Maximum Sustainable Yield Estimate for Tiger Shrimp, Penaeus monodon off Bangladesh Coast Using Trawl Catch Log

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Abstract

Tiger shrimp, Penaeus monodon is the most economically important penaeid shrimp in Bangladesh for both culture and capture fishery. This study reveals an analytical stock assessment of tiger shrimp in Bangladesh marine waters after three decades of the inclusive survey. A time series of annual Catch Per Unit Effort (CPUE) was derived from commercial logbook data during the period from 1986 to 2017 and used as a tuning series for a Schaefer biomass model through MS-Excel and CMSY/BSM interfaces. The standing stock and harvest rate were estimated to be around 1250 t and 23% respectively. The estimated Maximum Sustainable Yield (MSY) reference points with 95% confidence interval are optimum biomass BMSY2360 t (1670-3320 t) and optimum fishing mortality Fmsy = 22% (16-31%). The average annual catch of last two decades 308 t, below estimated MSY of 527 t (388-717 t). Overall the stock is estimated to be at alarming state despite average annual catch lower than MSY for the last two decades. The enigma for this loophole likely to be lies indiscriminate exploitation of postlarvae (PL) from nature for coastal aquaculture and an extensive collection of brood shrimp for shrimp hatchery broodstock.

Keywords: MSY, Tiger Shrimp, Bangladesh, SPM, Trawl Catch Log.

Introduction

Penaeus monodon (Fabricius 1798) is the main commercial species among the penaeid shrimps and is commonly known as tiger shrimp in the Indo-Pacific region (Rao, 2013). It is known as 'Bagdachingri' in Bangladesh. Among the penaeid shrimps *P. monodon,*

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P semisulcatus, P. indicus, P. merguiensis are important contributors as larger shrimp in trawl catch (Mustafa, 2003). P. monodon is widely distributed in the Indian waters but forms a substantial component of the prawn landings from the sea and the estuaries of the east coast of India (Muhammed, 1970). It supports commercial fishery from the inception of the trawl industry, through their intensive exploitation is causing a decline in trawl catches. Extensive collection of postlarvae (PL) from the natural stock throughout the coastal area restrict recruitment to the industrial fishery which results in lowering of trawl catch (Khan et al., 2003). Consequently, catches of adult penaeid shrimps as broodstock for the coastal aquaculture industry have declined in terms of CPUE and size (Khan, 2010).

Each of the species of the Penaeus has peculiar latitudinal and longitudinal distribution pattern (Rao et al., 1993). The species of P. monodon spawn in the sea, but their larvae and postlarvae enter into backwaters and estuaries (Mohammed, 1970). In these ecosystems, they grow into juveniles (Rao, 1967; Subramaniam, 1987). After reaching the sub-adult stage, they migrate into inshore waters and further migrate into deeper waters for spawning on attaining maturity. Semi digested matter of the animals observed in the stomach contents of penaeid shrimps (Rao, 1988c). However, vegetable matter, large crustaceans, polychaetes, molluscs and fish as its food and is classified as an omnivore (Hall, 1962). All the species of the genus Penaeus are heterosexual and sexes can be distinguished by external characters (Rao et al., 1993).

Sustainable production model can provide guidance on stock status, MSY reference points and associated uncertainties (Cadrineet al. 1997). Surplus Production Models (SPMs) also known as biomass dynamic models (BDMs) are an important approach to the capture fisheries. Incredible work of various fisheries specialists has been accounted for production modelling (Schaefer, 1970; Fox, 1970; Hilborn & Walters, 1992). Generally, production models are based on the simple equation comprising of two or three parameters and population state and fishing activity could be described by a single variable (Laloe, 1994).

Much of the information available on the biology of the species but very few studies have been conducted on the population dynamics (Rao et al., 1993). Several researchers have studied the length-weight relationship of P. monodon following Thompson and Bell (1934) model (Rao et al.,1993; Lalita Devi, 1987, Khan et al., 2003). Barua et al. (2018) had assessed offshore shrimp stock of Bangladesh trawl catch using SPM. Some studied the P. monodon stock using SPM (Khan et al., 2003). However, there is no up-to-date published information available on stock assessment of P. monodon off the Bangladesh coast. The aim of the present study is to provide information on the stock status of P. monodon so that advice on reference points can be possible in order to drive optimum yields.

Materials and Methods

Data Collection

The time-series data (catch and effort) of Penaeus monodon of trawl catch log off the

Bangladesh coast from 1986 to 2017 (Table 1) were used into biomass pool for estimating reference points. The catch data were converted from headless weight to total weight using the conversion factor of 0.63 for tiger shrimp (Barua et al., 2018b), though they have been started to export of head-on tiger shrimp from 2012. There is minimal risk of under-reporting of shrimp catch because the majority of the catch of major shrimp species is exported (Barua et al., 2018b). Shrimp trawler engaged in fishing in the EEZ of Bangladesh beyond 40 metres depth contour (Fig. 1). Shrimp trawlers usually have 150-250 tons gross tonnage capacity including main engine power of 500-900 BHP. The maximum days of fishing per trip is 30 days. Every day 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 seaworthiness of the vessel itself (Uddin et al., 2012). The catch is expressed in metric tons (t), effort as the number of fishing days.

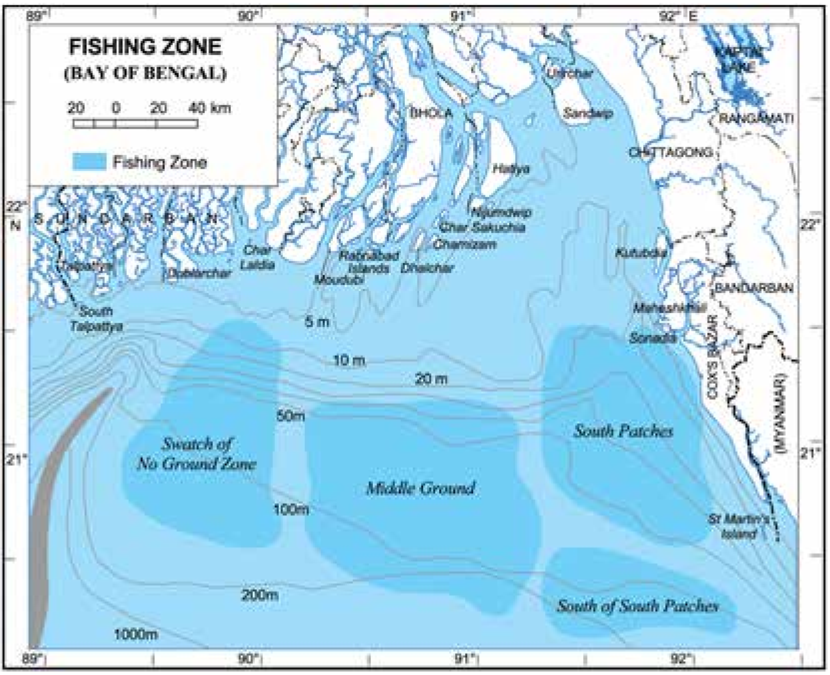

Fig.1. Map showing trawl fishing zone in Bangladesh EEZ.

Stock Production Models

For this study, a Schaefer model was applied, which was based on the logistic population growth model.

The model is described as:

$B_{(t+1)}=B_t+rB_t\,(1-Bt/K)-Ct$………………………………… (i)

Where B is the biomass, t is the time (year), K is the carrying capacity, C is the catch

Table 1. The time-series data of P. monodon from trawler catch (Source: Marine Fisheries Office report).

Year	Time (fishing day)	Catch (t)	CPUE (t/d)
1986	6429	776.19	0.121
1987	6642	922.22	0.139
1988	7806	863.49	0.111
1989	7394	785.71	0.106
1990	5658	568.25	0.100
1991	5529	782.54	0.142
1992	6588	761.90	0.116
1993	7113	488.89	0.069
1994	6691	474.60	0.071
1995	6502	446.03	0.069
1996	6914	533.33	0.077
1997	7044	330.16	0.047
1998	7645	371.43	0.049
1999	7152	260.32	0.036
2000	7289	323.81	0.044
2001	6935	292.06	0.042
2002	7069	303.17	0.043
2003	7442	347.62	0.047
2004	7866	349.21	0.044
2005	7466	328.57	0.044
2006	5919	330.16	0.056
2007	5969	353.97	0.059
2008	5956	395.24	0.066
2009	4581	385.71	0.084
2010	4718	339.68	0.072
2011	4116	247.62	0.060
2012	4436	188.21	0.042
2013	4935	257.02	0.052
2014	4543	235.02	0.052
2015	4703	296.95	0.064
2016	4635	274.54	0.059
2017	5258	289.24	0.055

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).

MS-Excel

A non-equilibrium Schaefer surplus production model was fitted to the time-series input data. The initial biomass (B0), K and r for the stock was predicted at the beginning of the trend analysis. Then next year biomass was calculated by the following function:

Biomass= max (B0+r B0*(1- B0/K)-catch)*---------------------------------(ii)

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 the observed and expected index for estimating these parameters. Sums of squared normal residual error (RSS) were then calculated. These estimated parameters were also transformed (loge) 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)*--------------------(iii)

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

This was done to check the uncertainty of the model. Then, the solver was used to estimating the most reasonable output of desired parameters by targeting a minimum residual sum of square (RSS).

The CMSY method

The Catch-MSY method (CMSY) as proposed here was inspired by the stock reduction analysis of Kimura and Tagart (1982) and Kimura et al., (1984). As input data, it requires a time series of removals, prior ranges of r and k, and possible ranges of relative stock sizes in the first and final years of the time series. It then uses the Schaefer production model to calculate annual biomasses for a given set of r and k parameters. As no prior distributions of r and k are available for most fish stocks, we randomly draw r-k pairs from a uniform prior distribution and then use a Bernoulli distribution as the likelihood function for accepting each r-k pair that has never collapsed the stock or exceeded carrying capacity and that results in a final relative biomass estimate that falls within the assumed range of depletion (Martell & Froese 2012).

Derived Parameters

The estimated parameters *r, q* and *K* can be used to calculate management reference points such as *MSY*, Biomass that gives MSY (B_{MSY}), Fishingmortality at MSY(F_{MSY}) as in:

$MSY = (rK/4)$---(iv)

$B_{MSY} = (K/2)$ ---(v)

$F_{MSY}= (r/2)$ or (MSY/B_{MSY}) ---(vi)

Results

The base parameters of the stock production model were quite similar irrespective of the interfaces used to assay. The intrinsic growth rate r, catchability coefficient q and carrying capacity K were estimated 0.447 (0.321-0.623), 0.0000467 (0.0000364-0.000060) and 3391 t (12039-26489 t) respectively. The bracketed value indicates a 95% confidence interval of estimated quantity (Table 2). The estimated MSY reference points with 95% confidence intervals are optimal biomass BMSY = 2360 t (1670–3320 t) and fishing mortality rate FMSY = 22% (16–31%). The average annual catch in this period is 289 t, less than the estimated MSY of 527 t (388-717 t) (Table 2).

Observed and expected index of tiger shrimp catch fitted to the CPUE used for tuning the SPM model (Fig. 2). The residue sum of square (RSS) was 1.10. The negative log-likelihood was -8.48, which is indicated the most likely precision between observed and expected fit.

The catch was far below from MSY reference point (527 t) for the last two decades although the catch was higher than MSY in the first decade of the study. The calculated biomass is 1250 t, which is far lower than the biomass reference point (2360 t) since last two and half decades. But, surprisingly the exploitation rate is above Fmsy reference point almost throughout the study period. Therefore, the relative biomass over relative effort indicates stock at an alarming state though catch has been showed far lower than MSY level for the last two decades (Fig. 3).

Table 2: Point estimates and 95% confidence intervals of estimated parameters, biomass in 2018 and reference points.

Quantity	Estimate	95% CI
r	0.447	0.321-0.623
K	4720	3350-6650
q	0.0000467	0.0000364-0.000060
Sigma	0.185	0.126-0.213
MSY	527	388-717
B_{MSY}	2360	1670-3320
F_{MSY}	0.224	0.160-0.312
F_{2017}	0.232	0.186-0.327
B^{2018}	1250	885-1550

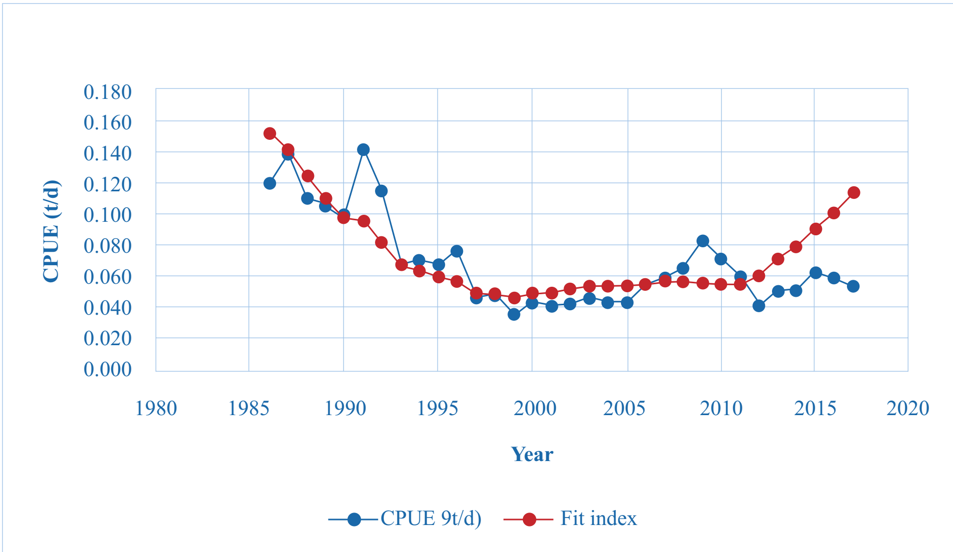

Fig.2. Observed and expected index fit to the CPUE used for tuning the stock production model.

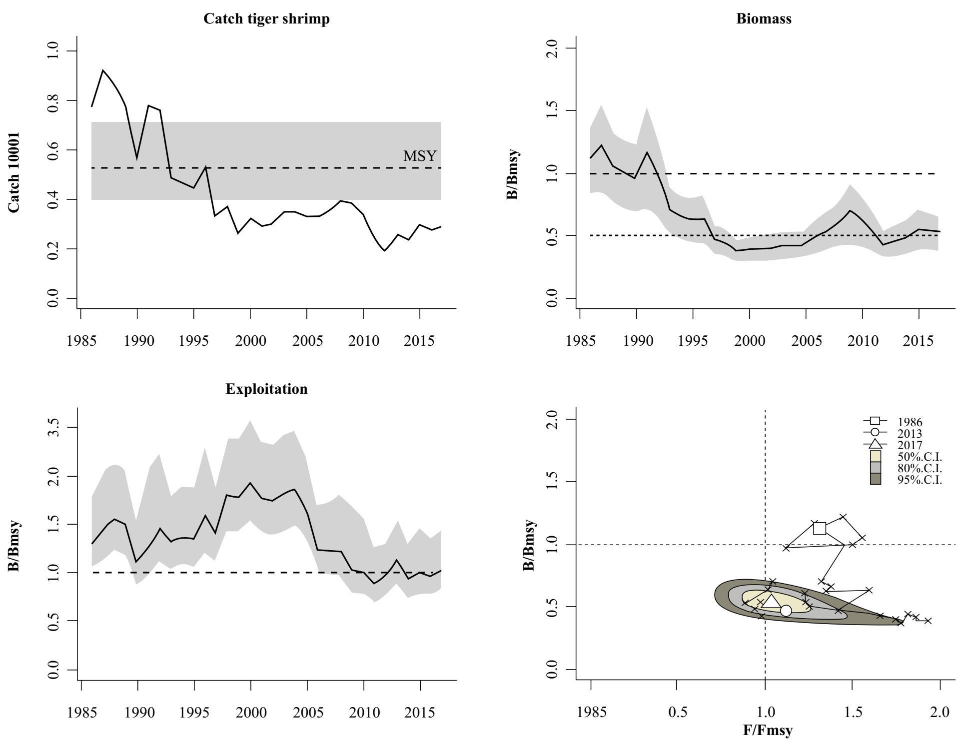

Fig. 3: Results for management including stock status based on CMSY/BSM analysis for Tiger shrimp for the period from 1986 to 2017.

Discussion

The surplus production model is important in assessing the stock of aquatic species. Estimated reference points on biomass and harvest rule which are described here can be applied depends on reliable estimates of r and K. Most of the production models require a time series catch and effort data to provide dependable parameter estimates (Prager et al. 1996). In the case of less informative data to estimate parameters, independent data can be used to fix certain parameters. For instance, Prager (1993) fixed the value of r to provide guidance on MSY, but fixing r will determine the level of FMSY.

SPM has some assumptions. Practically, many of the assumptions are not met but this does not mean the method cannot be used. As long as it is used critically the model is a very powerful tool for initial assessment of a stock (Musick & Bonfill, 2004). In SPM, Maximum Sustainable Yield (MSY) is considered as a biological reference point on which sustainable exploitation goal can be achieved (Hilborn& Walters, 1992; Maunder et al., 2006; Musick&Bonfill, 2004 and Prager, 1994).

The present study provides information on reference point through SPM of P. monodon. The value of intrinsic growth rate, r obtained in the present study correspond to the findings of Komi et al. (2013), who studied r of P. monodon in the Andoni River, Nigeria (r = 0.87) and Barua et al. (2018), who assessed stock status of Bangladesh offshore shrimp including r = 0.76. The estimation of r, K and q from this study were 0.45, 4720 t and 0.0000467 respectively. Application of Verhulst equation and Pauly's model to the data on shrimp stock of Bangladesh from the year 1981-82 to 1997-98 by Ray & Khan (2003) resulted in r and K values of 1.33 and 11400 t respectively. The catchability coefficient of the present study is lower than the value of q (0.000097) estimated by Ray & Khan (2003).

The relative biomass over relative effort (Fig. 3) indicates stock at alarming state though catch has been showed lower than MSY level for the last two decades. The enigma of this loophole likely to be lies indiscriminate exploitation of post larvae from the coast (Khan et al., 2003; Quader 2010, DoF 2013) an extensive collection of brood shrimp from wild source for tiger shrimp hatchery (Khan, 2010).

Conclusion

The stock of tiger shrimp is in an alarming state not due to commercial fishers but mostly due to lack of management strategy. For its rejuvenation, some steps are deemed necessary. First, an attempt has to be taken on stop collection of PL from the natural source (coast) and second, discourage collection of broodstock for shrimp hatchery from a wild source.

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