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Maximum Sustainable Yield Estimates of Offshore Finfish in Bangladesh Marine Waters Using Non-Equilibrium CEDA Package

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Abstract

Assessment of offshore finfish in Bangladesh marine waters was analyzed using catch and effort data analysis (CEDA) computer programmer with a view to estimate Maximum Sustainable Yield. The major parameters of this package are Maximum Sustainable Yield (*MSY*), catch ability coefficient (*q*), carrying capacity (*K*), intrinsic growth rate (*r*), replacement yield and final biomass. CEDA has ability to assess the parameters of Fox, Schaefer and Pella-Tomlinson models. In addition, it has an ability to estimate three error assumptions i.e., least square fit, log transfer and gamma. In this study, the maximum sustainable yield outputs of least square fit of three models of Fox, Schaefer and Pella-Tomlinson are 325160MT (R^2=0.927), 379610 MT (R^2=0.931) and 379610MT (R^2=0.931) respectively. The outputs of error assumption of log transfer are 7951653 MT (R^2=0.88) and 1431298 MT (R^2=0.87) in Fox and Schaefer models respectively, which are far beyond from expectation. Pella-Tomlinson showed similar value in all error assumptions and in all estimated parameters. The coefficient of variation (CV) of the estimated MSY was about 0.7. The observed and expected catches are close and similar for all three models with normal error assumption. The Fox model output are more conservative hence the best fit and the estimated value are greater than the annual landings, which indicates fishery stock is in satisfactory level.

Keywords: Maximum yustainable yield; Finfish; CEDA; Bangladesh marine waters

Introduction

Since after liberation in 1971, Bangladesh went through a number of surveys to assess such a virgin stock of fish and shrimp of the Bay of Bengal, which was commenced by an FAO consultant Dr. WQB West in 1973, that encouraged the introduction and development of demersal trawling for white fish and shrimp together with the public sector, Bangladesh Fisheries Development Corporation (BFDC). Subsequently, a number of stock assessments were carried out by international scientists in association with local experts had assessed a virgin stock of 2 64,000-3,73,000 mt of demersal white fish and 9000 mt of shrimp standing stock [1]. Then, R.V. Fridtjof Nansen carried our survey during 1979-80 and reported a stock of 1,60,000 mt [2], the R.V. Anusandhani surveyed during 1981-83 and reported a standing stock of 1, 52,000 mt [3] and finally in 1984-86 same research vessel estimated a standing stock of 1,57,000mt [4]. Commercial fishing through private ownership has been undertaking since then [5] based on various surveys and stock assessments. In 2012, there were 162 industrial fishing vessels operating within the EEZ in waters of over 40m in depth, contributing about 7% of total marine production (DoF 2013). There are 475 marine fish species reported in the country [6] of which, more than 90 are commercially important. Hilsa, catfish, hair-tail, croaker, scads, shark, pomfret, bombay duck, grunter, snapper and jewfish are the major commercial finfish species in Bangladesh [1] Demersal species were dominating in the catch, but recently large quantities of small pelagic such as sardines, mackerel, small tuna etc. has been reported in trawl catches [7].

The Maximum Sustainable Yield (MSY) estimated through the surplus production models has been an accepted fishery management tool, though its application has not out of question [8-13]. There are abundant literatures on surplus production models (also known as biomass dynamic models). They are among the most fish stock assessment models and pool all the effects of recruitment, growth, and mortality into a single production function and are widely used in tropical fisheries where age estimation is difficult or impossible (Haddon, 2011). [8] stated that the production of fish or other aquatic animals is often sought as a means of establishing an upper limit to the annual harvest. Since the fish stock remains unstable or at non-equilibrium state because of natural fish mortality or environmental fluctuations, equilibrium modeling has failed [10].However, in recent years, there has been a fundamental change in the perception of MSY as a limit to be avoided rather than a target that can routinely been exceeded (Mace, 2001). MSY reference points such as Bmsy and Fmsy are commonly used as management benchmarks (Jacobson et al., 2002).

No up-to-date information is available on the stock assessment of finfish after reported surveys conducted on two and half decades ago. This is the first step to estimate MSY through time series catch and effort data of fishing vessel using catch and effort data analysis (CEDA) computer programme. Keeping sustainability in marine fisheries resources, it is aimed to estimate the maximum yield; which may help fishery administrators and fishery biologists in achieving management goals and take appropriate management strategy for their sustainable exploitation.

Materials and Methods

Data sources

The time series data (catch and effort) of finfish trawlers were taken from Marine Fisheries office, Department of Fisheries, Chittagong, Bangladesh. The catch is in the form of weight in metric tons (MT) and effort is in the form of number of fishing days. Finfish trawlers are of two kinds including wooden body and steel hull engaged in fishing in the EEZ of Bangladesh. The smaller wooden trawlers usually sail for 14 days and steel-hull vessels for 30 days in every trip. They usually complete 5-6 hauls in a day taking 3-3.5 hours per haul. But the number of hauling and fishing days substantially depends on weather, sea worthiness and functioning of trawler itself [7] (Figure 1).

Figure 1: Map of Bay of Bengal showing location of Bangladesh.

Surplus production models

Surplus production model (SPM) is also known as biomass dynamic models are among the simplest and most widely used in stock assessment. They are easy to use because they require only two or three types of data. These models are flexible and have different variations; the Schaefer, Fox and Pella-Tomlinson models are some of the best known. SPM are based on the following principles:

I. Next biomass=last biomass + recruitment + body growth - catch - natural mortality

II. Surplus production=Production - natural mortality

III. Where production is the sum of recruitment and body growth

IV. Thus, New biomass= last biomass + surplus production – catch

The first widely used biomass dynamic model was formulated by Schaefer MB [14] based on the earlier work by Graham. The Schaefer model had been the most commonly used SPMs, which is based on the logistic population growth model. This model is expressed in the following way (differential equation or continuous model):

$$\frac{dB}{dt} = rB(1-\frac{B}{K})$$

The continuous logistic model can also be written in discrete form in the following way [10]:

$$B_{t+1} = B_t + rB_t(1-\frac{B_t}{K})$$

When catch is included in the above equation we obtain the following discrete version of the Schaefer surplus production model:

$$B_{t+1} = B_t + rB_t(1-\frac{B_t}{K}) - C_t$$

Later work of Fox in 1970 is supposed to be more realistic because it assumes that the population can never be totally driven to extinct [15] The model is based on the Gompertz growth equation:

$$B_{t+1} = B_t + rB_t(1-\frac{1n\,B_t}{1n\,K}) - C_t$$

Pella and Tomlinson [16] projected a generalized production equation:

$$\frac{dB}{dt} = rB - \frac{rB^m}{K}$$

Where B = biomass, t = time (year), K = carrying capacity, and r = intrinsic rate of population increase. The carrying capacity of the system is the maximum population size that can be achieved. Mortality, age-structure, reproduction and tissue growth are all expressed by a simple parameter called the intrinsic rate of increase or intrinsic rate of production, r. In theory, r is fully realized at the lowest population level while the finite rate of population growth is highest at the midpoint of *K*.

CEDA computer package (FAO, 2006)

In this study, we used catch effort data analysis (CEDA, ver. 3.0) package which is capable and allows fitting three production models, namely Schaefer, Fox and Pella-Tomlinson. This package

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is based on the no-equilibrium assumption of the stocks. In addition, CEDA has ability to estimate three model error assumptions of normal, log-normal and gamma distributions. Key parameters which can be estimated by CEDA package are: *MSY* (Maximum Sustainable Yield), *q* (Catchability coefficient), *K* (Carrying capacity), *r* (Intrinsic growth rate), replacement yield, final biomass, whereas CV (coefficient of variation) of estimated MSY values were computed separately.

The CEDA package requires an input of initial proportion (IP) or ratio of starting biomass (Bi) over carrying capacity (K) by the user. When the IP has set as zero or near zero, it indicates that the fishery started from a virgin population; if IP is near 1, it indicates that the fishery started from a heavily exploited population. IP is an indicator that explains how the fishery data series is started. However, in some cases the starting biomass is fixed at Bi=Ci/(qEi), where C, catch; q, catchability; E, Fishing effort or Bi =K by some programmers.

Results

Catch and effort data analysis (CEDA) package has applied to the annual landing data of fishing vessels. The parameter estimations between Schaefer and Pella-Tomlinson production models are the same. *MSY* of about 325160 MT was estimated from Fox model for the least square fit error assumption is more conservative than that from the Schaefer and Pella-Tomlinson models. For the Schaefer and Pella-Tomlinson model, there are relatively high estimates of *K* and *r* in contrast for the Fox model there are relatively low estimates of *K* and *r*. Moreover, the values of coefficient of determination, R^2 showed fitting of the model (Table 1 & 2). The observed and expected catches are close and similar for all three models with normal error assumptions (Figure 2).

Table 1: MSY estimates (MT) for finfish in Bangladesh marine waters (Coefficients of variation in brackets) using CEDA, initial proportion was set at 0.9.

Error models	MSY		
	Fox model	Schaefer model	Pella-Tomlinson model
Leastsquare fit	325160 (0.7071)	379610 (103.096)	379610 (166.40)
Log transfer	7951653 (0.7067)	1431298 (7.995)	1431298 (8.3)
Gamma	1689765 (0.3926)	322637 (172.221)	322637 (42.7)

Table 2: Parameter estimates for the catch and effort data of finfish in Bangladesh marine waters using the Schaefer, Fox and Pella-Tomlinson production models including three error assumptions.

Fox model						
Model parameter	K	q	R	R_{yield}	$F_{biomass}$	R^2
Leastsquare fit	332937	0.0038	2.65	189902	250127	0.927
Log transfer	2126699	0.0000015	0.101	143054	2112517	0.885
Gamma	1760439	0.00024	2.009	449526	1578396	0.947
Schaefer model						
Leastsquare fit	539195	0.00082	2.816	55117	518856	0.931
Log transfer	2379081	0.000014	2.401	1315613	1537725	0.876
Gamma	456297	0.00093	2.828	67983	430840	0.940
Pella-Tomlinson model						
Leastsquare fit	539195	0.00082	2.816	55117	518856	0.931
Log transfer	2379081	0.000014	2.401	1315613	1537725	0.876
Gamma	456297	0.00093	2.828	67983	430840	0.940

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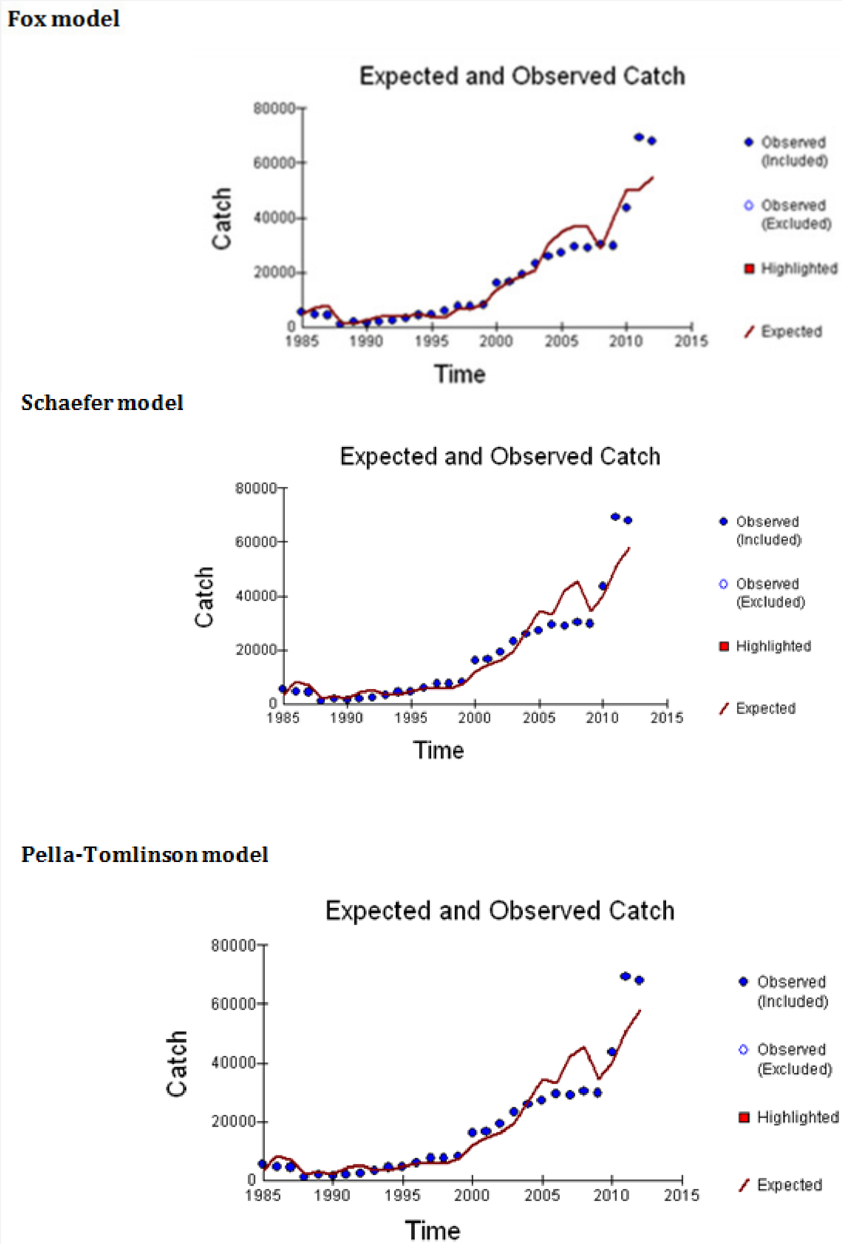

Figure 2: Comparison of observed and expected catches for the three models of Fox, Schaefer and Pella-Tomlinson with normal error assumption using time series catch and effort data of finfish trawlers in Bangladesh marine waters.

CEDA package requires an input of initial proportion (IP, starting population size over the carrying capacity). Our results showed that the package is sensitive to the starting IP value. When IP is < >0.5, CEDA basically failed to produce reasonable MSY estimates (the MSY outputs were too high for all three models and three error assumptions). Because the starting catch in 1985-86 is about 10% of the maximum catch in 2011-12, we used the results of initial proportion close to 0.9.

Discussion

The surplus production model usually has the following assumptions:

a) There are no species interactions,

b) R is independent of age composition,

c) No environmental factors affect the population,

d) Intrinsic growth rate r responds instantaneously to changes in population B (no time delays),

e) Catch ability coefficient q is constant,

f) There is a single stock unit,

g) Fishing and natural mortality take place simultaneously,

h) No changes in gear or vessel efficiency have taken place,

i) Catch and effort statistics are accurate.

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In practice, many of the above assumptions are not met but this does not mean that the method cannot be used. As long as it is used critically, the production model is a very powerful tool for an initial assessment of a stock [17]. Maximum sustainable yield of finfish in Bangladesh marine waters of the Bay of Bengal was analyzed using non-equilibrium CEDA package. This package offers two significant advantages. It does not assume the population is at equilibrium state and allows different error assumptions which can significantly improve the fitting procedure and the accuracy of the estimates and their confidence intervals [18,19] All the models in CEDA package are based on the concept of depletion and they required two types of data. First the catch data cause the depletion in the population. Second, the model needs an index of abundance, which should be proportional to the population size. The abundance index need not to be computed over the series, although enough indices still have to be available to obtain meaningful parameters estimates [19].

In surplus production models, MSY is considered as a biological reference point on which sustainable exploitation goal can be achieved [10,18,17,9]. According to [20] the assumption that catch per unit effort data can reliably quantify temporal variability in population abundance is important, hence the modeling results would be wrong if such an assumption is not met. Pella and Tomlinson [16] considered an extension of the Schaefer model. In practice, this model has substantially been used because of the popularity of the computer programme GENPROD [15], which provides a method of estimating the parameters using this equilibrium assumption. This model is not much more useful despites its 'flexibility' because the fit will probably be worse than Schaefer or Fox models as there is a known inverse relationship between the number of parameters to be estimated and the performance of the models. 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 intuitive but is probably wrong in light of the severe depletion of fishery resources [17].

The MSY estimation from three error assumptions normal, log normal and gamma from Schaefer and Pella Tomlinson were about 3,79,000 MT whereas in Fox model it was about 3,25,000 MT at the lowest CV (0.70). Although, it was 3, 22, 637 MT from Schaefer and Pella-Tomlinson for gamma error assumption, it is not accepted due to very high of CV (172.221 and 47.2 respectively). It seems that the Schaefer or Pella Tomlinson MSY estimations were larger than that of the Fox, which is more conservative. The concept of Maximum Sustainable Yield which is the output from the production models is commonly used as the target biological reference point. When the reliability of the CPUE data in indexing fish population abundance is unknown, we should be cautious with the interpretation and use of the derived population and management parameters [20].Generally, if surplus production is greater than catch, mean population size increases, if catch equals surplus production, catch is sustainable and population size remains constant; if catch is greater than surplus production, population size declines. Fish stocks sizes and distribution can fluctuate widely even in their natural, unexploited state due to variation in environmental factors and effects of other species with which they interact.

This study reveals that the CEDA is quite easy to operate and quite suitable for MSY estimation. However, the reliability of the CPUE data is not out of question and initial proportion is more than 0.5. Hence, it should be imperative to consider empirical situation before using estimated MSY [21]. Although, the Fox model estimates are greater than the annual landings of finfish caught from offshore, it gives a perception of stock size. This seems to appear that the fishery stock is in satisfactory level.

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