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FISHERY STOCK ASSESSMENT OF *MEGALASPIS CORDYLA* BY USING NON-EQUILIBRIUM SURPLUS PRODUCTION MODELS IN THE ARABIAN SEA COAST OF PAKISTAN

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ABSTRACT

Catch effort data for *Megalaspis cordyla* of Pakistani marine fishery from 1996 to 2009 was analyzed using the special surplus production models in order to grasp the inventory situation of fishery. The special tools were used using catch and effort data analysis (CEDA) and a stock production model incorporating covariates (ASPIC) for estimate the maximum sustainable yield (MSY). Three surplus production models of Fox, Schaefer and Pella-Tomlinson with three error assumptions, usually gamma, normal and log normal are used in CEDA. The Fox model calculated these MSY for normal, lognormal and gamma error hypotheses as 2592 tons (CV = 0. 154, R^2 = 0. 593), 2806 tons (CV = 0. 104, R^2 = 0. 620) and 2673 tons (CV = 0. 134, R^2 = 0. 608) respectively at the initial proportion (IP) of 0.7. The estimated MSY using normal and lognormal error assumptions for the Schaefer and Pella-Tomlinson models were 2887 tons (CV= 0. 178, R^2= 0. 579) and 3248 tons (CV = 0. 072, R^2 = 0. 606). Whereas, the gamma error resulted minimization failure of both models here. The calculated parameters of the Fox model in ASPIC by way of MSY, CV, R^2, F_{MSY} and B_{MSY} were 2578 tons, 0.108, 0.743, 0.132 and 19520 tons, and corresponds to the values 2477 tons, 0.142, 0.738, 0.101 and 24550 tons per year calculated by the logistic model. Present estimated MSY values are lower than annual catch is shows that the stock of this fish is in overexploitation state. Present findings would be helpful to fishery managers for sustainable fishery.

Keywords: Pakistan; stock evaluation; fishery management; *Megalaspis cordyla.*

INTRODUCTION

In Pakistan, marine fisheries sector plays a vital role in economic development including employment and fish food is a great source which provides protein to the people. Marine fisheries sector comprises about 70% of the fishery resources (FAO, 2009). It has been observed that with the passage of time fishery catch is decreasing (FAO, 2009). This decreased fishery production is a consequence of many factors which have negative effect on Pakistani fisheries sector such as overfishing, illegal fishing, unreported fishing and unregulated fishing. The coastline of Pakistan is 1120 km in length and spans over two provinces viz. Sindh and Baluchistan (Figure 1). The coastline of each province differs from the other in its topographical features. Baluchistan coast is relatively narrow and its continental shelf width is 12 – 32 km. On the other hand, Sindh continental shelf coast width varies 40 to 120 km. Another difference between the coast of Baluchistan and Sindh is that Baluchistan coast is steep and rough whereas Sindh coast is flat and mostly sandy and muddy also have freshwater inflow from The Indus River. The Indus Delta is a house of many marine biota due to freshwater inflow in to sea. Pakistani marine waters are rich in marine biodiversity from which 250 commercially demersal fish species, 20 large pelagic fish species, 50 small pelagic species and other different shellfishery also commercially important (FAO, 2009)

Megalaspis cordyla is a marine water fish and belongs to Perciformes group of fishes. This fish mostly found at is reef associated areas at about of 20–100 m depth (Al-Sakaff and Esseen, 1999). It is found in the tropical regions including East Africa to Japan, Australia and Indo-west Pacific region including Pakistan. This species can attain a maximum length of 80 cm and gain maximum weight up to 4 kg (Bykov, 1983). They are pelagic fish species which form schools (Kuiter and Tonozuka, 2001). Their food and feeding habits mainly consist of other fish species. This fish is economically important fish (Sousa and Dias, 1981).

In the field of fishery management the surplus production models are very famous. They are the excellent tools for the fishery stock assessment used for fishery sustainable. Sometimes surplus production models may be referred to another name of biomass dynamic models. The popularity of these models exists in fact that these models require simple data such as catch and effort (number of fishing boats or number of fishermen) which is easily available as compared to age structured data (Haddon, 2011). Especially for tropical fisheries it is very difficult to get age structure data because for tropical fisheries it is difficult to estimate age of the fish using otolith and hard parts of the fish. Several production models have been proposed by various scientists in the past. Earlier versions of these models (Maunder *et al*., 2006; Quinn and Deriso, 1999; Walter and Perma, 1996; Prager, 1994; Hilborn and Walters, 1992; Pitcher and Hart, 1982) assumed that fishery stocks in an equilibrium state. However, we know that fishery stock never remain in an equilibrium state rather fluctuate as a consequence of changing biotic and abiotic conditions.

In this scientific study maximum sustainable yield of *M. cordyla* is estimated along with other important fishery parameters by using non-equilibrium surplus models (Polacheck *et al*., 1993). Several researchers have done work on the other fish species of Pakistan and proposed several control measures to maintain single fishery resources (Kalhoro *et al*., 2015, 2017a,). Length frequency distribution data and MSY based stock assessment has been done on single fish species stock analysis like crab fishery, *Nemipterus* spp., Lizardfish, squid, indian scad and sardine fishery from Pakistani waters (Kalhoro *et al*., 2013; 2014 a,b, 2018; Kalhoro *et al*., 2017b; Soomro *et al*., 2015a,b; Afzaal *et al*., 2016; Nadeem *et al*., 2017). From above studies researcher suggests some management steps to maintain the different fishery stock from Pakistani waters. However, less work is published on the stock assessment of *M. cordyla* is less from Pakistani marine waters. Hence in the current study, the estimation of maximum sustainable yield of *M. cordyla*, using the annual catch and effort data utilizing tools i-e catch and effort data analysis (CEDA) and a stock production model incorporating covariates (ASPIC) is presented. The results of this study are expected to be helpful for the fishery managers to monitor the fisheries in best interest of the nation along with the priority of focusing and demonstrating this fishery resource in the marine waters of Pakistan.

MATERIALS AND METHODS

Data acquisition: From 1999 to 2014, the capture fishery data with effort of the *M. cordyla* in the Pakistan marine waters were analyzed and the fishing situation of this resource was evaluated (Fig. 1). The data is taken from the 'Handbook of Pakistan Fisheries Statistics' that is published by the Marine Fisheries Department (MFD) based in Karachi (Anonymous, 2016). The *M. cordyla* annual catch has been reported in the form of metric ton (MT), but its efforts have been reported in the form of number of fishing boats used in that time period (Fig. 2).

Evaluation of data: The annual catch data of *M. cordyla* (16 years) from 1999 to 2014 was taken and analyzed by using different surplus production models (SPMs). To this end, two designated stock evaluation tools Catch and Effort Data Analysis (CEDA) (Hoggarth *et al*., 2006) and a stock production model incorporating covariates (ASPIC) (Prager, 2005) developed by Fisheries Scientists from the United Kingdom (UK) and from the United States of America (USA), downloaded from the MRAG website (UK) and NOAA Fisheries toolbox. The stock valuation tools make the fishing industry unbalanced. In this research, these two computer packages were used to improve the reliability of the results, since each analysis may be subject to uncertainty.

The nominal catch per unit effort (CPUE) for the use of CPUE in the assessment of fish population was used by the explanation of Hoggarth *et al*. (2006). Sometimes, SPMs are also referred as biomass dynamics models by Fox, Schaefer and Pella-Tomlinson. These models are based on several premises. The Schaefer (1954) is based on the most commonly used logistic population growth model.

$$\frac{dB}{dt} = rB(B_\infty - B)$$ (Schaefer, 1954)

On the other hand, the Gompertz's growth equation and its corresponding generalized production formula is based on Fox and Pella-Tomlinson models.

$$\frac{dB}{dt} = rB(1nB_\infty - 1nB)$$ (Fox, 1970)

$$\frac{dB}{dt} = rB(B_\infty^{n-1} - B^{n-1})$$ (Pella-Tomlinson, 1969)

Where, B is the biomass of the fish stock, n is the shape parameter, t is the time (year), B_∞ is the carrying capacity and r represents the intrinsic growth rate of the population.

CEDA (version 3.0.1): The catch and effort data analysis (CEDA) computer package is a menu driven data adaptation tool that can estimate the customized parameters. A 95% confidential interval is used by bootstrap method. It continues to calculate further all SPMs of Pella-Tomlinson, Schaefer and Fox models further divided into three Normal, log-normal and gamma error assumptions. It has a very excellent tool such as residual plot and fitting of goodness. In this computer package, initial proportion (IP) or (B_1/K) input in the catch and effort data series is obligatory required and is calculated by dividing the initial annual catch value by the maximum annual catch of study period. In addition, the use of different IP values to obtain fishery resources, when the input value of IP is "0", calculated parameters of CEDA assume fishery stocks in the original state. Whereas, if the input IP value is "1", than it will be assumed that fishing has already started from a state that has been intensely exploited.

Following mathematical description, the initial biomass is fixed to $B_1=C_1/(qE_1)$ at sometimes, the emblems of C, q, and E give the corresponding catching, catchability and fishing ability/effort. Using a confidence interval estimated coefficient of variation (CV) is obtained and B_1 equal to K is used by some programmers. Using CEDA, following main parameters MSY (maximum sustainable yield), K (carrying capacity), q (catchability coefficient), r (intrinsic growth rate), R_{yield} (replacement yield) and final biomass were estimated.

ASPIC (version 5.0): ASPIC (a stock production model incorporating covariate) computer software program same as CEDA package also requires input IP values. In means of each value of IP as compared to CEDA, a separate input file is required using this fishery software with two SPMs Fox known as GENFIT a special case and Logistic model also known as Schaefer model. The files of FIT and BOT for all the IP values for both SPMs were prepared to calculate the CV. These FIT and BOT files are referred to the program mode used by this software. There are technical differences between them, during the FIT program mode; this software (ASPIC) estimates the interests of management or profit parameters, while using the bootstrapped confidence intervals, in a number of attempts to calculate parameters during the BOT program mode.

Therefore, the BOT mode performance time is greater than the FIT mode. To calculate the MSY, five hundred (500) trials were performed for each IP value. Critical parameters such as, maximum sustainable yield (MSY), intrinsic growth (*K*),catchability coefficient (*q*), coefficient of determination (R^2), stock biomass giving MSY (B_{MSY}) and fishing mortality rate at MSY (F_{MSY}) were estimated by using this software.

RESULTS

Results obtained from CEDA and ASPIC was evaluated taking into account three output parameters namely MSY, R^2 and CV values. In comparison with the data values, the unrealistic values (very large and very small) were neglected. Only models with R^2 value greater than 0.5 and CV values that fell into an acceptable range were considered.

During the research period (1999-2014), the total catch of *M. cordyla* form Pakistani marine waters was 64763 tons. The maximum catch was 6617 tons and minimum catch of 3134 tons per year were observed in 2000 and 2006 respectively, but the average catch remained 4048 ton / a (year). The highest catch per unit effort (CPUE) estimated as 0.546 and the lowest CPUE value 0.198 in 2000 and 2014 respectively (Table 1). While, during the study period the average CPUE sustained as 0.299 / a. Using CEDA and ASPIC computer software the computed results were further inspected by four factors i-e: MSY (maximum sustainable yield), R^2 (the goodness of fit), residual plots between observed catch and expected catch and CV (coefficient of variation). The calculated MSY values and data values were compared. Extreme MSY values (very large or very small) were ignored. The models were compared based on R^2 value and visual examination of residual plots. The better fit of the model is associated with the higher R^2 value and with the suitable and appropriate values of CV were accepted.

CEDA results: Since CEDA generates different output MSY statistics for different IP inputs, it showed that CEDA is sensitive to input IP values (Table 2). Sometimes, the assumption of gamma error showed minimization failure in all SPMs used. In addition to this, for Schaefer model only, a normalization assumption results in a minimization failure (MF) of IP value 0.2. The CV value was obtained using a special method called bootstrapping reliability limit method, which was below each MSY value. For all SPMs used with error assumptions, the MSY or R^2 values did not produce reasonable results other than IP 0.7. In the case of IP 0.7, the values of R^2 using normal, lognormal and gamma error assumption in the Fox model were 0.593, 0.620 and 0.608, respectively. Models, Schaefer and Pella-Tomlinson models produced R^2 values were the same in order of 0.579 and 0.606. The goodness of fit (R^2) value tells about model fitting, so it is very important to consider it. The calculated parameters for IP 0.7 are shown in Table 3. The MSY of the Fox model with normal, lognormal and gamma hypotheses and their CV estimates were correspondingly 2592 tons (0.154), 2806 tons (0.104) and 2673 tons (0.134). The calculated MSY values for all error hypotheses used in the Schaefer and Pella-Tomlinson models remained the same.

The MSY values were 2887 tons and 3248 tons, respectively for these both models. The CV values for both models were in order of 0.178, 0.072 and 0.198, 0.066 due to all error assumptions. The assumption of gamma error showed a minimization failure of both models. The observed annual catch values and the expected catch values are presented in figure 3. As seen in the figure, the observed catch value and the expected catch value correspond to each other for all error assumptions used in the three models, but in particular, they are different from one another. CEDA calculated higher MSY values with lower IP values than the other two models and vice versa.

ASPIC results: The different IP value ranges (0.1 to 0.9) were used to estimate the MSY values from were produced by ASPIC software (Table 5). The software calculates various parameters via IP 0.7 and the calculation parameters for IP 0.7 are given in Table 4. The MSY for SPMs, (Fox and Logistic) and their CV (coefficient of variation) values used in ASPIC are estimated at 2578 tons (0.108) and 2477 tons (0.142). In the Fox model, the R^2= 0.743 value was higher than the calculated R^2 = 0.738 value of the Logistic model, indicating that the fit is better. The fishing mortality rate at MSY (F_{MSY}), stock biomass giving to MSY (B_{MSY}) and K calculated by the Fox and Logistic models were 0.132, 19520 tons and 53070 tons and 0.101, 24550 tons and 49110 tons, respectively. Various factors calculated for IP 0.1 - 0.9 are listed in Table 5. Such as CEDA and ASPIC were sensitive to the IP values when the IP input values changed the output parameter results changed.

For smaller IP values, this software estimates larger MSY values. But, as compared to CEDA, this software calculated the parameters with less variation. For instance, MSY and CV computed by ASPIC are in the ranged in 1300 tons to 2600 tons (0.083 to 0.807) Table 5, and CEDA estimates range from 2400 to 5.15E+09 tons (0.000 to 2033.355) Table 2. Though, ASPIC is much sensitivity to input values but not as much as CEDA. As compared with CEDA (0.579 to 0.620), the ASPIC model shows a high R^2 value, ranged from 0.727 to 0.744, indicating good data fit.

The estimated fishing mortality rate (F) and biomass (B) value of *M. cordyla* using ASPIC are shown in Table 6. The result obtained from the Fox model and the Logistic model show that F increases from time to time from the period of 1999 to 2014, which shows from these variation values 0.099 to 0.180 and from 0.099 to 0.182 respectively. On the other hand, the biomass (B) dropped from 49,180 tons in 1999 to 20,110 tons in 2014, and from 49350 tons to 2000 tons in both models. The fishing mortality rate for F_{MSY} (F / F_{MSY}) increased from 0.749 in 1999 to 1.366 in 2014 and from 0.981 to 1.808, and the ratio of B_{MSY} (B / B_{MSY}) decreased from 2.519 in 1999 to 1.030 in 2014 and 2.010 to 0.815 during the study period respectively. These both parameters F / F_{MSY} and B / B_{MSY} show excessive catch of fishery resources.

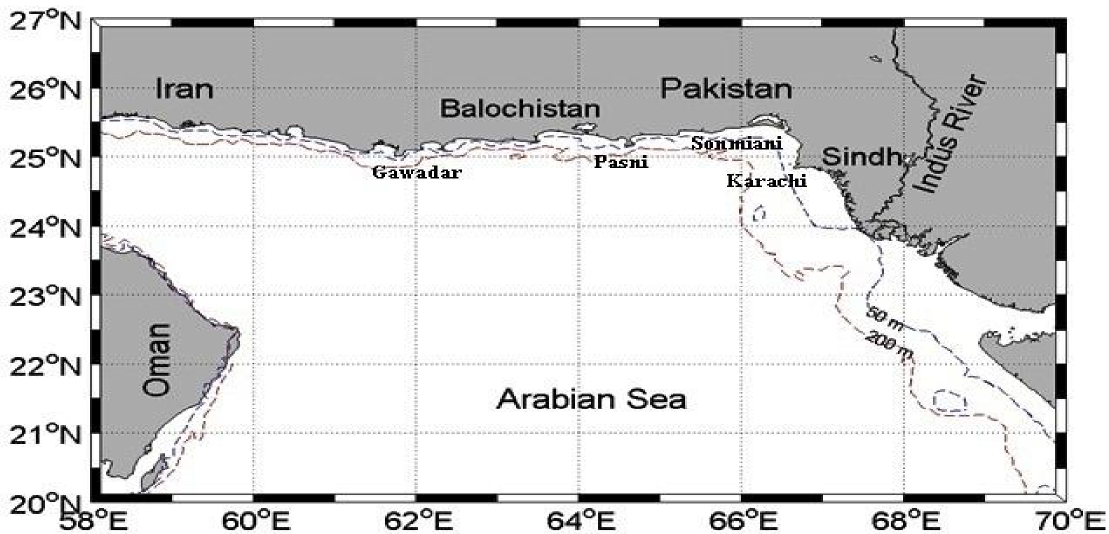

Fig. 1. Different fish landing sites (Karachi, Sonmiani, Pasni and Gwadar) along Pakistan coast, northern Arabian Sea.

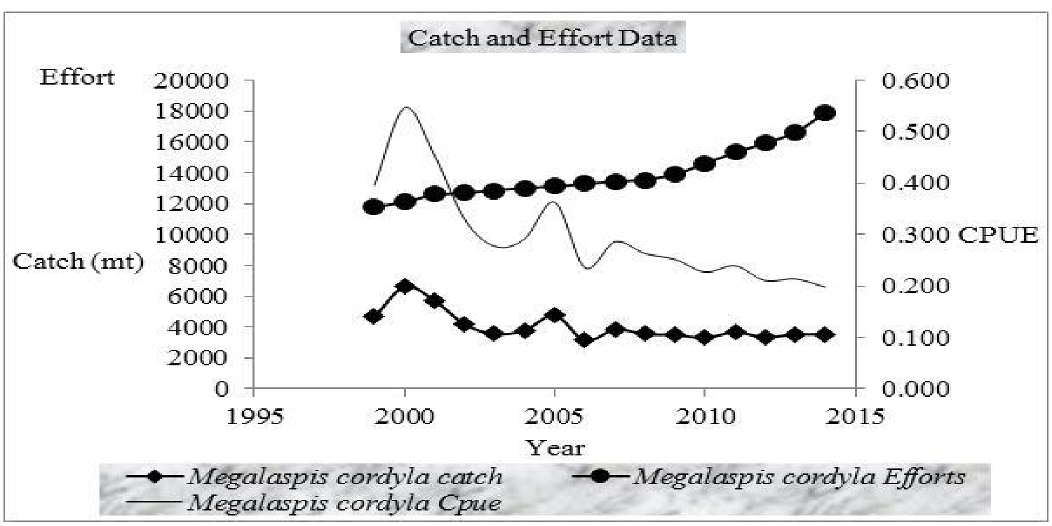

Fig. 2: Catch and effort data of *M. cordyla* obtained from 1999-2014 complied by Marine Fisheries Department, Karachi, Pakistan.

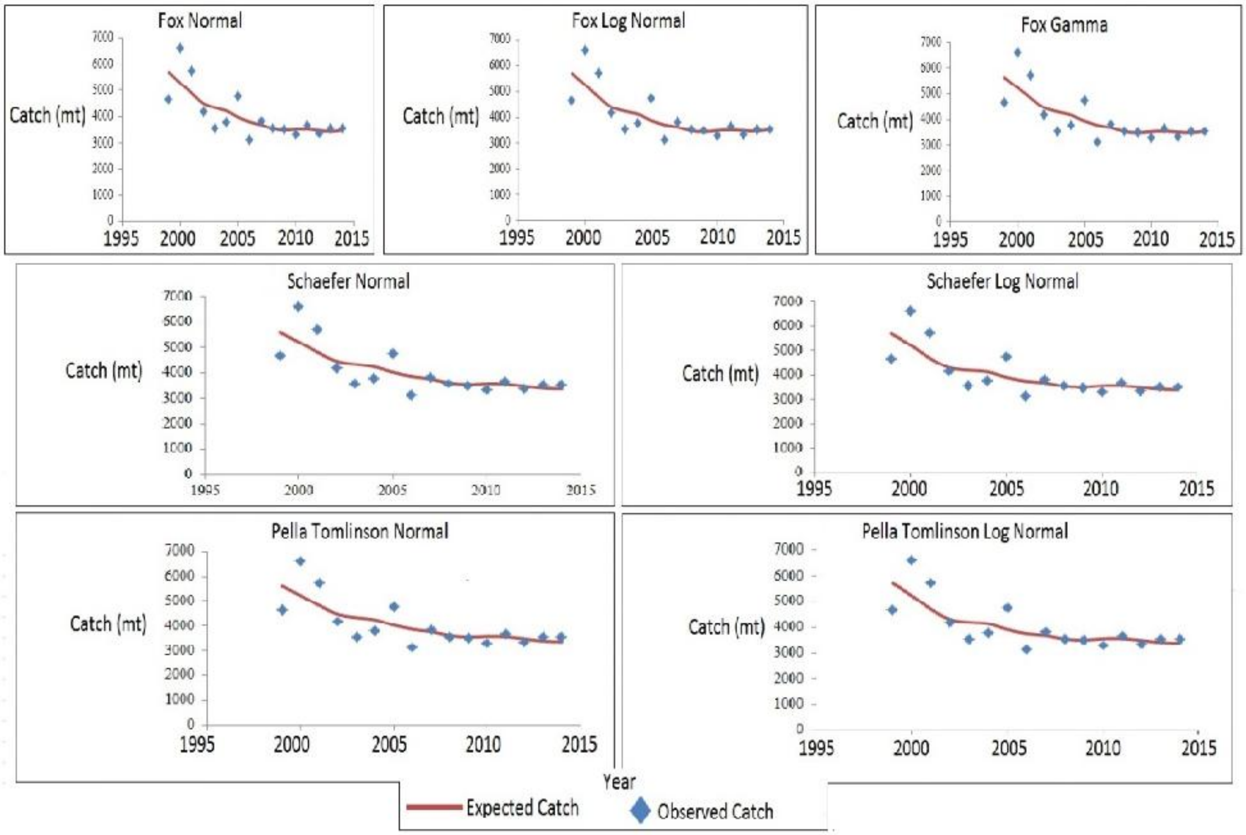

Fig. 3. Observed (dots) and expected (lines) annual catch computed by using CEDA for *M. cordyla* fishery in Pakistani marine waters.

Table 1. Time series catch and effort data of *M. cordyla* fishery from Pakistani marine waters.

Year	Catch	Effort	CPUE
1999	4661	11768	0.396
2000	6617	12114	0.546
2001	5722	12618	0.453
2002	4181	12695	0.329
2003	3561	12838	0.277
2004	3794	13002	0.292
2005	4765	13145	0.362
2006	3134	13308	0.235
2007	3841	13426	0.286
2008	3559	13522	0.263
2009	3498	13897	0.252
2010	3321	14619	0.227
2011	3673	15349	0.239
2012	3354	15937	0.210
2013	3544	16578	0.214
2014	3538	17889	0.198
Sum	64763	222705	4.782
Max	6617	17889	0.546
Min	3134	11768	0.198
Avg	4047.688	13919.063	0.299
SD	955.547	1710.692	0.097
CV	0.236	0.123	0.325

Efforts = Number of fishing boats, SD = Standard Deviation

Table 2. MSY estimation for *M. cordyla* fishery by using CEDA with different input IP values (0.1-0.9) in Pakistani marine waters.

B_1/K	*Fox*			*Schaefer*			*Pella Tomlinson*		
	Normal	Log normal	Gamma	Normal	Log normal	Gamma	Normal	Log normal	Gamma
1.000E-01	5.15E+09	6839	MF	71455	8911	71400	71455	8911	71400
	0.44	0.01	MF	0.03	0.10	0.01	0.03	0.10	0.01
2.000E-01	4980	4221	MF	MF	4966	MF	M F	4966	MF
	0.041	0.048	MF	MF	0.060	MF	MF	0.067	MF
3.000E-01	3905	3518	MF	3687	5988	109103	3687	5988	109103
	0.086	0.070	MF	0.236	0.000	1669.724	0.239	0.000	2033.355
4.000E-01	3409	2905	3409	4740	4583	4698	4740	4583	4698
	0.110	0.118	0.105	0.024	0.004	0.017	0.022	0.003	0.010
5.000E-01	2994	2691	MF	3792	4057	3884	3792	4057	3884
	0.123	0.151	MF	0.085	0.014	0.076	0.086	0.009	0.073
6.000E-01	2759	3096	2835	3269	3754	MF	3269	3754	MF
	0.135	0.075	0.137	0.149	0.025	MF	0.135	0.020	MF
7.000E-01	2592	2806	2673	2887	3248	MF	2887	3274	MF
	0.154	0.104	0.134	0.178	0.072	MF	0.198	0.066	MF
8.000E-01	2471	2724	MF	2583	2991	MF	2583	2991	MF
	0.167	0.111	MF	0.224	0.097	MF	0.208	0.087	MF
9.000E-01	2471	2724	MF	2338	2500	2461	2338	2500	2461
	0.171	0.118	MF	0.245	0.164	0.225	0.246	0.172	0.207

MF = minimization failure

Table 3. Various parameters estimated for *M. cordyla* fishery in Pakistani marine waters by using CEDA.

Model	*R-squared*	*K*	*q*	*r*	*MSY*	*Final Biomass*	*R_{yield}*	*CV*	*B_{MSY}*
Fox (Normal)	0.593	58900	1.21E-05	0.120	2592	15509	2475	0.154	21668
Fox (Log Normal)	0.620	51541	1.40E-05	0.148	2806	13754	2689	0.104	18961
Fox (Gamma)	0.608	56955	1.25E-05	0.128	2673	15430	2571	0.134	20962
Schaefer (Normal)	0.579	49092	1.43E-05	0.235	2887	12524	2194	0.178	24546
Schaefer (Log Normal)	0.606	37461	1.92E+05	0.347	3248	9374	2437	0.072	18730
Schaefer (Gamma)	MF	MF	MF	MF	MF	MF	MF	MF	MF
Pella Tomlinson (Normal)	0.579	49092	1.43E-05	0.235	2887	12524	2194	0.198	24546
Pella Tomlinson (Log Normal)	0.606	37461	1.92E-05	0.347	3248	9374	2437	0.066	18730
Pella Tomlinson (Gamma)	MF	MF	MF	MF	MF	MF	MF	MF	MF

Table 4. Computed parameters for *M. cordyla* fishery by using ASPIC software.

Model	*B_1/K*	*R-squared*	*K*	*Q*	*MSY*	*B_{MSY}*	*F_{MSY}*	*CV*
Logistic	7.00E-01	0.738	49110	1.01E-05	2477	24550	0.101	0.142

Table 5. MSY estimates of Fox and Schaefer models of ASPIC software.

Model	*B_1/K*	*R-squared*	*K*	*Q*	*MSY*	*B_{MSY}*	*F_{MSY}*	*CV*
Fox	1.00E+00	0.744	53420	9.65E-06	2559	19650	0.130	0.111
	2.00E+00	0.743	52730	1.05E-05	2595	19400	0.134	0.141
	3.00E+00	0.744	53740	9.36E-06	2549	19770	0.129	0.117
	4.00E+00	0.743	53240	9.84E-06	2568	19580	0.131	0.118
	5.00E+00	0.744	53550	9.57E-06	2555	19700	0.130	0.118
	6.00E+00	0.743	53090	1.00E-05	2576	19530	0.132	0.157
	7.00E+00	0.743	53070	1.01E-05	2578	19520	0.132	0.108
	8.00E+00	0.744	53700	9.31E-06	2549	19750	0.129	0.134
	9.00E+00	0.744	53450	9.63E-06	2559	19660	0.130	0.119
Logistic	1.00E+00	0.727	78670	5.59E-06	1392	39330	0.035	0.807
	2.00E+00	0.737	48920	1.02E-05	2484	24460	0.102	0.083
	3.00E+00	0.727	78670	5.59E-06	1392	39340	0.035	0.521

4.00E+00	0.727	78640	5.59E-06	1394	39320	0.035	0.405
5.00E+00	0.738	48940	1.02E-05	2484	24470	0.102	0.140
6.00E+00	0.738	49070	1.01E-05	2479	24530	0.101	0.133
7.00E+00	0.738	49110	1.01E-05	2477	24550	0.101	0.142
8.00E+00	0.737	49140	1.01E-05	2477	24570	0.101	0.130
9.00E+00	0.738	49210	1.01E-05	2475	24600	0.101	0.133

Table 6. Estimated population trajectory through non-bootstrapped of fishing mortality and biomass in ASPIC software using initial proportion (IP = 0.7) (1999-2014)

No of obs.	Year	Model							
		Fox				Logistic			
		F	***B***	***F/F$_{MSY}$***	***B/B$_{MSY}$***	***F***	***B***	***F/F$_{MSY}$***	***B/B$_{MSY}$***
1	1999	0.099	49180	0.749	2.519	0.099	49350	0.981	2.010
2	2000	0.156	45230	1.181	2.317	0.157	45070	1.554	1.836
3	2001	0.152	39850	1.148	2.041	0.152	39630	1.509	1.614
4	2002	0.121	35810	0.914	1.834	0.121	35690	1.198	1.453
5	2003	0.109	33570	0.822	1.720	0.108	33570	1.074	1.367
6	2004	0.121	32090	0.919	1.644	0.121	32200	1.197	1.311
7	2005	0.163	30480	1.236	1.561	0.162	30690	1.603	1.250
8	2006	0.113	28010	0.859	1.435	0.112	28300	1.112	1.153
9	2007	0.145	27260	1.096	1.396	0.143	27590	1.416	1.124
10	2008	0.141	25850	1.066	1.324	0.139	26210	1.375	1.067
11	2009	0.144	24760	1.092	1.268	0.142	25120	1.409	1.023
12	2010	0.142	23770	1.076	1.218	0.140	24100	1.391	0.982
13	2011	0.164	22980	1.241	1.177	0.162	23250	1.608	0.947
14	2012	0.156	21860	1.184	1.120	0.155	22040	1.541	0.898
15	2013	0.172	21080	1.304	1.080	0.172	21130	1.709	0.861
16	2014	0.180	20110	1.366	1.030	0.182	20000	1.808	0.815

F= total fishing mortality, B= starting biomass, F/F$_{MSY}$= ratio of fishing mortality to F$_{MSY}$, B/B$_{MSY}$= ratio of biomass to B$_{MSY}$.

DISCUSSION

CEDA is used to determine the MSY and other population parameters through simple time series data of catch and fishing efforts. Three surplus production models along with three error assumptions were used to estimate these parameters which are very crucial for fishery management (Hoggarth *et al*., 2006). However, these surplus production models do not include age-structured models and also fail to explain various environmental factors which can significantly affect the population. Though, CEDA is very effective tool for estimating MSY values because it does not assume the population in equilibrium state. Previous research were based on equilibrium production models but later on it was studied that fishery stock is not in equilibrium state due to biological, physical and chemical properties of water changed it may cause change in stock. In this case the non-equilibrium surplus models were frequently used for sustainable fishery because these models do not require any environmental parameters (Quinn and Deriso, 1999). Table 2 shows that when the IP value is in the range of 0.1 to 0.9, the CEDA package being sensitive to the IP value, the higher MSY values have been estimated with the lower IP value, and vice versa. According to table 3, with IP= 0.7, MSY estimates with three different error assumptions were ranged from 2500 t to 3300 t. Since, R-squared values were more than 0.5 thus the models seem to be good for various estimates. CEDA is also a better tool to estimate confidence intervals with the help of bootstrapping method which is responsible for 95% confidence interval. The CV estimates ranges from 0.06 to 0.19 with the same IP = 0.7 (Table 3). CEDA results reveals that the *M. cordyla* fishery from Pakistani waters is over-exploited because the MSY estimates show lower values than the recent annual catch

ASPIC is also used to determine the MSY and other population parameters using simple catch and effort data (Prager, 2005). The name indicates that non-equilibrium surplus production models assume that the population is not always in equilibrium state. The reason behind this fact is that population is severely affected by some other fishing, biological and environmental factors. Table 5 shows that, as compared CEDA, ASPIC is less sensitive for IP values. However, Fox model (2578 t) provides higher MSY values than Logistic model (2477 t). For the IP values ranging from 0.2–0.9, the MSY values ranged from 1300 to 2600 t. The R-squared values ranging from 0.727 to 0.744, also show the goodness of fit of the data into model. The MSY values obtained by ASPIC are lower than the recent annual catch, hence it can be concluded that *M. cordyla* fishery is in over-exploited from Pakistani waters.

Surplus production models have been used for the fishery management since the last decades. However, these models were used for stock assessment in Pakistani marine waters (Memon *et al*., 2015; Kalhoro *et al*., 2013, 2014). For instance, MSY estimates are generally considered as biological reference point which is used for fishery management. Generally, greater MSY estimates than the recent catch indicates that the fishery resource is in safe state. Similarly, when both viz. MSY estimates and recent catch are same, then stock is in a sustainable state. On the other hand, the lower MSY estimates than recent catch shows that fishery resource is over-exploited (Musick and Bonfil, 2004; Prager, 2002; Hilborn and Walters, 1992). In present study the estimated MSY values from those surplus production models are lower than the annual catch which shows that the stock of *M. cordyla* fishery is in over-exploitation state from Pakistani waters, northern Arabian Sea

Conclusion: Since MSY estimates from CEDA and ASPIC were rational with respect to the annual catch data, so it may suggest that the MSY of *M. cordyla* in Pakistani marine waters ranges from 1300–3300 tons per year. Pakistan's fisheries resources are openly accessed and there is no any effective planning to maintain the fish stocks. As the estimated MSY values being lower than the recent catch amount suggest that, it may be assumed that the *M. cordyla* fishery in Pakistani waters is over-exploited.

Therefore, we may suggest that the fishery managers should take some specific and severe steps to reduce catch to the MSY level. Measures such as, legislation for finishing, educating fishermen and check and balance on using of trawl mesh size that can be one of the assisting step to avoiding small fishing by catch that will help to grow small fishes and breeding. In addition, restriction on fish catch in breeding area for protection of the nursery grounds that can maintain the natural process, and avoiding the discard. Freshwater inflow from Indus River from Sindh coast creates best nursery grounds for the fin and shell fishery and some areas of Balochistan coast like Sonmiani bay, Astola Island. It may also be suggested the suggested areas should be declared as marine protected Areas (MPAs) as result to save small size fishery in order to growth and at least breed once in their life time. In the light of the limitations of the commercial fishery data, the research vessel surveys may be the solution to estimate the MSY level so as to maintain the fish stock then the stakeholders can get more benefits in the coming future.

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