supports the present study findings.

In this present study, mean length of *S. guttatus* was 462.26mm, 601.49mm and 643.43mm at age 1, 2 and 3 years respectively. However, Devaraj (1981) recorded shorter lengths at 1st year and 2nd year, while a much similar length at 3rd year compared to the present study. Parida *et al*. (2014) reported a much higher length in *O. militaris* population in different age classes from Mumbai waters compared to the present study. Therefore, it might be pointed out that growth of *O. militaris* was higher in Mumbai waters of Arabian Sea than in the Sundarban Estuary of the Bay of Bengal.

Rahman and Cowx (2008) observed two peaks in recruitment for *T. ilisha* population in Bangladesh waters; one major peak during March-May and another minor peak during November-January were reported. However, Nurul Amin *et al*. (2004) reported more or less continuous recruitment for this species with one major peak between June and September. Occurrence of gravid *T. ilisha* females off West Bengal coast was recorded during June through August in the present study. The results indicated that the peak spawning was in the monsoon period and during monsoon *T. ilisha* migrated to freshwater river for spawning and recruitment. In *P. argenteus* population a two-peak recruitment pattern was observed and the peaks were during March and August. Ghosh et al. (2009) recorded similar observation. Rashid *et al*. (2010) described the recruitment pattern of *S. guttatus* and reported two uneven seasonal recruitment peaks in May-July (77.1%) and October-November (23.0%). The present investigation recorded a major recruitment peak in August and another minor peak in March for *S. guttatus*. The recruitment peak of *O. militaris* was during April-May in the present investigation, however the spawning period for *O. militaris* occurred throughout the year. Jantan (2014) recorded the spawning peak for this species in June - July and December - February in the coastal area of Penang, Malaysia.

It was to be noted that mortality due to fishing was substantially higher than natural mortality. In the present study all four species were highly overexploited during the study period exhibiting an exploitation rate of (*E*) >0.50. Most of these species in pelagic waters do not die due to their old age rather die in earlier age, juveniles or semi-adult stage, due to high rate of fishing exploitation. If the value of *E* was more than 0.50, we could conclude that the fish was overfished in a particular area over some specific period (Gulland, 1971). In the present paper, the exploitation rate (*E*) of *T. ilisha* in coastal areas of the northern Bay of Bengal was recorded as 0.78 indicating that the natural population of this species was largely overexploited. Hashemi *et al*. (2010) estimated the rate of exploitation (*E*) of *T. ilisha* in coastal waters of Iran as 0.72 and

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Nurul Amin *et al*. (2002) found the exploitation rate (*E*) for *T. ilisha* in Bangladesh waters as 0.66, indicating also overexploitation of *T. ilisha* population. Dutta *et al*. (2012b) projected a threat of overexploitation of *T. ilisha* resources of the northern Bay of Bengal in near future. *P. argenteus* was one of the most overexploited fish resources due to its high market demand for good taste as reported from Pakistan (Siyal *et al*., 2013), Iran (Narges *et al*., 2011; Hashemi *et al*., 2012) and India (Ghosh *et al*., 2009). Our analysis showed that *P. argenteus* was also overexploited (*E=0.62*) in the costal Bay of Bengal. Rashid *et al*. (2010) showed that *S. guttatus* off Bangladesh coast of the Bay of Bengal were not overfished (*E*=0.45). However, the present study recorded that *S. guttatus* too were overexploited (*E*=0.75) in coastal West Bengal. *O. militaris* was also overexploited (*E=0.54*) at the present study area during the study period. Parida *et al*. (2014) reported that exploitation rate of *O. militaris* was 0.70 from Mumbai water, observing very high mortality rate in this species as compared to the present study.

The results of relative yield per recruit analysis indicated that current fishing mortality was high and most of the juveniles were caught by fishermen that lead to decline in fish population and loss of economic advantage. Principal limitation of the yield per recruit analysis was that it assumed there was no relationship between size of the spawning stock biomass and subsequent recruitment over a wide range of values of mortality due to fishing (Buxton, 1992). Ecological differences, physiological conditions of fish, feeding variability, fishing pressure and data resources may be the reasons for the variations in these values in different geographic locations.

The present work concluded that all four species were overfished in Sundarban Estuary of the northern Bay of Bengal. The numbers of juvenile catch in pelagic waters were very high as the fisherman used fishing nets of much smaller mesh size (<40-90 mm). Implementation of mesh size regulation and a substantial reduction in fishing effort on juveniles and sub-adults, especially during post monsoon were the need of the hour. The basic biological features of the studied species indicated a need to implement sustainable management approaches towards coastal capture fishery. In order to support increasing local and global demands for these fish along with the livelihoods and food securities of local communities, fishery managers need to rethink on their perceptions of short-term economic gain by overexploiting of these commercially important four species. However, for sustainable exploitation we need to conserve these vulnerable fish species in waters of the northern Bay of Bengal through stricter regulations and immediate implementations. The published literatures, as mentioned earlier, showed that overexploitation is the most common problem of these commercially important species throughout the world wherever they inhabit. All fishing activities, if not conducted in a sustainable non-destructive manner, could lead to crash of natural populations, leaving deleterious impact on other marine living resources. Browman

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and Stergiou (2004) and Worm *et al*. (2009) rightly pointed out that overexploitation of marine fish resources not only impacted target species but also cast major impacts on marine ecosystems as a whole, adversely influencing the socioeconomic backbone of a country dependent on marine resources modifying the ecosystem functioning.

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