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An assessment of overexploitation risk faced by cephalopod fisheries in China: A non-equilibrium surplus production model approach

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This study analyses catch and effort(CE) data, 2006-2014, of cephalopod fisheriesto access its stock status for better management practices. Data analysis was performed by using two fisheries software, *viz*., catch and effort data analysis (CEDA) and a stock production model incorporating covariates (ASPIC). In CEDA, initial proportion (IP) = 0.8, Fox model estimated *MSY*, *CV* and R^2 as 461687 t, 0.226 and 0.663 for log error assumption. The computed values of these parameters for log-normal and gamma error assumptions remained as 529612 t, 0.115, 0.671 and 503394 t, 0.176, 0.657, correspondingly. Estimated *MSY* values by using error assumptions, *i.e*., log and log-normal in Schaefer and Pella-Tomlinson models were same, *i.e*., 452106 t and 536284 t, in that order. However, gamma error assumption produced minimization failure. Fox model estimated the highest value of R^2 (0.671). In ASPIC, Fox model assessed *MSY*, *CV* and R^2 and F_{MSY} as 545100 t, 0.090, 0.785 and 0.222 y^{-1}, in that order. Whereas, Logistic model calculated similar parameters as 558700 t, 0.198 y^{-1}, 0.111 and 0.78, respectively. The results of this preliminary study represent overexploitation of this fishery resource. Thus, effective management strategies with proper implementation are direly needed to conserve this commercially important marine fishery resource for its long-term economic gain. Moreover, supplement research on local fisheries resources by using single fish species data is strongly suggested in order to further strengthen this preliminary research.

[**Keywords:**Cephalopod fisheries; China; Economics; Management; Overexploitation; Risk]

Introduction

Surplus production models (SPMs) are commonly referred to biomass dynamic models. These models are traditionally used to assess fisheries stock status based on available time series catch and effort (CE) data or index of abundance, *i.e*., catch per unit effort (*CPUE*)[1]. Therefore, they are favoured over the other fisheries stock assessment models. These models are particularly important for the stock assessment of fish fauna dwelling tropical regions because in these regions mostly age of fish cannot be determined by counting growth rings on their otoliths. Fishery parameters, such as maximum sustainable yield (*MSY*),can easily be computedby means of these models in order to make harvest strategies for sustainable fishing[1].

Many studies have revealed that estimation of coefficient of generalized SPM is very complex[3-4]. Despite of this complication, generalized SPM is employed in various studies[5]. Fox[6], for instance, presented a computer-based package PRODFIT,which had the capacity to fit generalized equilibrium SPM. In contrast, SPMs used in this study assume fisheries stock in a non-equilibrium state and use non-linear regression techniques. Hence, SPMs are comparatively complex to execute. These non-equilibrium SPMs require uninterrupted catch data because data gaps may led to incorrect assessment of stock. These models also require good index of comparative population size in comparison of real population size. Besides this, catch per unit effort (*CPUE*) can also be employed to approximate different aspects of the fisheries stock. Thus, the fish stock can be accessed through catch statistics or *CPUE*[7].

Cephalopods belong to Phylum Mollusca and are exclusively marine animals[9]. In recent decades, the commercial importance of cephalopods has risen considerably[10-11], and it has been predicted that cephalopods are one of the last fisheries resource proficient for withstanding significant development in fisheries landings[12-14]. Their commercial and ecological importance to marine fisheries is estimated by possible trade-offs between cephalopod demands which may be recognized by an assessment approach[15].

Out of total 800 living species of cephalopods[16], 125 species are distributed in China Seas, *i.e*., Bohai and Yellow Sea, East China Sea and South China Sea with 14, 40 and 103 species, respectively[17]. Since the 1980s, the wild capture production of cephalopods has increased significantly all over the world due to the decrease in finfish stocks and rising customer popularity. Recently, annual cephalopod capture fisheries average more than 3 million t, making around 4 % of the world fish trade[18]. In 2013, the total value of trade flow of cephalopods was about $ 6 billion globally. China is both the largest importer and exporter in terms of volume with total exports and total imports of 445000 tonnes (t) and 362000 t correspondingly. The cephalopod fisheries exports worth more than $ 1.5 billion from China exported mainly to Japan, the EU, Korea and the US[19].

Chinese researchers have conducted a lot of research on various species of cephalopods including octopus, cuttlefish and squids in the various fields like biology, fishing grounds, fishing technology etc. [20-25]. However, available literature is devoid of cephalopods in context of resource assessment. Thus, this is the first attempt to investigate cephalopod fisheries stock in Chinese marine waters.

Materials and Methods

Fisheries stock status of cephalopods (including all species) dwelling Chinese marine waters was accessed by using available CE data.

Data Acquisition

CE data of cephalopod fisheries spanning over a period of nine years, 2006-2014, was used in this study. Data was obtained from published China Marine Statistics Yearbook[26].

Data Analysis

Obtained time series CE data of cephalopod fisheries was estimated in this study through non-equilibrium SPMs by using specialized fisheries software *viz*. CEDA and ASPIC. These statistical tools were downloaded from MRAG website (CEDA software)[7] and NOAA Fisheries Toolbox (ASPIC software)[27]. Classical SPMs frequently used equilibrium conditions which seldom exist in naturally occurring fish stocks[28]. However, SPMs used in these assessment tools, CEDA and ASPIC, assume fisheries resource in non-equilibrium state which is more realistic. The purpose of using both the software in the same study is to increase reliability of the estimated results. On the behalf of three different scientists Fox, Schaefer and Pella-Tomlinson, SPMs have three different kinds.

Schaefer model depends on growth model (logistic) and is the most frequently employed model in stock assessment.

$$\frac{dB}{dt} = rB(B_\infty - B)$$ [29]

On the other hand, Fox and Pella-Tomlinson models rely on growth equation (Gompertz) and common production equation, respectively.

$$\frac{dB}{dt} = rB(1nB_\infty - 1nB)$$ [30]

$$\frac{dB}{dt} = rB(B_\infty^{n-1} - B^{n-1})$$ [3]

Where, B is for fish biomass, t indicates for time, *i.e*., year, n represents shape parameter, *r* denotes population intrinsic growth rate and B∞ represents carrying capacity (*K*).

Catch and Effort Data Analysis (CEDA)

Customized parameters can be evaluated through CEDA which is a menu based data fitting statistical program. This program employs confidence interval method, 95 % through bootstrapping. It uses three SPMs. *viz*., Fox, Schaefer and Pella-Tomlinson with three error assumptions, *i.e*., log, log-normal and gamma. A key indicator, IP (B_1/K), is needed in CEDA which is used to access fisheries resource. If IP value, for instance, is zero or one then it represents virgin fisheries stock or fully overexploited fisheries stock, correspondingly. Key parameters assessed by using this software include *MSY* (maximum sustainable yield), *K* (carrying capacity), *CV* (coefficient of variation), final biomass, *r* (intrinsic growth rate) and *q* (catchability coefficient).

A Stock Production Model Incorporating Covariates (ASPIC)

ASPIC also requires IP input. But, in contrast to CEDA, it requires separate IP input files for each value. ASPIC uses two SPMs, *i.e*., Fox and Logistic. In order to evaluate *CV* for all IP values, FIT and BOT files were prepared. In order to compute *MSY*, 500 trails were performed. Various important parameters evaluated by using ASPIC include *MSY*, *q*, R^2 (coefficient of determination), F_{MSY} (fishing mortality rate at *MSY*), *K* and B_{MSY} (stock biomass giving*MSY*). Sensitivity analysis was conductedthrough different IP values (Tables 1 to 4). Estimated results were

Table 1 — *MSY* estimates for Cephalopod fisheries in Chinese marine waters by using CEDA software (IP = 0.1-0.9)

IP	Model: Fox Log	Fox Log-normal	Fox Gamma	Schaefer Log	Schaefer Log-normal	Schaefer Gamma	Pella-Tomlinson Log	Pella-Tomlinson Log-normal	Pella-Tomlinson Gamma
0.1	3.61E+11	1431935	MF	568	2498263	MF	568	2498263	MF
	1.380	0.000	MF	2152.370	0.000	MF	2151.979	0.000	MF
0.2	977716	983101	984710	MF	1388803	MF	MF	1388803	MF
	0.018	0.000	0.017	MF	0.000	MF	MF	0.000	MF
0.3	751668	824249	MF	MF	1030590	MF	MF	1030590	MF
	0.072	0.009	MF	MF	0.000	MF	MF	0.000	MF
0.4	633688	643746	658271	MF	735332	914156	MF	735332	914156
	0.103	0.068	0.082	MF	0.032	0.009	MF	0.029	0.008
0.5	562811	625784	MF	760657	772888	MF	760657	772888	MF
	0.129	0.064	MF	0.063	0.011	MF	0.058	0.013	MF
0.6	515972	595441	549180	617493	608091	651460	617493	608091	651460
	0.158	0.072	0.127	0.130	0.100	0.104	0.144	0.090	0.113
0.7	484024	559957	521162	521228	566558	MF	521228	566577	MF
	0.187	0.09	0.155	0.187	0.117	MF	0.204	5.756	MF
0.8	461687	529612	503394	452106	536284	MF	452106	536284	MF
	0.226	0.115	0.176	0.265	0.130	MF	0.249	0.135	MF
0.9	446158	504828	492683	399714	481433	449183	399714	481433	449183
	0.28	0.154	0.217	0.326	0.180	0.242	0.323	0.168	0.248

Note; MF: minimization failure, *CV*: written below the *MSY* values

Table 2 — Different parameters estimated by using CEDA software for Cephalopod fisheries in Chinese marine waters (IP = 0.8)

Model	K	q	r	MSY	R_{yield}	CV	R^2	B	B_{MSY}
Fox (Log)	8659889	4.00E-07	0.145	461687	461039	0.226	0.663	3355995	3185795
Fox (Log-Normal)	7302640	4.83E-07	0.197	529612	528725	0.115	0.671	2843452	2686491
Fox (Gamma)	7954803	4.38E-07	0.172	503394	502211	0.176	0.657	3129253	2926408
Schaefer (Log)	8016712	4.29E-07	0.226	452106	428215	0.265	0.631	3086930	4008356
Schaefer (Log-Normal)	6405999	5.44E-07	0.335	536284	512081	0.130	0.655	2522555	3203000
Schaefer (Gamma)	MF	MF	MF	MF	MF	MF	MF	MF	MF
Pella-Tomlinson (Log)	8016712	4.29E-07	0.226	452106	428215	0.249	0.631	3086930	4008356
Pella-Tomlinson (Log-Normal)	6405999	5.44E-07	0.335	536284	512081	0.135	0.655	2522555	3203000
Pella-Tomlinson (Gamma)	MF	MF	MF	MF	MF	MF	MF	MF	MF

Note; MF: minimization failure, *K*: carrying capacity, *q*: catchability coefficient, *r*: intrinsic population growth rate, *MSY*: maximum sustainable yield, *CV*: coefficient of variation, R^2: coefficient of determination, *B*: current biomass, B_{MSY}: biomass giving *MSY*

Table 3 — Various parameters estimated by using ASPIC software for Cephalopod fisheries in Chinese marine waters (IP = 0.8)

Model	IP	MSY	K	q	F_{MSY}	B_{MSY}	R^2	CV
Fox	0.8	545100	6685000	5.29E-07	0.2216	2459000	0.785	0.090
Logistic	0.8	558700	5652000	6.21E-07	0.1977	2826000	0.780	0.111

further considered along with visual inspection of the graphs between observed and expected catch and R^2 values for model selection.

Results

During the study period, cephalopod capture production was totalled as 7069175 t. The average catch remained 785464 t y^{-1}. The maximum and the minimum catch quantity was observed in 2007 (1047713 t) and 2010 (658309 t), correspondingly (Fig. 1). Likewise, average *CPUE* was estimated as1.874 y^{-1}, whereas, the highest and the lowest values of *CPUE* were recorded during the 2007 (2.755) and 2013 (1.468),*i.e.*, second and eighth study years, correspondingly (Fig. 2). Acquired results were further appraised by observing four factors *viz*., R^2 values, *MSY*, CEDA graphs and *CV*. Calculated *MSY* values were compared with catch statistics. Very large or small values of *MSY*were not considered for results. Models were compared by visual examination of graphs and R^2 values. Higher R^2 values indicated better model fitting. Results having only appropriate *CV*were acknowledged.

Table 4 — ASPIC software estimates for Cephalopod fisheries in Chinese marine waters (IP = 0.1-0.9)

Model	IP	*MSY*	*K*	*q*	F_{MSY}	B_{MSY}	R^2	*CV*
	0.1	1443000	9666000	2.67E-06	0.406	3556000	0.847	0.006
	0.2	989200	6147000	2.24E-06	0.438	2261000	0.807	0.024
	0.3	790200	6271000	1.49E-06	0.343	2307000	0.793	0.047
	0.4	683700	6354000	1.11E-06	0.293	2338000	0.789	0.058
Fox	0.5	619400	6453000	8.73E-07	0.261	2374000	0.788	0.068
	0.6	582500	6453000	7.29E-07	0.245	2374000	0.786	0.080
	0.7	558500	6554000	6.16E-07	0.232	2411000	0.785	0.085
	0.8	545100	6685000	5.29E-07	0.222	2459000	0.785	0.090
	0.9	539600	6857000	4.59E-07	0.214	2522000	0.785	0.112
	0.1	2523000	7922000	2.88E-06	0.637	3961000	0.850	0.001
	0.2	1424000	3627000	3.23E-06	0.785	1813000	0.874	0.000
	0.3	1090000	2389000	3.46E-06	0.912	1194000	0.873	0.000
	0.4	944500	2052000	3.26E-06	0.921	1026000	0.822	0.005
Logistic	0.5	814100	2941000	1.91E-06	0.554	1471000	0.787	0.039
	0.6	698300	4049000	1.16E-06	0.345	2024000	0.781	0.067
	0.7	621200	4829000	8.33E-07	0.257	2415000	0.779	0.087
	0.8	558700	5652000	6.21E-07	0.198	2826000	0.78	0.111
	0.9	516400	6262000	4.99E-07	0.165	3131000	0.780	0.134

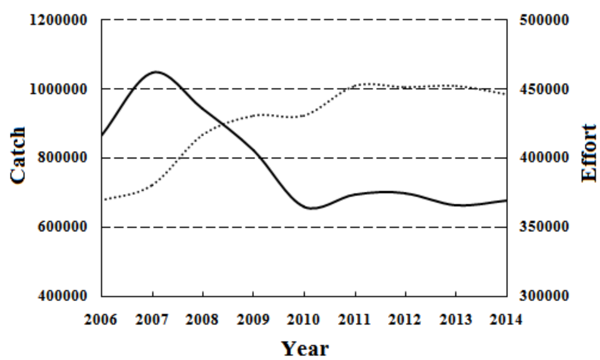

Fig. 1 — Catch and effort statistics of Cephalopod fisheries in Chinese marine waters
Source; China Marine Statistics Yearbook
Note; Effort (dotted line) is represented by the number of powered boats, whereas, catch (solid line) is in t

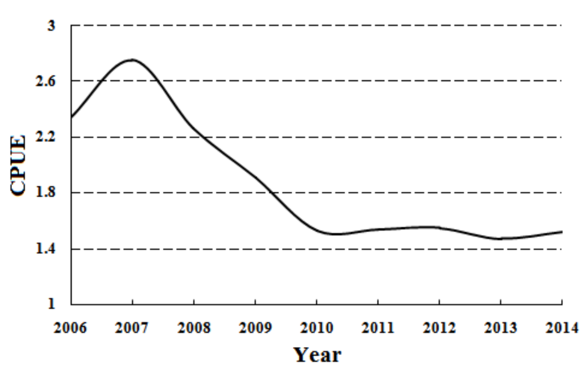

Fig. 2 — Computed *CPUE* for Cephalopod fisheries in Chinese marine waters

CEDA Results

CEDA computed diverse *MSY* values for different IP inputs (Table 1). This software computed higher *MYS* estimates against lower IP inputs. On the other hand, lower MSY approximations were obtained for higher IP inputs. For IP values 0.2, 0.3 and 0.4, log assumption produced minimization failure while calculating *CV* values. The *CV* value was computed by using bootstrapping method. Besides this, gamma error assumption sometimes produced minimization failure. Evaluated parameters, IP 0.8, are presented in Table 2. Computed figures of *MSY* and their *CV* for Fox model, log assumption, were 461687 t and 0.226, respectively. For log-normal their values were calculated as 529612 t and 0.115 in that order while for gamma error assumption their figures evaluated as 503394 t and 0.176, correspondingly. Estimated *MSY* values for log and log-normal error assumptions used in Schaefer and Pella-Tomlinson models produced same estimates as 452106 t and 536284 t, correspondingly. The estimated *CV* values for these models for both error assumptions were 0.265, 0.130 and 0.249, 0.135, in that order. The gamma error assumption showed minimization failure in Pella-Tomlinson and Schaefer models. Calculated B_{MSY} values are same for both Schaefer and Pella-Tomlinson models. This is because Pella-Tomlinson model perhaps congregated at 0.5 (B_{MSY}/K). It means that either one or more model assumptions do not have effect on estimated results.

R^2 values were computed by using all assumptions, IP 0.8, in Fox model were 0.663, 0.671 and 0.657, in that order (Table 2). R^2values for both the models, *i.e.*, Pella-Tomlinson and Schaefer models with log and log-normal error assumption were same as 0.631 and 0.655, in that order, while gamma assumption produced minimization failure. Figure 3 represents graphical demonstration of observed catch and predicted catch. From visual examination it can be observed that, for all the SPMs by using different error assumptions, observed and expected catch values are more or less similar. But, they have minute differences.

ASPIC Results

Computed parameters through ASPIC for IP 0.8 are given in Table 3. Fox model exhibited better fit because its R^2 value (0.785) was greater than estimated R^2 value (0.780) in Logistic model. *MSY* and their respective *CV* values for Fox and Logistic models were evaluated as 545100 t (0.090) and 558700 t (0.111), correspondingly. Calculated *K*, B_{MSY} and F_{MSY} remained 6685000 t, 2459000 t, 0.222 y^{-1} and 5652000 t, 2826000 t, 0.198 y^{-1} for Fox and Logistic models, correspondingly.

Table 4 presents numerous parameters computed for IP 0.1 – 0.9. Similar to CEDA, ASPIC also revealed sensitivity towards IP inputs. ASPIC software computed smaller *MSY* for larger IP value and vice versa. ASPIC computed *MSY* in a narrow range, 500000 t – 2550000 t, as compared to CEDA, 400000 t –600000 t. ASPIC models revealed greater R^2values which means better data fitting.

Calculated fishing mortality (*F*) and biomass (*B*) of cephalopods are given in Table 5. Calculated values represent that F is rising with the passage of time,

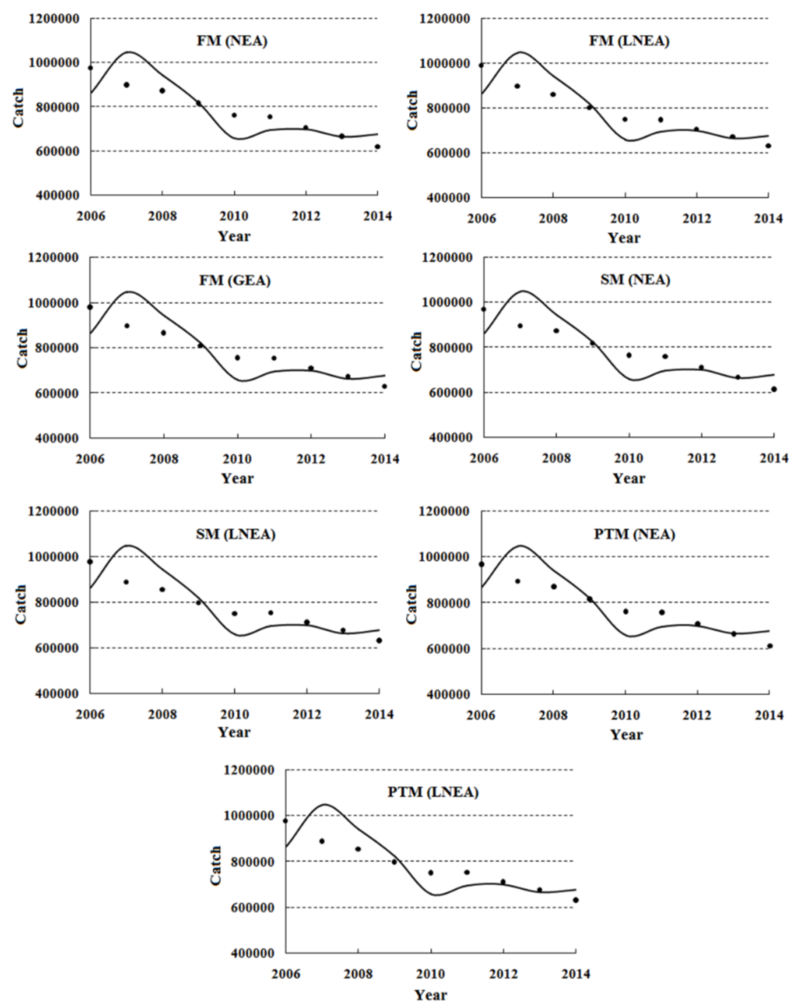

Fig. 3 — Graphs obtained by using CEDA software for IP 0.8
Note; Dots indicate expected catch, whereas, straight line represents observed catch in t

Table 5 — ASPIC software estimates of fishing mortality (F) and biomass (B) (IP = 0.8) (2006-2014)

Year	Model							
	Fox				Logistic			
	F	B	F/F_{MSY}	B/B_{MSY}	F	B	F/F_{MSY}	B/B_{MSY}
2006	0.171	5347000	0.772	2.174	0.202	4523000	1.022	1.600
2007	0.236	4793000	1.063	1.949	0.278	4068000	1.405	1.439
2008	0.242	4144000	1.093	1.685	0.286	3514000	1.444	1.244
2009	0.235	3666000	1.058	1.491	0.276	3113000	1.395	1.102
2010	0.201	3347000	0.907	1.361	0.235	2849000	1.190	1.008
2011	0.223	3207000	1.006	1.304	0.260	2749000	1.313	0.973
2012	0.237	3038000	1.068	1.235	0.276	2611000	1.395	0.924
2013	0.236	2874000	1.067	1.169	0.276	2465000	1.398	0.872
2014	0.253	2750000	1.139	1.118	0.298	2346000	1.505	0.830

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*

whereas, B is decreasing. F/F_{MSY} is increasing and B/B_{MSY} is decreasing. Both of these parameters signpost overexploitation of cephalopod fisheries.

Discussion

Since the 1970s, fluctuations have occurred in the world capture fisheries because of overexploitation and disintegration of traditional demersal fisheries stocks[31]. This overexploitation is actually because of increasing demand for seafood to domestic consumption and export which has led to the mechanization of fishing fleets and increase in their number[28]. Therefore, cephalopods (species with short life spans) have been frequently raising their contribution to the marine capture fisheries[32]. They are contributing significantly in sustaining and developing the world's capture fisheries production[33]. Hence, it becomes compulsory to appraise stock status of this valuable fisheries resource.

Previously, several studies were conducted to assess stock status of various fisheries resources in China and Pakistan[35]. All of these studies are based on the same SPMs used in this study. Fisheries management is a complex process which encompasses data sampling, investigation, explanation of outcomes, planning and decision choice[36] with the help of stakeholders[37]. Selection of the best fit model is very important step in analysis. Commonly, SPMs estimate more or less similar parameter results, however, differences may exist due to model assumptions. That's why sometimes similar results are obtained from different SPMs. Such results are obtained because model assumptions are independent of some biological assumptions which are un-testable. Therefore, generally, more SPMs are applied in the analysis and later on compared to find model with better fit[7].

R^2 is very helpful in selecting the best fit model. Selection of the best fit is done in two steps. First, considering the R^2 figures. Second, examination of CEDA graphs. If the model shows higher R^2 values but graph represents poor fit the results cannot be considered[7]. Thus, for considering a model, R^2 values and graphs both should be acceptable.

CPUE, catch or effort statistics can represent status of fisheries stock. If the effort, for example, is rising and on the other hand, catch is declining, this condition may represent that the fisheries stock is decreasing. Conversely, if effort does not change but catch increase or decrease, this condition may represent quantitative changes in fish stocks. However, if efforts and catch are rising and *CPUE* is more or less stable, in this condition it is supposed that the fishing is not affecting fish stock[7].

Reference points (RPs) was first time introduced in fisheries management literature in 1992. Now, they are a part of FAO code of conduct. This code is specially drafted for responsible fisheries[38]. Hence, either managing fishery resource or assessing fishery resource, in both the conditions, RPs are followed according to the directions of FAO code[7]. RPs are of two kinds, *i.e.*, TRPs (target reference points) which are wanted RPs and LRPs (limit reference points) which must be avoided[39-40]. RPs help to make decisions for fishery management.

Usually, three RPs are employed to manage fishery resources. These RPs are B_{MSY}, F_{MSY} and *MSY*. Among these three RPs, *MSY* is the most frequently used RP in managing fishery stocks all over the world. Some studies also advocate the advantages of *MSY* over the other RPs. This RP is included in the UN Convention on the Law of the Sea and UN Fish Stock Agreement.

Estimated *MSY* directly indicates fisheries stock status. For instance, if calculated *MSY* is lower than catch statistics, it indicates that fisheries stock is overexploited. If computed *MSY* is almost same with the recorded catch values, it means fisheries stock is safe and fishing can be continued without increasing catch further. If estimated *MSY* is higher than catch values, it means catch can be increased up to *MSY*. Some studies suggest that RP of F_{MSY}can be treated as lower bound of LRPs[7], whereas, some other studies describe them as upper bound of the same parameter[41]. Thus, it is essential to set TRPs lower than *MSY* level. Moreover, TRPs should be checked carefully because it will determine the fate of the fishery stock. If *MSY* is underestimated, economic loss will occur. On the other hand, if *MSY* is overestimated, fishery resource will decline because of overexploitation. It is necessary to mention that RPs just give us hint about the fisheries stock status. Thus, they do not permit constant catch. Their main purpose is to avoid overfishing[42].

There are some drawbacks in the use of SPMs. For instance, these SPMs suppose no immigration or emigration in fish population[7]. These models also assume that there is no interaction either intra or inter specific in natural environment. In the same way, it is also supposed that catch statistics are accurate, *r* does not rely on age composition, catchability coefficient does not change, catch efficiency of ships remain same, fishing and natural mortality occur simultaneously. Moreover, there is a single unit of fish stock. All these assumptions are not to be met in nature. SPMs don't utilize time delays between reproduction and recruitment. These models don't cover age-structure data and uncertainties are also associated with *MSY* estimation[43]. Even though these are deviations from assumptions, scientific method is not rebutted. In fact, SPMs are influential tools for the initial assessment of fisheries resource[44].

Conclusion

As compared to ASPIC, CEDA remained conservative in *MSY* calculation. Higher R^2values in ASPIC represent that its results are more dependable. Obviously, *MSY* range estimated by CEDA and ASPIC overlie each other. However, it is recommend that TRP for cephalopods in Chinese marine waters is 480000 t – 520000 t. Moreover, harvest quantity of 550000 t may be treated as LRP. F/F_{MSY} and B/B_{MSY} represent overexploitation of cephalopod fisheries. Therefore, cephalopod fisheries stock is declining. Hence, steps are urgently required to protect this fisheries resource for its long-term economic contribution. However, it should be noted that since this paper assesses the fisheries stock of all the species belonging to cephalopods therefore, it is mentioned that this study is not exhaustive rather further studies focusing on commercially important species and distributed over a smaller geographic area are direly needed.

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