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Maximum Sustainable Yield (MSY) estimates for industrial finfish fishery in marine waters of Bangladesh using trawl catch log

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Abstract. A time series of annual catch per unit effort (CPUE) is derived from commercial logbook data from 2007 to 2018 and used as a tuning series for a Schaefer biomass model. The estimated maximum sustainable yield (MSY) reference points are optimal biomass B_{MSY} = 206,082 t and optimal harvest rate u^{MSY} = 38%. The current stock size is estimated to be around 211,000 t and the annual harvest rate around 55%, slightly higher than the estimated optimal stock size and much higher than optimal harvest rate respectively. The average annual catch in last five years was 95,924 t, higher than the estimated MSY of 79,325 t. Overall, the stock is therefore estimated to be in an overfishing state. The catch rate of high value and large demersal species have gradually declined whereas low valued species such as small pelagic and miscellaneous groups have been appeared as major percentage in catch composition for the last couple of years.
Keywords: Finfish, MSY, Trawl catch log, Bay of Bengal

Introduction

Trawl fishery is the most important industrial fishery and contributes about 15% to the total marine production in the country. The estimated total annual finfish catch from industrial trawlers in Bangladesh is about 102,000 tons during 2015-16 (MFO 2016). Bangladesh marine fisheries is a multi-species fishery comprising of 475 species (Hussain 1971, Shafi and Quddus 1983), of which more than 90 are commercially important species(Barua *et al.* 2014).The targeting species are sardine, anchovies, shad, mackerel, ribbon fish, tuna, snappers, eel, cat fish, scads, Bombay duck, shark/rays, thread fin bream, croaker, pomfret, shrimps and cephalopods (Rahman *et al.* 1995,Barua*et al.* 2014). The multi-species nature of the trawl fishery by multi-type of vessels make the MCS system highly complex. Trawl fishing industry in the country includes multi-day fishing based on vessel category. Bottom trawlings are believed to wide spread damage of sea bottomas well as marine biota and therefore has developed mid-water trawlings. There has been a tremendous surge in marine fish production in Bangladesh. The high density of trawlers along the northern Bay of Bengal has induced changes in the ecosystem(Vivekanandan 2005). Modernization added to industrial trawl fishing fleets resulting in increased efficiency of effort has led to intense exploitation of commercial marine species in recent years, resulting in their biomass changes and in turn threaten their long time sustainability. The over fishing activities in many maritime countries are currently managed by input controls, which limit the fishing capacity of the vessels and gear used, indirectly controlling the amount of fish caught (Najmudeen *et al.* 2014).

Bangladesh went through a number of surveys to assess such a virgin stock of fish and shrimp of the Bay of Bengal after liberation in 1971. This was commenced by an FAO consultant Dr. WQB West in 1973 which encouraged the introduction and development of demersal trawling for white fish and shrimp in association 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 (Barua *et al.* 2016). West (1973) had assessed a virgin stock of 2,64,000-3,73,000 t of demersal white fish standing stock and 1,75,000 t of Maximum Sustainable Yield (MSY) using the survey data collected during the period 1968-1971(West, 1973). Latter, Saetre, 1981 had assessed 160,000t of demersal fish standing stock and 1,00,000 t of MSY using survey data collected by Dr. Fridtjof Nansen. In 1981-83, a group of local scientists assessed 152,000tof demersal fish standing stock and 40,000-50,000t MSY using survey data collected by research and survey vessel RV Anusandhani. In 1987, fish biologist M Lamboeuf had assessed 1,88,000 t of fish standing stock beyond 10 meter depth to EEZ using survey data collected by RV Anusandhani during 1984 to 1986 (Lamboeuf 1987). In 2015-16, there were 204 industrial fishing vessels operating within the EEZ in waters beyond 40m depth at high tide, of which 30 were shrimp vessels(MFO 2016).

The concept of Stock Production Model (SPM) suggesting MSY by exploiting the surplus production on the basis of biological growth model. SPM's are well known for their simplicity. These require only two or three types of data. These models are flexible and have different formulations either assuming equilibrium or non-equilibrium, which can be either single species or multi-species. The MSY estimated by the SPM has been an accepted fishery management goal, though its application has often been questioned (Hilborn and Walters 1992, Quinn and Deriso 1999). Schaefer (1954) was first among the scientists who has given a mathematical basis for fitting surplus production models that associated with MSY concept (Schaefer 1954). This equation expresses the change in the biomass of the population with time. In tropical fisheries, catch usually consists of many species and catch data are difficult to collect by species. Hilborn and Walters (1992) treated entire catch of such fishery as a biomass dynamic pool considering all the effects of recruitment, growth and mortality into a single production function is more appropriate than single species dynamics (Hilborn and Walters 1992).

No up to date information is available on the stock assessment of finfish after reported surveys conducted on three decades ago. This is the first step to estimate finfish stock using time series catch and effort data of industrial vessels through stock production models after assessment of offshore shrimp stock in 2015 (DoF 2015). This study was aimed to estimate the maximum sustainable yield of offshore finfish resources, which may provide information for fishery administrators and fishery biologists in achieving management goals and to take appropriate management strategy for their sustainable exploitation.

Materials and Methods

***Data sources*:** The time series data (catch and effort) of industrial finfish stock in Bangladesh marine waters since 2007 to 2018 (Fig. 1)were taken from logbook datasheet from Marine Fisheries Office (Table I).Trawl fishing has been restricted by ordinance to operate beyond 40 meters depth contour. Fish trawlers are of two kinds including wooden body and steel hull engaged in fishing in the EEZ of Bangladesh. All wooden body trawlers have chilling facilities and almost all steel hull trawlers have freezing facilities for processing of caught fish. The industrial fishing fleet has a capacity of gross tonnage ranged between 56 to 148 t for wooden body and 251 to 668t for steel hull trawlers. The overall length is ranged from 18.5 to 26.50 meters for wooden body trawlers and 34 to 54 meters for steel hull trawlers. The engine powers are varied from 420-600 BHP for wooden body and 716-1850 BHP for steel hull, but mostly fall within 500-1000 BHP. Industrial trawlers were mainly engaged in harvesting demersal fish and shrimp, but in recent years mid-water trawlers have been added to the fleet coupled with conversion of demersal trawlers into mid-water trawlers for fishing pelagic or epi-pelagic species. There is no by catch in true sense as almost all fish caught are brought ashore as alternate use of fishes which are not consumed directly. Discarding of trash fish/by-catch at sea is forbidden by Rule 7 of the Marine Fisheries Rules, 1983(The Bangladesh Gazette 1983). The fin fish trawlers use mostly high opening bottom trawls from the stern side with 60 mm mesh size at the cod-end. The head-rope length in the fish trawler fleet varies from 18m to 32m.The smaller wooden trawlers approved to sail for 14 days and steel-hull vessels for 30 days per trip. They usually complete 5-6 hauls in a day taking 3-3.5 hours per haul. Almost all the trawlers are equipped with modern navigations, communication and fish finding equipment (Barua *et al.* 2014). Shrimp trawlers catch finfish too as non-target species. Shrimp trawlers usually have 150-250 t gross tonnage capacity including main engine power of 500-900 BHP. The maximum days of fishing per trip is 30 days. Every day each trawler usually completes 5-6 hauls for a period of 3-4 hours. Though, the fishing days and number of hauling fully depends upon weather and sea worthiness of the vessel itself (Uddin *et al.* 2012).

***Standardization of CPUE*:** Sparre and Venema (1992) suggested a method in which the quantities of yield and CPUE are proportional to effort, where related different types of boats which fished at the same time and in the same fishing ground (Sparre and Venema 1992). The quantity of effort thus estimated is called relative effort. The relative CPUE for each gear and each year was calculated by dividing the CPUE for that year by the mean CPUE of the gear during the studied period. The relative effort is calculated by dividing the total yield of all gears by the sum of relative CPUE weighted by the yields each year. Here, catch (t) and effort (fishing days) of wooden body, steel hull and shrimp trawlers were used for standardizing CPUE in respective years.

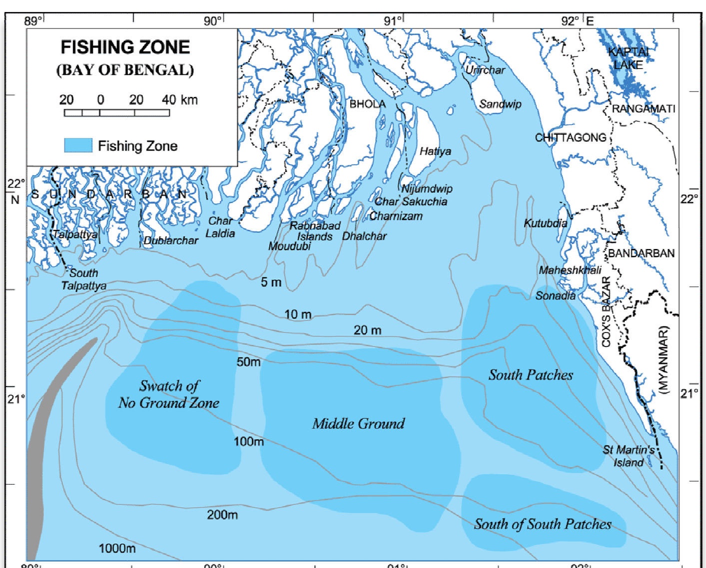

Fig. 1. Map showing Industrial fishing zone (beyond 40 meters depth) in Bangladesh marine waters.

Table I. The time series data of finfish from catch log of industrial trawlers

Year	Time (days)	Catch (t)	Standardized CPUE (t/day)
2007	17530	33248	0.946
2008	19562	31629	0.775
2009	20169	32652	0.707
2010	16816	31684	0.749
2011	20119	46143	0.834
2012	19647	71191	1.293
2013	21021	69946	1.165
2014	25926	73083	0.962
2015	27396	82112	1.028
2016	28658	102764	1.161
2017	28880	105260	1.342
2018	32553	116405	1.304

Source: Marine Fisheries Office Report from 2006-07 to 2017-18.

***Stock production models*:** A Schaefer model, which is based on the logistic population growth was applied in this study. The model is described as:

$$B_{t+1} = B_t + rB_t\left(1 - \frac{Bt}{K}\right) - C_t \text{.......................................} \quad \text{(i)}$$

Where, B is the biomass, t is the time (year), K is the carrying capacity, C is the catch and r is the intrinsic rate of population increase. 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 observed at the lowest population level while the finite rate of population growth is the highest at the midpoint of K (Schaefer 1954).

This equation is usually referred to as the biological model, where the population trajectory is simply a function of the initial biomass, the intrinsic growth rate (r), the carrying capacity (K) and the fishing mortality (F) (Polacheck *et al.* 1993). Indices of stock size such as catch rate (CPUE) are the most common available type of fisheries information where biomass information is inadequate. With the assumption that these indices are proportional to the stock size (Schnute and Richards 2002), then the equation below can be formulated:

$$CPUE_t = qB_t \text{--} \text{(ii)}$$

Here, q stands for catchability coefficient, which acts as a simple scaling factor.
MS-Excel: The time series input data was fitted to a non-equilibrium Schaefer surplus production model. The initial biomass (B_0), K and r for the stock was anticipated at the beginning of the trend analysis, where a indicates initial biomass over carrying capacity. Then next year biomass was calculated by following function:

Biomass = *max* ($B_0+r^* B_0^*(1- B_0/K)$-*catch*)----------------------------------(iii)

The max function ensures that the stock biomass cannot go extinct when using the solver. The values of catch and survey indices (CPUE) above were used to estimate catchability (*q*), while altering *r* and *K* in order to establish the most suitable fittings between observed and expected index for estimating these parameters. Sums of squared normal residual error (RSS) were then calculated. These estimated parameters were also transformed (log_e) in order to calculate negative log likelihood (neglogL), using the following formula:

*neglogL=0.5*n*LN(2*PI())+n*LN(sigma)+RSS/(2*sigma^2)*--------------------(iv)

Where, n was number of year, LN was log natural, and sigma was residue of error.

This was done to check the uncertainty of the model. Then, solver was used to estimate the most reasonable output of desired parameters by targeting minimum residual sum of square (RSS). CMSY: Those data provided e.g. catch per unit effort (CPUE) which was required in the CMSY and Bayesian Schaefer Model (BSM) analysis using R studio software (Froese *et al.* 2017).

***Derived parameters*:** The estimated parameters *r, q* and *K* can be used to calculate management reference points such as Maximum sustainable yield (*MSY*), Biomass that gives MSY (B_{MSY}), Optimal harvest rate (u_{MSY}) or optimal fishing mortality (*Fmsy*) as in:

$$MSY = \left(\frac{rK}{4}\right) \text{--(v)}$$

$$B_{MSY} = \left(\frac{K}{2}\right) \text{---(vi)}$$

$$u_{MSY} = \left(\frac{r}{2}\right) \; or \; \left(\frac{MSY}{B_{MSY}}\right) \text{---(vii)}$$

Results

***Estimates of parameters*:** The estimated parameters using SPM model in industrial finfish catch log are shown in Table II.

Table II. The estimated parameters through SPM model using the CPUE tuning series

Quantity	Estimate
r	0.769
K	4,12,164
q	4.12E-06
a	0.307
sigma	0.287
MSY	79,325
B_{MSY}	2,06,082
u^{MSY}	0.385

***Model fit to the tuning series*:** Observed and expected index of industrial finfish catch fitted to the CPUE used for tuning the SPM model (Fig. 2). The residue sum of square (RSS) was 0.340and negative log likelihood was -4.35, which are all indicated the fairly precision between observed and expected fit.

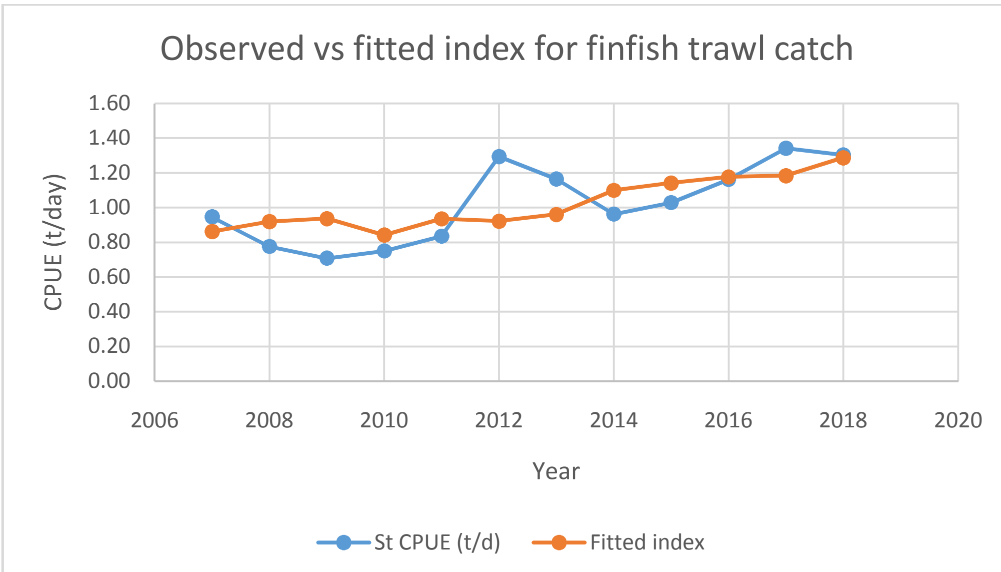

Fig. 2. Observed and expected index fit to the CPUE used for tuning the stock production model

Estimates of population trends and reference points: The standing stock biomass was always above the biomass reference point (206,082 t) since 2009, when the standing stock biomass was almost close to the reference point. The highest biomass was observed 313,478 t in the year of 2012. Then, it has gradually been down pace up to the last of the year studied. In 2018, the standing stock biomass was the lowest (211,413 t) since after 2010 (Fig. 3).

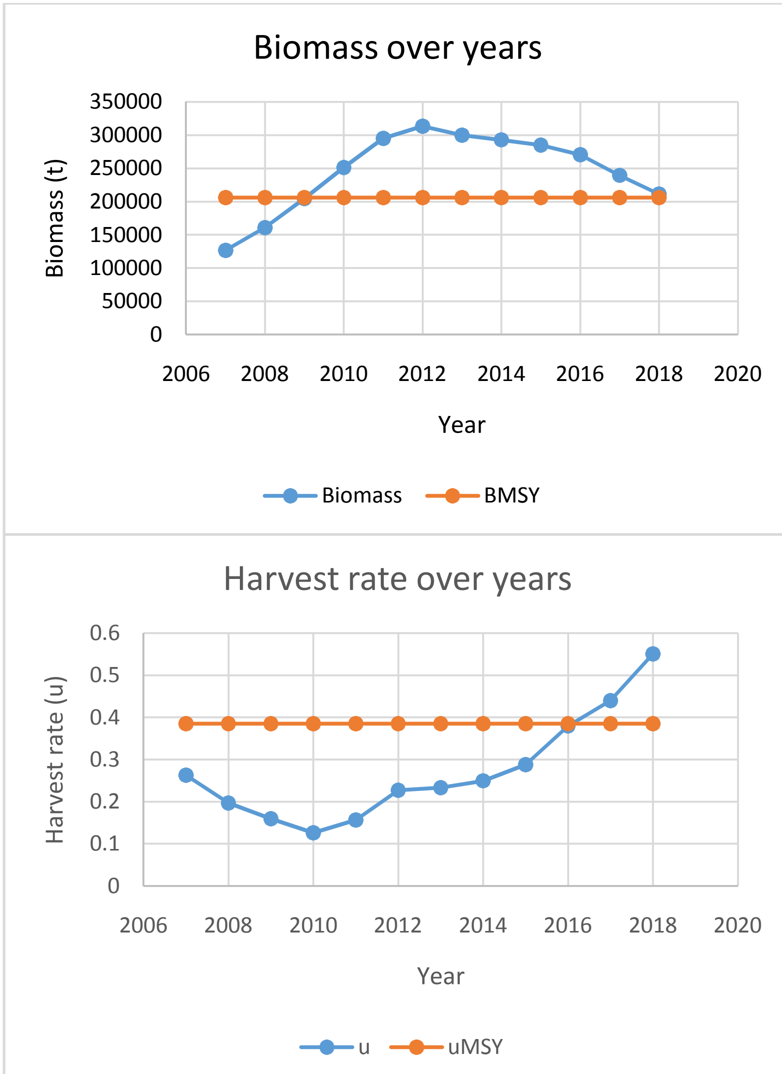

Fig. 3. Estimates of exploitable biomass (up) and harvest rate (down) for finfish fishery of Bangladesh trawl catch.

The harvest rate was always well below the reference point (0.38) since the inception of population studied. The lowest harvest rate (0.12) was observed in 2010. Then it has gradually increased for rest of the study periods. In 2015-16, its urpassed the reference point and followed same trend in rest of the years. In 2017-18 it rose to the highest up to the period studied (0.55)(Fig. 3).The catch was well below the MSY reference point since beginning of the period studied to 2011. During 2012 to 2014, the catches were close tothe MSY reference point (79,325 t). Then, the catch had taken increasing trend and it was sharply raised to 116,405 t in the year of 2018 (Fig. 4). Within a decade, lowest quantity caught by lowest efforts fishery has given the highest catch over the years studied by applying highest efforts (Fig. 5).

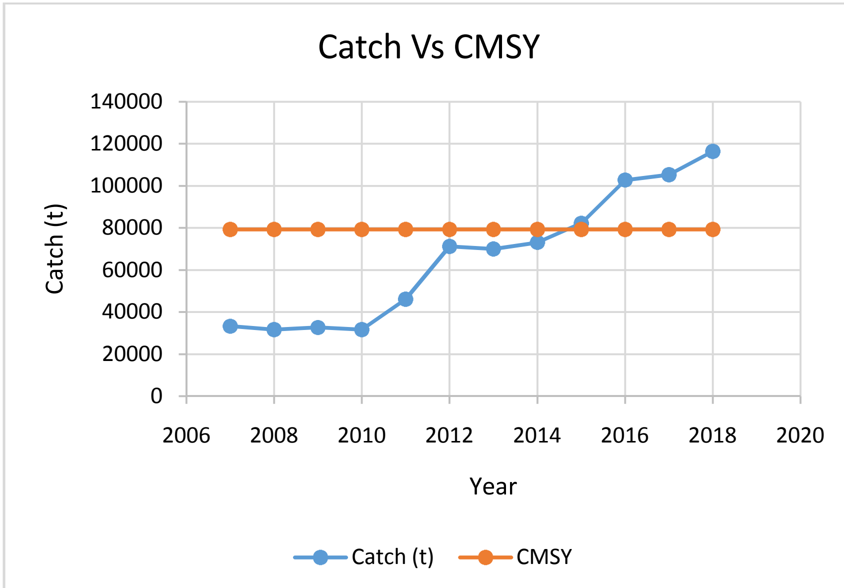

Fig. 4. Observed catch against maximum sustainable yield (*MSY*)

The abundance of large commercial species such as cat fish, croaker, grunters, scads, pomfrets, snappers etc. was higher in catch composition of Lamboeuf report (Lamboeuf 1987). In recent years, the major catch are small pelagic species such as sardine, Indian mackerels and miscellaneous in catch composition (Table III).

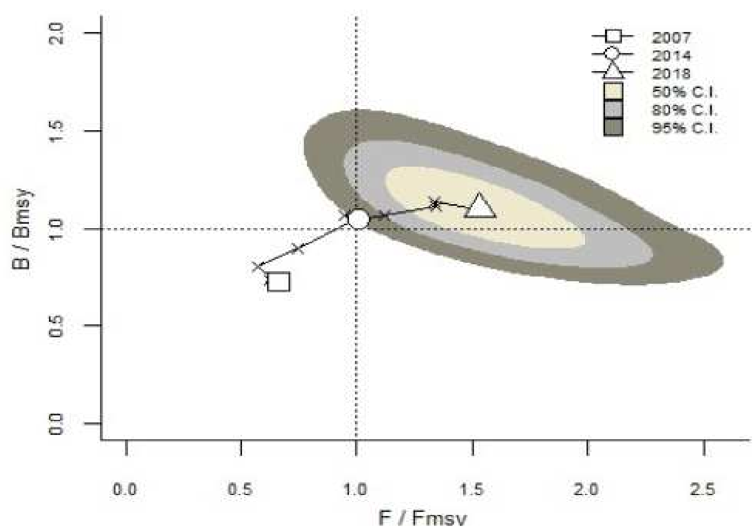

Fig. 5. Relative stock size over relative efforts.

Table III. Abundance of commercial species in various years

Family	Common name	Abundance (%)*	Abundance (%) as per daily fishing log of trawlers**		
			2015-16	2016-17	2017-18
Ariidae	Catfishes	11.99	2.19	2.24	2.47
Siaenidae	Croaker, Jew fishes	10.37	2.81	2.79	3.59
Nemipteridae	Threadfin breams	9.00	4.86	4.75	5.33
Trichiuridae	Hairtail fishes	6.19	4.65	4.75	7.35
Carangidae	Jacks, Scads, Black pomfret	5.77	5.18	3.63	3.93
Scombridae	Mackerels, Tunas	5.36	13.05	10.72	9.43
Clupeidae	Hilsha	3.57	3.60	6.68	9.44
	Sardines	-	41.43	42.58	34.94
Pomadasyidae	Grunters	2.47	0.61	0.07	0.08
Stromateidae	Pomfrets	1.82	0.26	0.63	0.73
Harpadontidae	Bombay duck	1.29	0.28	3.98	5.16
Lutjanidae	Snapper	1.07	0.69	1.28	0.23
Cephalopodae	Squids/Cuttle fishes	1.41	1.91	0.68	0.72
Elasmobranchii	Shark, Skates, Rays	3.38	0.24	0.59	0.47

* Report of Lamboeuf (1987)**Source: Marine Fisheries Office Reports

Discussion

Prediction or to know about reaction of a stock is necessary for authority or decision makers in order to proper fisheries management (Punt and Hilborn 1997). One of the main targets is to estimate the level of fishing effort so that maximum yield can be harvested from a stock without impairment of the original stock biomass. Besides, it is not a one-off activity because of its dynamic nature and changes in the amount and efficiency of fishing effort (King 1995). Catch and effort statistics data are commonly collected for all commercial fisheries with a view to calculate catch rate or CPUE, which used as an index of stock abundance. The collection and accurate interpretation of both catch and survey data are of primary importance to assess any fish stock. Both data should be considered together in order to provide a full information of stock (Kilduff *et al.* 2009).

This fitting of the surplus production models estimation have demonstrated some results of industrial finfish stock of Bangladesh. The results are interpreted on the basis of limitations ofthe model and input data of CPUE. Twelve years data is not enough for an analytical stock assessment. Here, the finfish dataset is therefore characterized as data-limited stocks (DLS). The advice for DLS stock should be precautionary, which suggests to maintain low fishing pressure in the stock, this study however might be given some effective indication of stock status. Besides, 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, and (i) catch and effort statistics are accurate. Practically, many of the above assumptions are not met but this does not mean that the method cannot be used or is not meaningful for the population estimation. As long as it is used critically, the production model is a very powerful tool for an initial assessment of a stock (Musick and Bonfil 2004), though an equilibrium is assumed to be contrasting in a fished population (Haddon 2011).

It is common to see the diverse catch composition for tropical fisheries. Regarding SPM study in tropical fisheries like many fisheries, the assortment of species treated as a single stock (King 1995, Menard *et al*. 2002). The biological interactions mean that the population dynamics of different species are inevitably linked. The simplest way to account for the multi-species nature of the catches is to uses a surplus production model for aggregated yield of individual species (Jennings *et al*. 2001). These multi-species yields can then be compared with the total effort in the fishery of interest (FAO 1978). It is suggested to manage the fishery by applying fishing effort in such a manner so that the catch never exceeds MSY level. This may act as a protective shield through given resilience to the species of low productivity as well as high productivity (King 1995).

The estimated parameters from a stock production model can be quite informative, such as the size or biomass of stock in virgin state (K),MSY, the harvest rate that will give MSY (u^{MSY}) and the biomass that gives MSY (B_{MSY}). For any rational stock, interpretation of management target is more likely an average, long term expected potential yield. MSY reference points such as B_{MSY} and F_{MSY} are commonly used as management benchmarks(Jacobson *et al.* 2002). Three exploratory surveys such as Dr. Fridtjof Nansen had assessed standing stock biomass 1,60,000 t in 1978-79 (Saetre 1981), RV Anusandhani had assessed standing stock biomass 1,52,000 t in 1981-83 (Khan 1983) and same research vessel had assessed 1,57,000 t during 1984-86 (Lamboeuf 1987). The average estimation of B_{MSY} by present study using commercial trawl catch log was 206,082 t, which is fairly close to the standing stock of previous surveys. The stock biomass was highest in the year of 2012. Then, the biomass has gradually been decreasing over the years. The stock biomass was down to 211,413 t in 2018. Simultaneously, the harvest rate has gradually been increasing over the years studied since after 2010. It had surpassed reference point, 0.38 in 2015-16 before reached to magnitude (55%) at the end of the year studied.

Maximum Sustainable Yield of reported survey studies like Dr, Fridtjof Nansen had suggested MSY of 1,00,000 t in 1978-79 and RV Anusandhani had suggested MSY of 40,000-50,000 t in 1983. The estimated MSY of present study was 79,325 t which is in between the value of MSY suggested by previous surveys. But, the actual catch had surpassed the MSY reference point in the year of 2014-15. The finfish catch was 116,405 t in the year of 2018, which is much higher than MSY reference point. The average annual catch of the last five years was 95,925 t, which is also higher than the estimated MSY. The main reason behind it is to increase fishing pressure gradually for last five years. The number of active fishing vessels were 126,165,204 and 222 in the year of 2007-08, 2011-12, 2015-16 and 2017-18 respectively (MFO 2016 and MFO annual report 2018). The number of trawlers increment in every year was about 10% over the last ten years. Besides, modern navigation and fish finding equipment including high engine power (HP), chart plotter, hull sonar, eco sounder, trawl eye, net sonaretc. has given much increased fishing efficiency of trawlers during last couple of years (DoF 2016). Consequently, the stock is therefore estimated to be in an overfishing state (Figs. 1 and 5), which is empirically being given small sized, low valued species as predominant catch instead of large-sized, commercial species in present catch composition (Table III).

Since the estimated MSY value was lower than the catch of recent years, indicating that the industrial finfish stock has been overfished. As a DLS stock, it is suggested that precautionary measures should be taken to reduce fishing pressure to a rational level with a view to manage the stock sustainably. Coordinated actions and efforts has to be addressed in order to reduce over exploitation of resources. This may include, input control such as to control vessel size, vessel number, fish hold capacity, engine horse power, installation of fish finding devices like sonar, trawl eye, etc., to impose mesh size regulation using gear selectivity, to proclaim Seasonal Fishing Ban (SFB) for a definite period, to apply Total Allowable Catch (TAC) or fish quota, to set up electronic logbook system, to properly implement MCS as per national and international marine fisheries law, etc. In this respect, a Seasonal Fishing Ban for 65 days from 20 May to 23 July has been ordained in 2015 and being implemented since then as a precautionary management scheme.

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