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# Maximum sustainable yield estimation of shellfish fishery in Chinese marine waters by using surplus production modelling approach

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In this study, maximum sustainable yield (MSY) of shellfish fishery from Chinese marine waters is estimated through two stock assessment softwares i.e. ASPIC (a surplus production model incorporating covariates) and CEDA (catch and effort data analysis). The initial catch was approximately 90%; hence, the MSY was estimated with initial proportion (IP) of 0.9 in both softwares. In ASPIC for this IP value, estimated MSY and goodness of fit ($R^2$) parameters for FM were observed as 336100 t and 0.857 while for LM their estimated values remained as 316600 t and 0.856, correspondingly. In CEDA for IP value 0.9, SM and PTM estimated same MSY 213957 t, 322791 t and 266213 t for all the three error assumptions. FM for log and log normal error assumptions estimated MSY as 249382 t and 338355 t and $R^2$ = 0.756 and 0.786, respectively. However, gamma error assumption produced minimization failure (MF).

[**Keywords*:*** Stock assessment; Fishery management; Shellfish; Surplus production models; China]

## Introduction

China is the world's largest seafood production market. It is considered that it will become a largest seafood import market also within a decade with exports earnings of approximately $15.5 billion. The rapid growth of the middle and high-income consumers has a strong influence on the consumption of more premium imported fresh and live shellfish[1]. Consequently, shellfish fishery including scallop, oysters, abalones, mussels, etc. became one of the most significant fishery resources landed on the harbour stations along the entire coastline of China.

Stock assessment based scientific advice is the key factor in the management of many of the world's marine fish and invertebrate stocks[2]. Stock assessment is usually used for one of the two reasons: first as a research tool to evaluate fundamental fishery/ biological relationships in a population model context, and second to give management advice and approximate quantities, of management interests, in the form of reference points. Management actions will take on the basis of these estimates which are frequently used as the source for applying harvest control rules or evaluating anticipated regulatory measures i.e. total allowable catches or limits on fishing effort[3]. Consequently, the most important intention is to use stock assessment for aquatic resources is to give significant biological suggestions for the wise use of the living aquatic resources for a long period.

Surplus production models (SPMs) are famous and conventional tools often employed in fishery stock assessment. In contrast to catch statistics, catch per unit effort (CPUE) can also be employed to calculate various parameters. The fishery stock status can also be accessed by the use of the commercial as well as survey catch statistics or CPUE data[4].

Previous forms of SPMs assumed that the fishery stocks are at an equilibrium state, which seldom occurs in natural fish populations[5]. On the other hand, recent versions of SPMs assume fishery stock in non-equilibrium state. These models are comparatively complicated to deduce because they often use non-linear regression. Currently, a variety of computer packages i.e. a stock production model incorporating covariate (ASPIC) and catch and effort data analysis (CEDA), have been developed which have the capacity to evaluate dynamics of the exploited fishery stock. A plethora of published literature reveals that SPMs are very vital tools in fishery stock assessment and have been used globally in fishery management[6-11].

China is a major contributor in global fish production. However, if over-exploitation of any fishery resource will occur in Chinese marine water then it will definitely have very deleterious effect on global fish production. Although, various managerial steps has been taken previously to control over-exploitation of shellfish fishery stock in Chinese marine waters. Nevertheless, unfortunately there is no concept regarding specific catchable value i.e. MSY. Hence, this research article is the first reporting about the fishery stock of Shellfish by using catch and effort data and estimating catchable value (MSY). It is expected that this finding will help to understand population dynamics of this fishery stock and help in making better fishery policies.

## Materials and Methods

The stock status of shellfish fishery was evaluated by analysing the available CE data of twelve years, 2003-2014, from Chinese marine waters. CE data was procured from published Chinese fishery yearbooks. Acquisition of data and their scientific treatment requires consent of the publishing authority.

SPMs are used to analyse the procured time series data of catch in tons (t) and effort in the form of no. of fishermen. Two stock assessment softwares i.e. CEDA[4] and ASPIC[12] downloaded from MRAG website and NOAA Fisheries Toolbox in that order were used for this purpose. We used nominal CPUE for fish stock assessment as per described by Hoggarth et al. (2006) in this regard. These SPMs are often called biomass dynamic models, which have three different versions on the names of three different scientist Fox, Schaefer and Pella-Tomlinson. SPMs are depended on few assumptions. The SM (1954) is most commonly used model and based on logistic population growth model.

$$\frac{dB}{dt} = rB(B_\infty - B) \quad 13$$

While, Fox and Pella-Tomlinson models are built on Gompertz growth equation and generalized production equation respectively.

$$\frac{dB}{dt} = rB(1nB_\infty - 1nB) \quad 14 \qquad \frac{dB}{dt} = rB(B_\infty^{n-1} - B^{n-1}) \quad 15$$

where, $B$ is fish stock biomass, $n$ represents shape parameter, $t$ shows the time (year), $B_\infty$ is carrying capacity ($K$) and $r$ stands for the intrinsic rate of population growth.

ASPIC software also requires an input of IP. Conversely to CEDA, ASPIC requires individual IP values. Two SPMs i.e. FM (a special case of GENFIT) and LM (also called Schaefer model) were employed by using this fishery software. ASPIC is also used to evaluate further various important parameters as MSY, $K$, $q$, $B_1/K$ (starting biomass over carrying capacity), $R^2$ (coefficient of determination), $F_{MSY}$ (fishing mortality rate at MSY), $B_{MSY}$ (stock biomass giving MSY).

For model selection, several factors were well thought-out as described by Hoggarth et al. (2006). Sensitivity analysis was performed by using IP values (Table 2 and Table 5). Computed results for various parameters were further considered along with $R^2$ values and visual inspection of the residual plots for model selection and comparison for depiction reliable results.

CEDA computer software has the capacity to compute customized parameters. It is a menu driven data fitting tool and requires a confidence interval of 95 percent through bootstrapping method. In addition, CEDA expects three error assumptions i.e. log, log-normal and gamma for all the SPMs i.e. FM, SM and PTM. It has very valuable tools having graphs and goodness of fit. This computer software needs an input of IP or $B_1/K$. Initial catch value is divided by the maximum catch value present in the CE data series to calculate IP value. Moreover, fishery stock status is also assessed by using different IP values. When the input IP value is zero or one then CEDA evaluates parameters by considering fishery stock in virgin state or started from already over-exploited state in that order. Occasionally, initial biomass is set as $B_1 = C_1/ (qE_1)$. In this mathematical statement, C, q and E denote catch, catchability and fishing effort in that order but some tools also consider $B_1 = K$. Confidence intervals are used to compute CV. Similarly, CEDA is also used to compute various further vital parameters viz. MSY (maximum sustainable yield), $K$ (carrying capacity), $q$ (catchability coefficient), $r$ (intrinsic growth rate), $R_{yield}$ (replacement yield) and final biomass.

## Results

During the study period, total capture production of shellfish fishery in Chinese marine waters was observed as 8250928 t. Maximum, minimum and average capture production of shellfish was remained as 885209 t (2005), 551607 t (2014) and 687577 t year $^{-1}$ in that order. Highest and lowest values of CPUE (catch per unit effort) were observed during the third and last three years of the study i.e. 0.125 (2005) and 0.071 (2012, 2013 and 2014) correspondingly (Table 1).

The average effort during the study period remained 14016402 no. of fishermen year$^{-1}$. Calculated results by using CEDA and ASPIC were further analysed by allowing for four factors viz. MSY, $R^2$, residual plots between observed, expected catches and CV. Calculated MSY values were compared with data values, and very large or small MSY values were not considered. Models were compared on the basis of $R^2$ values and visual assessment of graphs. The higher is the value of $R^2$ the better is the fitting of the model. Results with appropriate CV values were acknowledged.

Table 1 — Time series catch and effort data (2003-2014) of Shellfish fishery in Chinese marine waters

| Year | Catch | Fishermen | CPUE |
|---|---|---|---|
| 2003 | 806163 | 7007564 | 0.115 |
| 2004 | 846868 | 7109179 | 0.119 |
| 2005 | 885209 | 7100086 | 0.125 |
| 2006 | 770937 | 7054950 | 0.109 |
| 2007 | 743617 | 7553430 | 0.098 |
| 2008 | 643759 | 8474790 | 0.076 |
| 2009 | 669742 | 7577467 | 0.088 |
| 2010 | 622104 | 7641119 | 0.081 |
| 2011 | 584078 | 7983867 | 0.073 |
| 2012 | 563422 | 7903564 | 0.071 |
| 2013 | 563422 | 7886147 | 0.071 |
| 2014 | 551607 | 7814451 | 0.071 |

Computed parameters for IP 0.9 by ASPIC are listed in Table 2. FM revealed better fit as its $R^2$ value (0.857) was higher than the computed $R^2$ value (0.856) for LM. For the SPMs i.e. FM and LM used in ASPIC, estimated MSY along with their CV values were remains as 336100 t (0.206) and 315600 t (0.196) correspondingly. Estimated $K$, $B_{MSY}$ (stock biomass giving MSY) and $F_{MSY}$ (fishing mortality rate at MSY) observed as 11590000 t, 4266000 t, 0.0788 t and 11050000 t, 5524000 t, 0.05714 t for FM and LM in that order.

Table 3 shows various parameters estimated for IP 0.1 – 0.9. Similar to CEDA, ASPIC also revealed sensitivity to IP values as it evaluated various output

Table 2 — Various parameters computed by using ASPIC software for Shellfish fishery in Chinese marine waters (IP = 0.9)

| Model | $B_1$/K (IP) | MSY | $R^2$ | CV | $F_{MSY}$ | $B_{MSY}$ | $K$ | $q$ |
|---|---|---|---|---|---|---|---|---|
| Fox | 0.9 | 336100 | 0.857 | 0.206 | 0.0788 | 42660000 | 11590000 | 1.26E-08 |
| Logistic | 0.9 | 315600 | 0.856 | 0.196 | 0.0571 | 55240000 | 11050000 | 1.32E-08 |

Note: MSY: maximum sustainable yield; $R^2$: coefficient of determination and biomass; CV: coefficient of variation; F/$F_{MSY}$: ratio of fishing mortality to fishing mortality rate at MSY; B/$B_{MSY}$: ratio of biomass to biomass giving MSY; $K$: carrying capacity; $q$: catchability coefficient

Table 3 — ASPIC results for Shellfish fishery in Chinese marine waters by using ASPIC software (IP = 0.1-0.9)

| Model | $B_1$/K (IP) | MSY | $R^2$ | CV | $F_{MSY}$ | $B_{MSY}$ | $K$ | $q$ |
|---|---|---|---|---|---|---|---|---|
| Fox | 0.1 | 1252000 | 0.867 | 0.019 | 0.232 | 5404000 | 14690000 | 8.86E-08 |
| | 0.2 | 770700 | 0.860 | 0.056 | 0.143 | 5392000 | 14660000 | 4.48E-08 |
| | 0.3 | 591700 | 0.858 | 0.084 | 0.117 | 5057000 | 13750000 | 3.19E-08 |
| | 0.4 | 492300 | 0.858 | 0.099 | 0.101 | 4899000 | 13320000 | 2.46E-08 |
| | 0.5 | 439400 | 0.858 | 0.134 | 0.096 | 4596000 | 12490000 | 2.11E-08 |
| | 0.6 | 399200 | 0.857 | 0.139 | 0.089 | 4476000 | 12170000 | 1.80E-08 |
| | 0.7 | 372300 | 0.857 | 0.163 | 0.085 | 4363000 | 11860000 | 1.58E-08 |
| | 0.8 | 349400 | 0.857 | 0.233 | 0.081 | 4324000 | 11750000 | 1.40E-08 |
| | 0.9 | 336100 | 0.857 | 0.206 | 0.079 | 4266000 | 11590000 | 1.26E-08 |
| Logistic | 0.1 | 2277000 | 0.889 | 0.000 | 0.514 | 4428000 | 8855000 | 1.31E-07 |
| | 0.2 | 1281000 | 0.899 | 0.000 | 0.600 | 2134000 | 4268000 | 1.40E-07 |
| | 0.3 | 970900 | 0.884 | 0.002 | 0.652 | 1489000 | 2977000 | 1.41E-07 |
| | 0.4 | 773100 | 0.858 | 0.038 | 0.322 | 2398000 | 4797000 | 6.85E-08 |
| | 0.5 | 607300 | 0.856 | 0.081 | 0.167 | 3629000 | 7258000 | 3.62E-08 |
| | 0.6 | 496200 | 0.856 | 0.101 | 0.112 | 4421000 | 8842000 | 2.47E-08 |
| | 0.7 | 417600 | 0.856 | 0.158 | 0.085 | 4942000 | 9883000 | 1.89E-08 |
| | 0.8 | 360300 | 0.856 | 0.154 | 0.068 | 5279000 | 10560000 | 1.55E-08 |
| | 0.9 | 315600 | 0.856 | 0.196 | 0.057 | 5524000 | 11050000 | 1.32E-08 |

parameter values for different IP input. ASPIC computed larger MSY for smaller IP value and vice versa. However, parameters evaluated by this software did not show higher difference as compared to CEDA. Calculated MSY, for example, by ASPIC ranged in 31500 t – 2300000 t while for CEDA its estimated range was 210000 t – 8200000 t. It shows even though ASPIC is sensitive to IP values but its sensitivity is less than CEDA. In converse to CEDA, ASPIC models revealed higher $R^2$ values representing better fitting of the data.

Computed fishing mortality (*F*) and biomass (*B*) values of shellfish by using ASPIC are listed in Table 4. Figures obtained point out that F has shown rising trend with the passage of time whereas *B* is declining. $F/F_{MSY}$ is increased and $B/B_{MSY}$ is decreased during the course of study period. Both, $F/F_{MSY}$ and $B/B_{MSY}$ designate overexploitation of this fishery stock.

CEDA revealed sensitivity towards the input IP values as it created various output MSY values for different IP inputs (Table 5). Gamma error

Table 4 — ASPIC software estimates of Fishing mortality (*F*) and Biomass (*B*) (IP = 0.9) (2003-2014)

| Year | Model: Fox | | | | Logistic | | | |
|---|---|---|---|---|---|---|---|---|
| | *F* | *B* | $F/F_{MSY}$ | $B/B_{MSY}$ | *F* | *B* | $F/F_{MSY}$ | $B/B_{MSY}$ |
| 2003 | 0.080 | 10420000 | 1.017 | 2.442 | 0.084 | 9966000 | 1.466 | 1.804 |
| 2004 | 0.090 | 9723000 | 1.147 | 2.279 | 0.094 | 9302000 | 1.653 | 1.684 |
| 2005 | 0.102 | 9032000 | 1.294 | 2.117 | 0.106 | 8649000 | 1.863 | 1.566 |
| 2006 | 0.096 | 8344000 | 1.213 | 1.956 | 0.100 | 7999000 | 1.743 | 1.448 |
| 2007 | 0.098 | 7803000 | 1.249 | 1.829 | 0.102 | 7493000 | 1.793 | 1.356 |
| 2008 | 0.090 | 7314000 | 1.147 | 1.715 | 0.094 | 7033000 | 1.643 | 1.273 |
| 2009 | 0.099 | 6943000 | 1.259 | 1.628 | 0.103 | 6686000 | 1.803 | 1.210 |
| 2010 | 0.097 | 6561000 | 1.234 | 1.538 | 0.101 | 6321000 | 1.767 | 1.144 |
| 2011 | 0.096 | 6239000 | 1.215 | 1.463 | 0.099 | 6010000 | 1.741 | 1.088 |
| 2012 | 0.097 | 5964000 | 1.225 | 1.398 | 0.100 | 5739000 | 1.757 | 1.039 |
| 2013 | 0.101 | 5717000 | 1.278 | 1.340 | 0.105 | 5490000 | 1.838 | 0.994 |
| 2014 | 0.103 | 5476000 | 1.306 | 1.284 | 0.108 | 5241000 | 1.886 | 0.949 |

Note: F: fishing mortality; B: biomass; $F/F_{MSY}$: ratio of fishing mortality to fishing mortality rate at MSY; $B/B_{MSY}$: ratio of biomass to biomass giving MSY

Table 5 — CEDA results for Shellfish fishery in Chinese marine waters by using ASPIC software (IP = 0.1-0.9)

| IP | Model: Schaefer | | | Pella-Tomlinson | | | Fox | | |
|---|---|---|---|---|---|---|---|---|---|
| | Normal | Log normal | Gamma | Normal | Log normal | Gamma | Normal | Log normal | Gamma |
| 0.1 | MF | 2257996 | 8173947 | MF | 2257996 | 8173947 | 1294272 | 1294244 | 1206904 |
| | 0.000 | 0.000 | 0.158 | 0.000 | 0.000 | 2.979 | 0.001 | 0.000 | 0.021 |
| 0.2 | MF | 1258573 | MF | MF | 1258573 | MF | 721928 | 642682 | 895437 |
| | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.100 | 0.025 | 0.000 |
| 0.3 | MF | 942237 | MF | MF | 942237 | MF | 532306 | 505098 | 565486 |
| | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.166 | 0.054 | 0.134 |
| 0.4 | 723751 | 734022 | MF | 723751 | 734022 | MF | 431740 | 470923 | 468641 |
| | 0.053 | 0.003 | 0.000 | 0.052 | 0.003 | 0.000 | 0.218 | 0.066 | 0.157 |
| 0.5 | 524953 | 608293 | 566261 | 524953 | 608293 | 566261 | 368477 | 415531 | 408399 |
| | 0.184 | 0.013 | 0.137 | 0.175 | 0.016 | 0.132 | 0.261 | 0.112 | 0.205 |
| 0.6 | 399923 | 531054 | MF | 399923 | 531054 | MF | 324847 | 416507 | MF |
| | 0.288 | 0.036 | 0.000 | 0.303 | 0.026 | 0.000 | 0.347 | 0.117 | MF |
| 0.7 | 316791 | 378250 | 369144 | 316791 | 378250 | 369144 | 293600 | 410868 | MF |
| | 0.405 | 0.160 | 0.282 | 0.392 | 0.149 | 0.283 | 0.433 | 0.148 | MF |
| 0.8 | 257831 | 364424 | MF | 257831 | 364424 | MF | 2687701 | 413041 | 314823 |
| | 0.521 | 0.212 | 0.000 | 0.528 | 0.170 | 0.000 | 0.498 | 0.161 | 0.372 |
| 0.9 | 213957 | 322791 | 266213 | 213957 | 322791 | 266213 | 249382 | 338355 | MF |
| | 0.687 | 0.287 | 0.453 | 0.685 | 0.267 | 0.482 | 0.626 | 0.270 | MF |

CV: coefficient of variation is written below MSY values; MF: represents minimization failure assumption sometimes produced minimization failure in all the SPMs used. This is a statistical method used to estimate uncertainty in an analysis. This method involves data re-sampling. It is used to estimate confidence intervals. Actually, this method simulates new data sets after comparing the difference between observed and expected data sets[4]. Moreover, normal assumption produced minimization failure for IP values of 0.1, 0.2 and 0.3 for Schaefer and Pella-Tomlinson model. CV values were calculated by using a special method called bootstrapping confidence limit method. CEDA estimates parameters by using method of non-linear minimization techniques through employing Simplex method. A number of iterative steps are used in these complex statistical methods. In each step change in the values of estimated parameter are simultaneously correlated with the minimization of the function to be evaluated. Calculated parameters for IP 0.9 are given in Table 6.

For all the SPMs used along with their error assumptions either MSY or $R^2$ value did not produce rational results except for IP 0.9. For IP 0.9, both the models i.e. SM and PTM estimated $R^2$ values were same as 0.753, 0.782 and 0.768 in that order. In FM values of $R^2$ were 0.756 and 0.786 by using normal and log normal assumption correspondingly while gamma showed minimization failure. $R^2$ (the goodness of fit) values are very important to judge as they tell us about the appropriation of the model.

Estimated MSY figures for all the error assumptions used in SM and PTM remained same. For both of these models, their values were 213957 t, 322791t and 266231 t in that order. Computed CV values for both of these models for all the error assumptions were 0.687 0.287, 0.453 and 0.685, 0.267, 0.482 respectively. Calculated $B_{MSY}$ estimates are identical for the entire SM and PTM. This may be due to the convergence of PTM at 0.5 of $B_{MSY}/K$, which implies the results of this model may not be considerable. However, for model evaluation full criteria used has already been described. Computed values of MSY and their CV for FM with normal assumption were 249382 t and 0.626 correspondingly while for log normal their values examined as 338355 t and 0.27 in that order. Gamma error assumption produced MF for FM. Figure 1 shows the graphical representation of experiential and predictable annual catch values. From visual examination it can be recognized that experiential and predictable catch values are close to each other for all the error assumptions used in Fox model, however in detail, they are at variance from each other. CEDA estimated higher MSY values with lower IP values and vice versa.

## Discussion

Previous simulation analyses propose that both i.e. the model and the original data are the key components in presentation of the models[16]. Schaefer (1954), Fox (1970) and Pella-Tomlinson (1969) derived the formulation of SPMs. Since then, the other researchers have been originated many alternate production models[5]. Previously, the stock status of various important fish resources has been assessed by these SPMs[17-22]. Hence we selected the same SPMs for the estimation of different reference points e.g. MSY, $B_{MSY}$ and $F_{MSY}$.

They are usually preferred as compared to age-structured models because data for age-structured models is difficult to collect. On the other hand, SPMs require simple data onto catch and effort or index of abundances (CPUE). Their estimated parameters can be easily computed based on biological reference points or MSY. They give us the direction in making harvest strategies for sustainable fishing[23]. Moreover, these SPMs are used to calculate other different important parameters such as $B_{current}$, $F_{current}$, $B_{MSY}$, and

Table 6 — Various parameters computed by using CEDA computer package for Shellfish fishery in Chinese marine waters (IP = 0.9)

| Model | MSY | $R^2$ | CV | *K* | *q* | *r* | $R_{yield}$ | *B* | $B_{MSY}$ |
|---|---|---|---|---|---|---|---|---|---|
| Schaefer (Normal) | 213957 | 0.753 | 0.687 | 13551660 | 1.06E-08 | 0.063 | 211701 | 6080042 | 6790850 |
| Schaefer ( Log Normal) | 322791 | 0.782 | 0.287 | 11159780 | 1.31E-08 | 0.116 | 320062 | 5066825 | 5929465 |
| Schaefer (Gamma) | 266213 | 0.768 | 0.453 | 12469550 | 1.16E-08 | 0.085 | 263832 | 5645121 | 6234775 |
| Pella-Tomlinson (Normal) | 213957 | 0.753 | 0.685 | 13551660 | 1.06E-08 | 0.063 | 211701 | 6080042 | 6790850 |
| Pella-Tomlinson ( Log Normal) | 322791 | 0.782 | 0.267 | 11159780 | 1.31E-08 | 0.116 | 320062 | 5066825 | 5929465 |
| Pella-Tomlinson (Gamma) | 266213 | 0.768 | 0.482 | 12469550 | 1.16E-08 | 0.085 | 263832 | 5645121 | 6234775 |
| Fox (Normal) | 249382 | 0.756 | 0.626 | 13581700 | 1.06E-08 | 0.050 | 243461 | 6124108 | 4996428 |
| Fox ( Log Normal) | 338355 | 0.786 | 0.27 | 11858930 | 1.23E-08 | 0.078 | 329513 | 5397392 | 4362657 |
| Fox (Gamma) | MF | MF | MF | MF | MF | MF | MF | MF | MF |

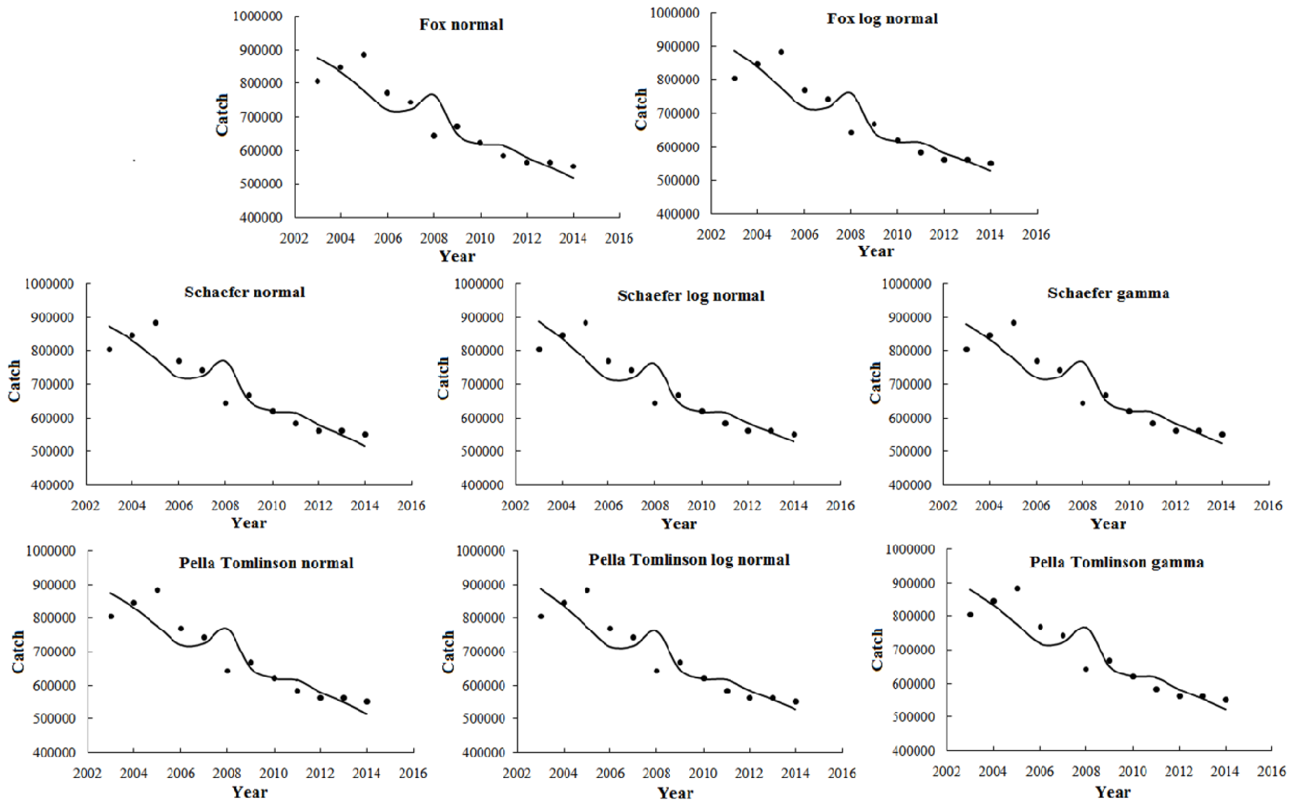


Fig. 1 — Annual observed (dots) and estimated (lines) catches (metric tons) for shellfish fishery by using CEDA computer package in Chinese marine waters

$F_{MSY}$. In the same manner, current population size can also be used in estimation of the fish mortality ($F_{MSY}$) and catchability co-efficient (*q*).

Relatively simple statistical data of CE and CPUE can also be employed for indication of the status of fishery stock. For instance, if effort is increasing and catch is decreasing, this may indicate that fish stock is declining rapidly. Moreover, when effort maintains to a fix point i.e. not increasing or decreasing, but catch increase or decrease then it may be due to quantitative fluctuation in fishery stock. Additionally, when both effort and catch reveals rising trend, it may be predicted that fish stock is not disturbing because of over-fishing[4].

Statistical calculations, which are the fundamentals of SPMs, are computed by definite assumptions. However, various assumptions are not found in nature. Various SPMs, for instance, assume that there is no inter or intra specific interactions in natural environment. Similarly, SPMs also perceived that there is no emigration or immigration in fish stock. These both are completely wrong perceptions concerning natural environment[4].

Another disadvantage of these models is their incompetence towards age structure data. These models also do not consider time delays between recruitment and reproduction. Moreover, uncertainty is also associated with estimation of MSY. Generally, it is also implicated that all the gathered CE data is true, fishing and mortality increase and decrease all together, age composition do not affect the *r*, gear and vessels always remain equally efficient and catchability coefficient remains constant[24].

Nevertheless, all of these uncertainties and deviations from assumptions, the scientific approach of these models is not neglected. Instead, considerable use of these models make them powerful tool for assessment the stock status of important fishery resources[25].

Fishery management is principally an integrated process, which engages data collection, analysis, explanation of results, consultation, and planning and decision making[26] involving stakeholders[27]. RPs are frequently used to set administration objectives and track fishery status in the science of fishery management. The different RPs for fish stock can be estimated after obtaining best-fit data, which is accessed by using model parameters[4]. Idea of RPs was first described in 1992 however; they are a part of the FAO Code of Conduct for Responsible Fisheries recently[28]. These RPs are usually classified into two types: TRPs (target reference points) and LRPs (limit reference points). As the name reveals that TRPs are the desirable fishery points while, LPRs are undesirable fishery points, which must be avoided, or if not the fish stock shall deteriorate[29-30]. RPs assist as an indicator by providing definite values and guide fishery managers in suitable management e.g. when $F_{MSY}$ below $B_{MSY}$ limit then fishing will continue. On the other hand, when it is above $B_{MSY}$ fishing may be stopped. This simple decision making rule is known as "pulse fishing" in fishery management science[45].

Three RPs i.e. MSY, $F_{MSY}$ and $B_{MSY}$ are commonly used to estimate highest possible fish catch hypothetically as the purpose of fishery management. The concept of MSY was pioneered in 1992 for the first time which later was built-in the UN Convention on the Law of the sea.

Estimated MSY through SPMs points out fishery stock states. Thus, MSY is preferred among these three RPs due to its protuberance in fisheries studies. For example, when estimated MSY and catch values are the same then fishery stock is generally thought in equilibrium state. On the other hand, when computed MSY is higher than catch statistics then there is a potential of more fishing up to estimated MSY and fishery resource is in thriving state. In contrast, if computed MSY is lower than catch data then fishery stock is in overexploited state and must be checked to save from harm for future[4].

UN Fish Stock Agreement defined MSY as $F_{MSY}$ and $B_{MSY}$ in 1995. According to Gabriel and Mace (1999)[31] $F_{MSY}$ is upper bound for LPRs while according to Hoggarth et al. (2006) [4] $F_{MSY}$ should be in use as lower bound of LRPs. Therefore, TRPs for MSY should be documented very carefully and should be kept below MSY level. Fishery stock shall continuously decline in future, if the MSY is overrated. Nevertheless, underestimated MSY will result in economic losses. Consequently, it should be noted that RPs are indicators and does not demonstrate invariable quantities. Instead, they should be well thought-out as overfishing alarms but their recommendations does not allow constant yield[32].

## Conclusion

The computed value of MSY, IP 0.9, ranged as 210000 t – 8200000 t and 31500 t – 2300000 t for CEDA and ASPIC in that order. Thus, CEDA seems to be more conventional in terms of MSY calculation as compared to ASPIC. The results of CEDA are more trustworthy because of higher values of $R^2$. Since the estimated MSY range by Fox and Logistic models overlaps thus by in view of the results of both the software and applying pulse fishing rule we propose that in Chinese marine waters, the MSY TRP range of shellfish is as 300000 t – 350000 t.

Capture production of 400000 t or more must be measured as a LRP. By comparing computed MSY values with recorded data (Table 1) and considering $F/F_{MSY}$ and $B/B_{MSY}$, it can be illustrated that this fishery resource has consistently been overexploited in the past. Shellfish stock is shrinking with the passage of time due to overfishing.

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