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Estimation of the marine Pomfret fishery status of the Bay of Bengal, Bangladesh: Sustainability retained

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The status of Pomfret fishery of the Bay of Bengal, Bangladesh was analyzed by using non-equilibrium surplus production models with a view to evaluate *MSY* based on (2003-2015) 13 years catch and effort data. Three surplus production models of Fox, Schaefer and Pella-Tomlinson including three error assumptions of normal, log-normal and gamma were used by applying CEDA software package. Initial proportion (*IP*) value of 0.2 was used because the starting catch was only about 20% of the maximum catch. The *MSY* output of Fox models were 22,177MT and 21,177MT under the error assumptions of normal and log-normal, while Schaefer and Pella-Tomlinson models produced similar *MSY* of 33,511MT and 33,138MT. The outcomes from the log-normal error assumption of Fox model was produced goodness of fit R^2 (0.678) value which was smallest among all models whereas highest biomass, B_{final} (137640) was found from the same model. The estimated *MSY* from Schaefer and Pella-Tomlinson models were not as suitable to accept as because the value of coefficients of variation (*CV*) were too small. The Fox model estimates (normal and log-normal assumption) are close to the recent landings (11,067MT) of Pomfrets which are more conservative and hence the best fit. This study points out that Pomfrets stock of Bangladesh remains in a satisfactory level.

[Keywords: Pomfrets, Bangladesh, maximum sustainable yield (*MSY*), surplus production models]

Introduction

The existing total fish production of Bangladesh is 3.84 million MT of which marine capture fisheries backs around 15.6%[1]. Coastal and marine capture fisheries of Bangladesh exploit a complex, multi-species resource, and can be subdivided into two sections i.e. artisanal (small-scale, non-commercial) and industrial (large-scale, commercial) fisheries sectors. Amongst of the total catch, more than 93% is captured by artisanal fishing crafts, while industrial fisheries contribute around 6% of the total catch[1]. At present, more than 200 industrial trawlers engaged in harvesting demersal fish. Supervision of marine fisheries in Bangladesh has concentrated mostly on industrial trawler fleets while limited consideration was focused on other sectors. Thus, uncontrolled expansion of fishing effort generates a deep crisis to this sector.

Pomfrets, one of the major target groups of fishes in the artisanal sector which belong to the family Stromatidae (*Pampus argenteus* & *Pampus chinensis*) and Carangidae (*Parastromateus niger*) have been widely distributed in coastal, estuarine and marine habitats ranging from 5-105 meter depth in the Bay of Bengal, Bangladesh coast[2].

These are extremely relished table fishes in home and export markets. Department of Fisheries of Bangladesh collects only grouped data of Pomfrets (Silver, Chinese and Black Pomfrets) that are now comprises more than 1.3% of the total marine capture fishery[3].

Fig. 1— Map represents the total Maritime waterbody of the Bay of Bengal, Bangladesh

Over the last 15 years, annual average catch was about 21,890MT, in which less than 4% came from industrial trawl landings and the rest of 96% through artisanal captures[4]. Pomfrets are abundant mostly inshore areas i.e. Sundarban Mangrove Forest (SMF) adjacent marine areas of the south patches and the Chittagong and Cox's Bazar, southeast parts of Bay of Bengal, Bangladesh. They largely forms small shoals associated with other demersal fishes over the muddy-sandy bottoms feed mainly on zooplankton, ctenophores, jellyfish, medusa and small benthic organisms[5]. Though few catch survey of Bay of Bengal, Bangladesh in earlier studies provides some valuable fishery data, but still there are limitations in the survey system and also lack of data collecting methodology[6,7,8,9]. These limitations mostly relate with sample size and sampling techniques in the multi-species, multi-gears and fluctuating coastal fisheries system of Bangladesh, and they require more attention. There are some changes in commercially captured fishery that has been observed in recent years. Catch per unit effort (*CPUE*) not only in Pomfrets but also in all fishery is steadily decreasing and is approximately 50% of *CPUE* from the early 1990s [9,10]. It is thus important to assess biological and economic overfishing of Bangladesh fish stocks. Pauly[11]presented lessexpensive approaches i.e. observing certain indicators like percentage composition change of species and/or size overtime, *CPUE*, changes in market supplies, price etc. which can be good indication of overfishing. Based on the above-mentioned indicators, it is marked that there was biological overfishing but not severe for the fishery resources in Bangladesh.[8] Therefore, this study aims to exact quantification of the maximum sustainable yield (*MSY*) of Pomfret fishery of Bangladesh through analyzing time series catch and effort data from the year of 2003 to 2015 that were collected from the log book of Fisheries Resources Survey System (FRSS), Department of Fisheries (DoF), Bangladesh.

The surplus production model has been carefully chosen for this study because it is simple and easy to integrate environmental effects and its parameters can be easily assessed by using only catch and effort data and estimated parameters can easily computed on the basis of biological reference point. Likewise, this model is especially well fitted and relaxed to identify the potentially serious affects[12]. One of the major plus-point of this model is limited data requirements in the both case e.g. single-species or multi-species fishery. Surplus production models have been approved as a fishery management tool to estimate *MSY*, though its application has not been out of question[13,14,15,16,17,18]. The assembly of a fish population or other aquatic animals are frequently sought as a means of establishing an upper limit to the annual harvest[19]. Former versions of SPMs usually use non-linear regression which are relatively difficult to interpret [15,19]. Over-all fish stocks remain unstable (non-equilibrium state) because of fishing mortality or environmental fluctuations, natural mortality, therefore, equilibrium modeling has frequently unsucceeded[15]. For this reason, we used non-equilibrium modeling approach in this study. At present, several soft wares have been developed which can assess biomass dynamics of the exploited fish stock i.e. ASPIC (A Stock Production Model Incorporating Covariant)[20] and CEDA (Catch and Effort Data Analysis)[21]. These computer packages are easily reckonable and very effective tools.

This study may be the opening attempt to estimate *MSY* through time series catch and effort data of Pomfret fishery using CEDA (catch and effort data analysis) computer package. Keeping sustainability in marine fisheries resources in mind, this study is designed to estimate the *MSY*; which may assist fishery authorities to take suitable management strategy for sustainable exploitation.

Materials and Methods

Data source

In order to estimate maximum sustainable yield (*MSY*), time series catch and effort data of Pomfrets for the period of 2003 to 2015 (total 13 years) were taken from the logbook of FRSS (Table 1). Fishing effort is obtainable by the number of operational fishing boats in the maritime region of Bangladesh, and the per annum total catch is presented in the form of catch weight (Metric Tons). The average catch of marine Pomfrets of the Bay of Bengal, Bangladesh in 2003 to 2015 was 24,376MT. The observed highest catch in 2009 was 50,245MTwhile in 2015the lowest catch was 11,067MT (Table 1). Mostly two types of crafts are engaging for fishing i.e. Industrial trawlers and boats of steel structure with mechanized engines in the EEZ of Bangladesh. The industrial fishing trawlers usually spend at least 20 days and mechanized crafts spend 23-24 days in each voyages. On an average both fishing crafts generally complete 4-6 hauls per day in which per haul takes 3-4 hours. Nevertheless, the number of hauling and fishing days substantially influence by on the worthiness of sea, weather forecasting and operation of trawler itself[6]. Thus, the efforts were taken as total fishing days of total number of mechanized boats that engaged in fishing.

Table 1: Catch and *CPUE* data of marine Pomfrets of the Bay of Bengal, Bangladesh from 2003 to 2015

Year	Industrial catch (MT)	Artisanal Catch (MT)	Total Catch (MT)	*CPUE* (Catch/day)
2003	91	11298	11389	0.037193
2004	282	11753	12035	0.038384
2005	388	11635	12023	0.037326
2006	377	12684	13061	0.036416
2007	607	16121	16728	0.029095
2008	313	46330	46330	0.06139
2009	334	49911	50245	0.061959
2010	362	40116	40478	0.04579
2011	487	39050	39050	0.043545
2012	428	29265	29693	0.039412
2013	505	22850	23355	0.032493
2014	487	10950	11437	0.016582
2015	462	10605	11067	0.01648

Surplus production models (SPM)

SPM is also called biomass dynamic model (BDM) which is among the simplest and mostly widely used models. It is relaxed to use because it requires only two sorts of data. These models are flexible and have different deviations i.e. the Schaefer[22], Fox[23] and Pella-Tomlinson[24]models, which are mainly based on the following ideologies:

- Subsequent biomass = latest biomass + body growth + recruitment - natural mortality- catch
- Surplus production = Production - natural mortality
- Wherever production is the totality of recruitment and body growth
- Therefore, Fresh or new biomass = last biomass + surplus production – catch

The above three SPMs are used in CEDA package. The most frequently used model is Schaefer[22]which is based on the logistic population growth function:

$$\frac{dB}{dt} = rB(B_{\infty} - B)$$

Later work of Fox[23] offered a Gompertz population growth equation,

$$\frac{dB}{dt} = rB(1nB_{\infty} - 1nB)$$

Pella and Tomlinson[24] projected a comprehensive population production equation,

$$\frac{dB}{dt} = rB(B_{\infty}^{n-1} - B^{n-1})$$

Where *B* is fish stock biomass, *t* is time, *r* is intrinsic rate of population increase and $B\infty$ is carrying capacity. Population size increases only when surplus production is greater than catch and population size remains constant through catch remains sustainable when catch equals to surplus production. Similarly, decline of population size is result of greater catch than surplus production. The carrying capacity of the procedure is the extreme population size that can be attained. Growth, age-structure, mortality and reproduction are all demonstrated by the intrinsic rate of production (*r*), which is low at the smallest and highest population levels while high at the midpoint of $B\infty$.

Catch and effort data analysis (CEDA, version 3.0.1)

The collected and compiled catch and effort data of Pomfrets were analyzed by CEDA (Catch and Effort Data Analysis) software package, which was developed by fisheries scientists from UK[25]. CEDA (version 3.0.1) package comprises three non-equilibrium surplus production models i.e. Schaefer[22], Fox[23]and Pella and Tomlinson[24] with three error assumptions (normal, log normal and gamma). The software package can analyze the following key parameters: Maximum sustainable yield (*MSY*), carrying capacity (*K*), coefficient of catchability (*q*), intrinsic rate of growth (*r*), final population and replacement yield, coefficient of variation (*CV*) also assessed from the estimated confidence intervals. The package needs an input value of initial biomass (B_1) or initial proportion (*IP*) over the carrying capacity by the operator. When the value of *IP* has fixed at zero or close to zero, it designates that the fishery started from a virgin population; if *IP* is close to 1, it points out that the fishery started from a heavily captured population. The value of *IP* is a sign that clarifies how the fishery data series is progressed. However, in some cases starting biomass is settled by programmer such as $B_1=K$.

Results

The technique named 'Bootstrapping confidence limit' was used for calculating the coefficient of variation (*CV*). The outcomes from the CEDA package are greatly responsive to the initial proportion (*IP*) values. The *MSY* and *IP* values were inversely proportionate with each other, when *IP* values were small, the assessed *MSY* values were greater and when *IP* values were high the evaluated *MSY* values were minor (Table 2). In this study, the starting catch in 2003 is about 20% of the maximum catch in 2009; we used the results of initial proportion close to 0.2. All of the three models Fox, Schaefer and Pella-Tomlinson with error assumptions normal and log normal produced outcomes while gamma error assumption of all models produced minimization failure (Table 4). The assessed values of *MSY* with *CV* (coefficient of variation) from the Fox model with two error assumptions (normal and log normal) were 22,177.12MT (*CV* = 0.210) and 21,177.01MT (*CV* = 0.172) respectively.

Table 2: Estimation of *MSY* of marine Pomfrets catch fishery of the Bay of Bengal, Bangladesh using CEDA package, with the initial proportion (*IP*) ranging from 0.1 to 0.9

	Models								
IP	**Fox**			**Schaefer**			**Pella-Tomlinson**		
	Normal	**Log-normal**	**Gamma**	**Normal**	**Log-normal**	**Gamma**	**Normal**	**Log-normal**	**Gamma**
0.1	34956.62	34076.96	MF	50992.86	54764.57	40870.87	50992.86	54764.57	40870.87
	0.039	0.048		0.073	0.026	0.0012	0.0811	0.029	0.0012
0.2	22177.12	21177.01	MF	33510.97	33137.9	MF	33510.97	33137.9	MF
	0.21	0.172	MF	0.02	0.017	MF	0.021	0.022	MF
0.3	14106.56	1.94E+07	1.47E+10	25368.05	24656.19	MF	25368.05	24656.19	MF
	0.619	0.298	0.22	0.135	0.092	MF	0.135	0.1	MF
0.4	3802.48	496.92	MF	19464.85	1052680	MF	19464.85	1052680	MF
	3.64	29.65	MF	0.31	7.28		0.322	10.47	MF
0.5	2.83E+11	252.07	MF	2.88E+09	5.83E+07	8.33E+08	2.88E+09	5.83E+07	8.33E+08
	0.69	66.66	MF	25.2	0.28	11.34	20.95	0.26	13.3
0.6	0.037	241.48	MF	5.60E+10	622.59	MF	5.60E+10	622.59	MF
	3.17	78.14	MF	0.3	27.12	MF	0.23	27.63	MF
0.7	1.67E+11	320920.4	MF	4.16E-02	202.14	MF	4.16E-02	202.14	MF
	0.18	155.29	MF	2.97	99.8	MF	5.95	94.4	MF
0.8	7.65E-02	1462251	MF	1.37E-02	1760487	MF	1.37E-02	1760487	MF
	2.2	136.26	MF	2.29	5.4	MF	3.38	9.33	MF
0.9	4.39E+10	3400973	MF	7.63E-02	17.29	MF	7.63E-02	17.29	MF
	0.19	17.19	MF	1.95	1804.6	MF	4.49	1780.44	MF

Table 3: *MSY* estimates (in Metric Ton) of marine Pomfret fishery of Bangladesh including coefficients of variation (*CV*) found from CEDA package when initial proportion was set at 0.2 (*MF=minimization failure)

Error Assumption	*MSY* (with *CV*)		
	Fox model	Schaefer Model	Pella-Tomlinson Model
Normal	22177.12 (0.210)	33510.97 (0.02)	33510.97 (0.021)
Log normal	21177.01 (0.172)	33137.9 (0.017)	33137.9 (0.022)
Gamma	MF*	MF*	MF*

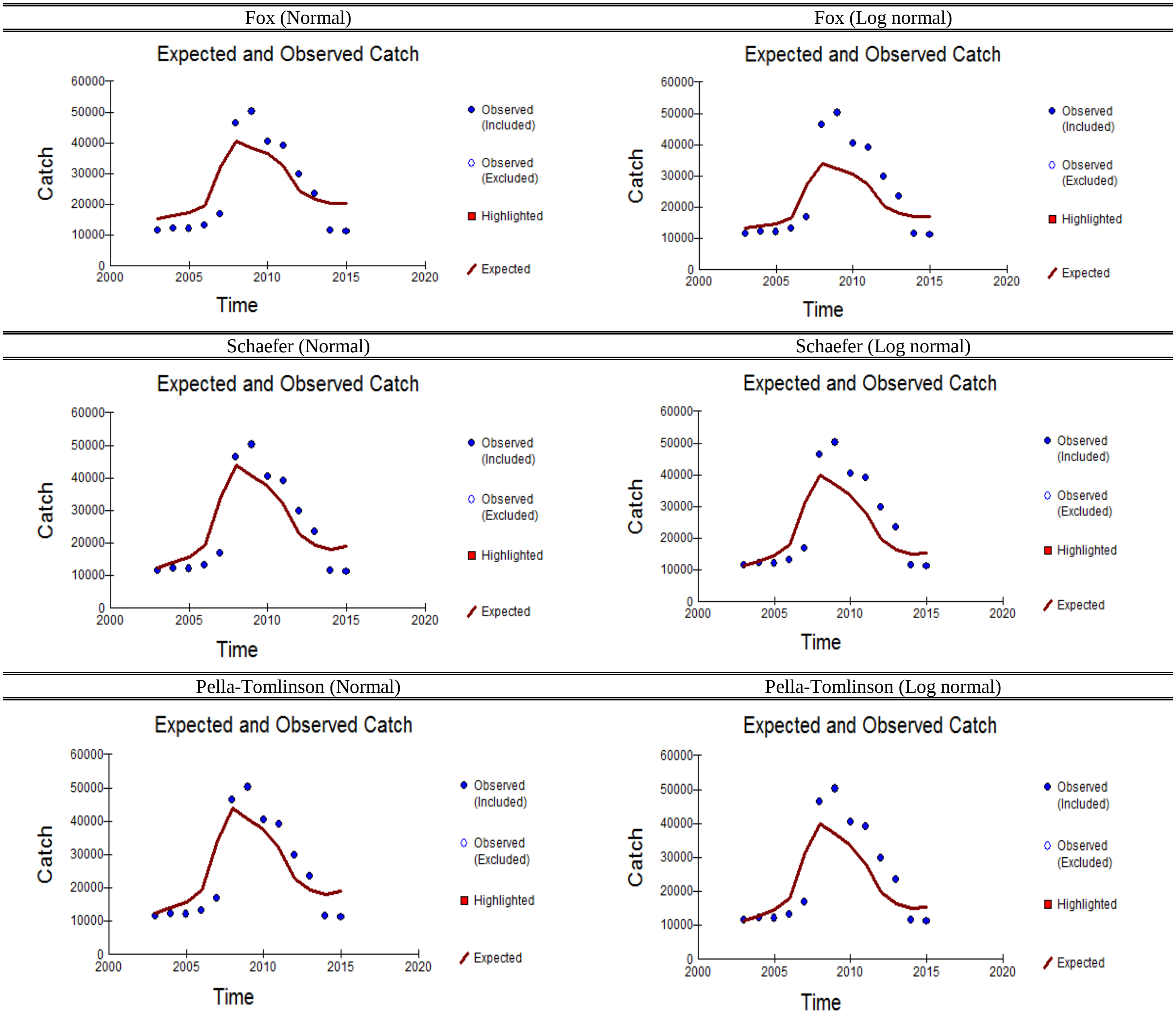

Figure 2: Comparison of observed and expected catches of the three models- Fox, Schaefer and Pella-Tomlinson with three error assumptions of the Pomfret fishery of Bangladesh.

Table 4: Parameters estimates using the Schaefer, Fox and Pella-Tomlinson production models including three error assumptions for the catch and *CPUE* data of marine Pomfret fishery of Bangladesh (*IP*=0.2)

Model Parameters						
Fox Model						
Error Assumptions	K	q	r	$Y_{replace}$	B_{final}	R^2
Normal	1063521	2.296E-07	5.67E-02	15768.49	134566.5	0.716
Log normal	1143635	1.845E-07	5.03E-02	14669.12	137640.1	0.678
Gamma	MF	MF	MF	MF	MF	MF
Schaefer Model						
Normal	473637.1	4.0073E-07	0.28301	17425.4	72744.29	0.746
Log normal	475868.4	3.694E-07	0.278547	15193.56	62845.5	0.714
Gamma	MF	MF	MF	MF	MF	MF
Pella-Tomlinson Model						
Normal	473637.1	4.0073E-07	0.283	17425.4	72744.29	0.746
Log normal	475868.4	3.694E-07	2.79E-01	15193.56	62845.5	0.714
Gamma	MF	MF	MF	MF	MF	MF

The parameters are: K = carrying capacity, r = intrinsic population growth rate, $Y_{replace}$= replacement yield, q = catchability coefficient, R^2 = coefficient of determination, $B_{final=}$final biomass

Similarly, in case of Schaefer model with two error assumptions of normal and log normal, the values of *MSY* and *CV* were found 33,510.97MT (*CV* = 0.020) and 33,137.9MT (*CV*=0.017) while and for Pella-Tomlinson models, 33,510.97MT (*CV* = 0.021) and 33,137.9MT (*CV*=0.018) respectively (Table 3). The *MSY* values were inappropriate for the error assumptions of log normal and gamma for all three models as because of the higher coefficient of variation (*CV*) values. The R^2 values of Fox model for normal and log normal assumptions were 0.716 and 0.678 respectively, whereas Schaefer and Pella-Tomlinson models produced similar values of R^2 =0.746 and 0.714 respectively. All of the three models were produced higher values of carrying capacity (*K*) and relatively lower estimates of coefficient of catchability *(q)* whereas the intrinsic population growth rate (*r*)values were the same for Schaefer and Pella-Tomlinson but different for Fox model with two assumptions. There were some variations among the assessed values of replacement yield $(Y_{replace})$ and final biomass (B_{final}) for all models, while evaluated R^2 values show a good fit to the data particularly for Fox model. From graphical view, the observed and estimated catches were closed in case of Schaefer and Pella-Tomlinson models with normal and lognormal error assumptions (Figure 2).

Discussion

Sustainable management strategy in capture fisheries are generally reliant on stock assessment outputs. Therefore, it is crucial that fisheries experts deliver a dependable diagram of stock dynamics and stock status to the authorities[26]. The major apprehension of this study was to estimate the maximum sustainable yield (*MSY*) of Pomfrets of the Bay of Bengal, Bangladesh through surplus production model (SPM) by using CEDA software packages.

CPUE can be calculated by catch and effort data that may be used as an indicator of fishery status although these are less significant in statistical analysis. Fish stock is not being troubled when both catch and effort show cumulative trends and *CPUE* is remained impartially constant. Nevertheless, when either catch rises or drops and effort remains constant that points out quantitative changes in the fish stock. However, when catch is decreasing and the effort is increasing this may propose that the fish stock is declining rapidly[25].

CPUE is frequently observed to be proportionate to the fish population and used as the relative abundance index. Numerous population dynamic models were used to calculate the relative abundance index in order to achieve the future values of predicted absolute abundance by multiplying with a constant catchability coefficient (*q*)[27]. Actually, there were largely two mathematical approaches used in fisheries science (i) Surplus production models considered to be the earliest approach which initially suggested by

Schaefer[22]and then by Fox[23] and (ii) the yield-per-recruit analysis[28] is the second approach. The SPMs are the sensible approach due to their holistic or simplicity in nature. The SPM can determine the level of effort at which a fishery produces a maximum yield of a fish stock in a sustainable means without changing the long-term output that is designated as *MSY*[29]. In SPM, *MSY* is considered as a biological reference point on which sustainable exploitation goal can be achieved [15,16,18,30]. Whenever the computed *MSY* values are higher than the recent catch data then it signifies that the population is under protected circumstances. In addition, when the catch data is comparable to the estimated *MSY* values then we may assume that the stocks are in tenable condition. Nevertheless, whenever the annual catch is higher than the predicted *MSY* results from SPMs then we may consider that the fish stock is being over exploited and going towards the decline state.

CEDA package was used to estimate *MSY* of the Pomfret fishery of the Bay of Bengal, Bangladesh. This package does not assume the fish population at equilibrium state and permits different error assumptions which can significantly progress the fitting method and the precision of the estimates and their confidence intervals [25,31]. All of the models in this package are based on the theory of depletion and they required two types of data. First, when a time series catches are available the operator can guess how much exploitation took place before the start of the fishery. Second, the model needs fishing effort data or an index of abundance, which should be proportional to the population size. The abundance index need not to be complete over the series, although adequate indices still have to be available to find significant parameters estimates[31].

Pella-Tomlinson[24]model is considered as an extension of the Schaefer model, which is demonstrated as less beneficial. Despite its “flexibility”, the fit will probably be worse than Fox or Schaefer models as there is a recognized inverse relationship between the number of parameters to be assessed and the performance of the models[30]. The Fox model is supposed to be more “realistic” because it assumes that the population can never be totally driven to extinction, something that sounds spontaneous but is probably incorrect in light of the severe reduction of fishery resources[30].

The estimated *MSY* values of Pomfrets from Fox, Schaefer and Pella-Tomlinson except gamma error assumptions (Table 2) point out that the assumptions of normal and log normal of Schaefer or Pella-Tomlinson assessments were larger than that of the Fox, which is more conservative. Similarly, the coefficient of variance (*CV*) values of Schaefer and Pella-Tomlinson models under normal and log normal error assumptions is not so suitable due to their lower values. The *MSY* estimates of Fox model of normal and log normal error assumptions are close (22,177MT and 21,177MT) to the recent annual landings (11,067MT) of the Pomfrets of Bangladesh, which is accepted as the best fits. The estimated *MSY* values from CEDA package for all models were higher than the recent catch, therefore we may assume that the stock of Pomfret fishery in the Bay of Bengal, Bangladesh is in satisfactory level. However, in the light of great uncertainties of the fisheries science, more research and investigation should be needed to assess *MSY* exactly for the Pomfrets fishery of the Bay of Bengal, Bangladesh in future. Actually, except FAO country profile report, no update information about the finfish stock assessment is available[32] with this fishery in Bangladesh as because the last surveys for resource assessment was conducted on two and half decades ago. For this reason, this study is to provide an initial concept of stock assessment of Pomfrets fishery through using surplus production models.

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