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Fishery stock assessment of Kiddi shrimp (*Parapenaeopsis stylifera*) in the Northern Arabian Sea Coast of Pakistan by using surplus production models*

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Abstract Pakistani marine waters are under an open access regime. Due to poor management and policy implications, blind fishing is continued which may result in ecological as well as economic losses. Thus, it is of utmost importance to estimate fishery resources before harvesting. In this study, catch and effort data, 1996–2009, of Kiddi shrimp *Parapenaeopsis stylifera* fishery from Pakistani marine waters was analyzed by using specialized fishery software in order to know fishery stock status of this commercially important shrimp. Maximum, minimum and average capture production of *P. stylifera* was observed as 15 912 metric tons (mt) (1997), 9 438 mt (2009) and 11 667 mt/a. Two stock assessment tools viz. CEDA (catch and effort data analysis) and ASPIC (a stock production model incorporating covariates) were used to compute MSY (maximum sustainable yield) of this organism. In CEDA, three surplus production models, Fox, Schaefer and Pella-Tomlinson, along with three error assumptions, log, log normal and gamma, were used. For initial proportion (IP) 0.8, the Fox model computed MSY as 6 858 mt (CV=0.204, R^2=0.709) and 7 384 mt (CV=0.149, R^2=0.72) for log and log normal error assumption respectively. Here, gamma error produced minimization failure. Estimated MSY by using Schaefer and Pella-Tomlinson models remained the same for log, log normal and gamma error assumptions i.e. 7 083 mt, 8 209 mt and 7 242 mt correspondingly. The Schafer results showed highest goodness of fit R^2 (0.712) values. ASPIC computed MSY, CV, R^2, F_{MSY} and B_{MSY} parameters for the Fox model as 7 219 mt, 0.142, 0.872, 0.111 and 65 280, while for the Logistic model the computed values remained 7 720 mt, 0.148, 0.868, 0.107 and 72 110 correspondingly. Results obtained have shown that *P. stylifera* has been overexploited. Immediate steps are needed to conserve this fishery resource for the future and research on other species of commercial importance is urgently needed.

Keyword: stock assessment; fishery management; *Parapenaeopsis stylifera*; surplus production models; Pakistan

1 INTRODCUTION

Shrimp are one of the major fishery resources landed on the dock stations on the coast of Pakistan (Fig.1). The Indus Delta estuary is particularly rich in shrimp diversity. Over 30 species of shrimps live in mangrove creeks around this delta (Hayat, 2003). Commercial catches of shrimps from this region are categorized into three groups i.e. Jaira (white shrimp), Kalri (pink-brown shrimp) and Kiddi shrimps. Kiddi shrimps belong to the family Penaeidae, a family of marine crustaceans, which is represented by 48 genera worldwide (De Grave et al., 2009). In Pakistan, 27 penaeid shrimp species have been reported from marine waters. Commercially important penaeid shrimps include *Fenneropenaeus penicillatus*, *F. merguiensis*, *Penaeus semisulcatus*, *Metapenaeus affinis*, *M. monoceros* and *Parapenaeopsis stylifera* (Tirmizi and Bashir, 1973). *P. stylifera* (Milne-Edwards, 1837) is the most landed commercial

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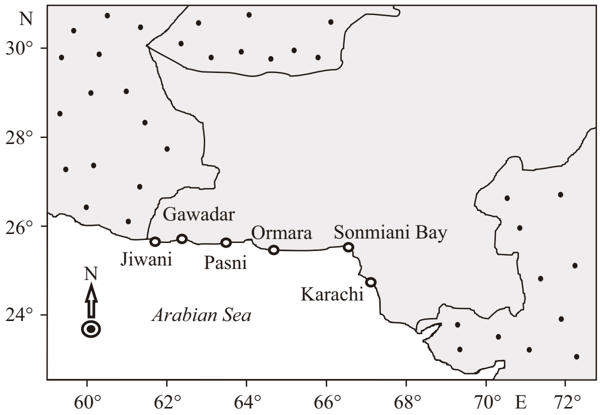

Fig.1 Coastline of Pakistan showing main landing sites (circles)

penaeid species in Pakistan (Ayub and Ahmed, 2001). The English name of *P. stylifera* is the Kiddi Shrimp and in Pakistan, it is called Kidi in the Punjabi language (Holthuis, 1980). This tropical shrimp is an inhabitant of the Indian Ocean and is distributed from Kuwait to Indonesia (Pérez and Kensley, 1997). It occurs to the depth of 90 m from the coast and is generally found at a depth of 50 m on soft sandy or muddy substrates (Carpenter et al., 1997). They can attain a maximum length of 14.5 cm. These creatures are gonochoric and show precopulatory courtship (Rupert et al., 2003).

The demand for large shrimp from USA, Japan and West European countries has increased. To respond to this rise in demand, the number of commercial mechanized fleets is increasing with the passage of time. The number of trawlers increased from 3 (1958) to 1 631 (1985) (FAO, 2011). Their recent operating number is even higher, around 2 400. Despite the overall increase in capture fisheries due to these efforts, the fisheries production from the marine sector is gradually decreasing. The main reason for this is that Pakistani marine waters are under an open access regime due to the absence of effective management or policy applications (FAO, 2009). This blind commercial fishing is not just ruining aquatic resources but also resulting in economic losses (Mohsin et al., 2015). To get maximum benefit and to protect marine resources, understanding the population dynamics of aquatic creatures is crucial.

Surplus production models (SPMs) are conventional tools frequently used in fishery resource assessment. Their popularity stems into their ease of use and their ability to compute exclusive parameters. Surplus production refers to that fish stock biomass which will grow without fishing. Thus, fishing can be done sustainably by maintaining fish stock at constant level. SPMs depend on the concept of fishery stock depletion. The depletion concept refers to the fall in abundance indicator due to the removal of fishery stock. Depletion models require comprehensive continuous record of catch statistics. Data gaps may give errors in assessment, thus data without gaps is preferred. These models may also require a good index of relative population size. A good index refers to the representation of the actual population size. Not necessarily instead of catch statistics, CPUE can also be used to estimate various parameters. Both the commercial the survey catch statistics and CPUE data can be employed to assess the fishery stock (Hoggarth et al., 2006).

They are usually preferred to age structured models. Data for age structured models is difficult to collect. The bands on the otoliths are not easy to interpret particularly for fishes living in tropical regions as the bands on otoliths are hard to identify due to changing weather patterns. On the other hand, SPMs require simple data on catch and effort (CPUE) as well as on abundances. Their estimated parameters can be easily computed on the basis of biological reference points or maximum sustainable yield. They give us the direction in making harvest strategies for sustainable fishing (Jensen, 2002). A plethora of published literature indicates that SPMs are very important tools in fishery stock assessment and have been used worldwide in fishery management (Ricker, 1975; Pitcher and Hart, 1982; Hilborn and Walters, 1992; Prager, 1994, 2005; Quinn and Deriso, 1999; Maunder et al., 2006; Panhwar et al., 2012).

Earlier versions of SPMs assumed that a fishery stock is in a stable state, but this is rarely the case in natural fish populations (Hilborn and Walters, 1992). However, current SPMs use non-equilibrium state of the fish stock. These SPMs usually use non-linear regression and are relatively difficult to interpret. Nowadays, various software have been developed which can estimate biomass dynamics of the exploited fish stock e.g. A Stock Production Model Incorporating Covariant (ASPIC) (NOAA, 2016) and Catch and Effort Data Analysis (CEDA) (MRAG, 2016). These computer packages are easily assessable and very useful time-saving tools.

In Pakistan, the Marine Fisheries Department (MFD) is the sole public department which monitors and manages marine fisheries. Although, it publishes catch statistics of the entire captured fishery, dissemination and usage of data for scientific studies

Table 1 Time series catch and effort statistics (1996–2009) of *P. stylifera* in Pakistani marine waters

Year	Sindh	Baloch	EEZ	Total	Fishermen	CPUE
1996	13 171	0	0	13 171	113 669	0.116
1997	15 912	0	0	15 912	118 094	0.135
1998	13 854	0	0	13 854	119 199	0.116
1999	12 121	0	0	12 121	121 520	0.100
2000	11 945	0	0	11 945	127 181	0.094
2001	11 082	0	0	11 082	128 531	0.086
2002	10 998	0	0	10 998	132 412	0.083
2003	11 769	250	0	12 019	138 072	0.087
2004	11 912	446	0	12 358	140 023	0.088
2005	10 111	0	0	10 111	142 123	0.071
2006	9 414	313	0	9 727	144 591	0.067
2007	9 100	341	0	9 441	146 740	0.064
2008	9 721	1443	0	11 164	148 706	0.075
2009	9 134	304	0	9 438	152 887	0.062

Note: Taken from the Handbook of Fisheries Statistics of Pakistan.

require special permission. MFD does not report on-age composition data. Few studies have been done on the population dynamics of fish fauna inhibiting Pakistani marine waters. However, every fishery resource needs to be evaluated individually to access its stock status because the population dynamics and catch data patterns are different for different fishery stocks.

Earlier reported work on *P. stylifera* from Pakistani marine waters is either related to their abundance or encompasses some other biological aspects. Ayub and Ahmed (2001) described the species composition of landed Jaira, Kalri and Kiddi shrimps at the Karachi fish harbor. They found that *M. Affinis* and *P. stylifera* are the most landed shrimp species in Pakistan. The reproductive characters of four penaeid shrimp species, *Penaeus penicillatus*, *P. merguiensis*, *Metapenaeus affinis* and *P. stylifera* collected from Pakistan's inshore waters have also been studied (Ayub and Ahmed, 2002). This study concluded that the ovaries of these shrimp species undergo color changes during maturation. They also found that in *P. stylifera* spawning takes place more frequently during November to February. Muhammad et al. (2014) studied the structure of vasa deferentia and spermatophores in *P. stylifera*. Their study concluded that spermatophores are minute and spindle shaped entities that exist in large numbers. Further, they revealed that the vas deferens or ejaculatory duct in *P. stylifera* is without any partition.

Despite the commercial importance of *P. stylifera*, no published literature is available on the stock assessment of this aquatic creature in Pakistani marine waters. This research article is the first report about the fishery stock of *P. stylifera* by using catch and effort data. It is expected that this finding will help to understand population dynamics of this fishery stock and thus help to improve fishery policies.

2 MATERIAL AND METHOD

2.1 Data acquisition

Available catch and effort data (CE), 1996–2009, for the *P. stylifera* fishery from Pakistani marine waters were analyzed to evaluate the fishery status of this resource. Data was procured from the Handbook of Fisheries Statistics of Pakistan published by Marine Fisheries Department (MFD), Karachi. Most of the *P. stylifera* catch is reported from Sindh because its coast is muddy, sandy and rich in biodiversity due to fresh water flow from Indus River. The contribution of the catch from Baluchistan, with a sheer coast and with less biodiversity, is very low and from the EEZ, there is no reported catch (Table 1). Catch and fishing effort are in the form of metric tons (mt) and the number of fishermen respectively.

2.2 Data evaluation

Collected time series data of *P. stylifera* from 1996–2009, a 14-year period, was statistically analyzed by using SPMs. For this purpose two specialized stock assessment tools viz. catch and effort data analysis (CEDA) (Hoggarth et al., 2006) downloaded from MRAG website and a stock production model incorporating covariates (ASPIC) (Prager, 2005) downloaded from NOAA Fisheries Toolbox were used. These computer packages have been developed by fishery scientists form UK and USA. These stock assessment tools assume fishery stocks to be in a non-equilibrium state. The purpose of using these two computer packages simultaneously in this study is to improve confidence in the results as each analysis may have uncertainty.

Following the description of Hoggarth et al. (2006) regarding the use of CPUE in fish stock assessment we used nominal CPUE. Occasionally, SPMs are also called biomass dynamics models which have three different versions by three different scientists Fox, Schaefer and Pella-Tomlinson. These models are based on some assumptions. Schaefer (1954) model is built on a logistic population growth model and is most commonly used.

$$\frac{\mathrm{d}B}{\mathrm{d}t} = rB(B_\infty - B) \text{ (Schaefer, 1954).}$$

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

$$\frac{\mathrm{d}B}{\mathrm{d}t} = rB(\ln B_\infty - \ln B) \text{ (Fox, 1970),}$$

$$\frac{\mathrm{d}B}{\mathrm{d}t} = rB(B_\infty^{n-1} - B^{n-1}) \text{ (Pella and Tomlinson, 1969),}$$

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

2.3 CEDA (version 3.0.1)

CEDA (catch and effort data analysis) computer package is menu driven data fitting tool and has the ability to estimate customized parameters. It uses a confidence interval of 95% through bootstrapping method. CEDA further makes three error assumptions viz. log, log-normal and gamma for all the SPMs i.e. Fox, Schaefer and Pella-Tomlinson models. It has very good tools including residual plots and goodness of fit. This computer package requires an input of IP or B_1/K. IP is calculated by dividing initial catch value by the maximum catch value available in the catch and effort data series. Further, various IP values are used to access fishery stock. When the IP input value is zero, CEDA computes parameters by assuming fishery stock in a virgin state. On the other hand, when IP input value is one this computer package supposes that fishing started from already heavily exploited state. Sometimes, initial biomass is fixed as $B_1=C_1/(qE_1)$. In this mathematical statement, C, q and E stand for catch, catchability and fishing effort correspondingly. Some programmers also use B_1 equal to K. CV (coefficient of variation) is estimated by using confidence intervals. Other important parameters estimated by using CEDA are MSY (maximum sustainable yield), K (carrying capacity), q (catchability coefficient), r (intrinsic growth rate), R_{yield} (replacement yield) and final biomass.

2.4 ASPIC (version 5.0)

ASPIC (a stock production model incorporating covariates) software also needs an input of IP. However, in contrast to CEDA, it requires separate input files for each IP value. Two SPMs were employed by using this fishery software viz. Fox (a special case of GENFIT) and Logistic model (also called Schaefer model). To calculate CV (coefficient of variation), for both of the SPMs, FIT and BOT files were prepared for all IP values. FIT and BOT refer to program modes used in ASPIC. There exists a technical difference between them. During FIT program mode ASPIC software estimates parameters of management interest while during BOT program mode it uses bootstrapped confidence intervals with many trials for the calculation of parameters. Therefore, the execution time of BOT mode is much higher than FIT mode. In order to compute MSY, for each IP value, 500 trials were done. Important parameters estimated by using this computer package include 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 multiple factors were considered as described by Hoggarth et al. (2006). Sensitivity analysis was performed for constant recruitment model. However, due to unreliable results obtained we switched to non-equilibrium SPMs evaluation i.e. three production models. Within these models again sensitivity analysis was performed by using IP values (Tables 2, 5). The results obtained for various parameters were further considered along with R^2 values and visual inspection of the graphs for model selection and comparison for drawing reliable results.

3 RESULT

Capture production of *P. stylifera* form Pakistani marine waters totaled 163 341 mt during the study period. Maximum and minimum catch quantities were observed in 1997 (15 912 mt) and 2009 (9 438 mt) respectively, while the average catch remained 11 667 mt/a. Highest and lowest values of CPUE (catch per unit effort) were examined during the first and last year of the study i.e. 1996 (0.116) and 2009 (0.062) in that order (Table 1). The average effort during the study period remained 0.089/a. Computed results by using CEDA and ASPIC were further examined by considering four factors viz. maximum sustainable yield (MSY), the goodness of fit (R^2), residual plots between observed and expected catches and coefficient of variation (CV). Computed MSY values were compared with data figures and very large or small MSY values were not considered. Models were compared on the basis of R^2 values and

Table 2 Estimated MSY values for *P. stylifera* in Pakistani marine waters by using CEDA computer package (IP=0.1–0.9)

IP	Model								
	Fox			Schaefer			Pella-Tomlinson		
	Normal	Log normal	Gamma	Normal	Log normal	Gamma	Normal	Log normal	Gamma
0.1	2.06E+10	18 604	18 552	MF	26 791	MF	MF	26 791	MF
	0.527	0.003	0.053	MF	0.028	MF	MF	0.029	MF
0.2	15 095	15 092	MF	MF	13 161	MF	MF	13 161	MF
	0.005	0.000	MF	MF	0.045	MF	MF	0.037	MF
0.3	11 158	9 265	11 237	0.25	9 168	15 915	0.25	9168	15 915
	0.063	0.022	0.065	0.574	0.039	0.000	0.532	0.038	0.001
0.4	9 482	7 825	MF	12 528	13 467	57 589	12 528	13 467	57 589
	0.104	0.058	MF	0.031	0.000 2	5 669.467	0.030	0.000	4 756.955
0.5	8 434	7 291	8 526	10 806	12 245	MF	10 806	12 245	MF
	0.128	0.082	0.121	0.065	0.000 4	MF	0.070	0.000 4	MF
0.6	7 727	7 422	MF	9 273	9 740	9 430	9 273	9 740	9 430
	0.138	0.131	MF	0.127	0.017	0.125	0.124	0.021	0.122
0.7	7 225	7 281	7 313	8 054	9 089	8 209	8 054	9 089	8 209
	0.181	0.142	0.162	0.169	0.026	0.166	0.172	0.032	0.161
0.8	6 858	7 384	MF	7 083	8 209	7 242	7 083	8 209	7 242
	0.204	0.149	MF	0.211	0.084	0.196	0.216	0.095	0.196
0.9	6 587	7 268	6 693	6 309	7 176	6 462	6 309	7 176	6 462
	0.232	0.135	0.229	0.248	0.154	0.265	0.249	0.150	0.239

CV: coefficient of variation is written below MSY values; MF: represents minimization failure.

visual examination of residual plots. The higher is the value of R^2 the better is the fit of the model. Results with suitable CV values were accepted.

3.1 CEDA result

CEDA showed sensitivity towards the input IP values as it produced different output MSY figures for various IP inputs (Table 2). Sometimes gamma error assumption showed minimization failure in all the SPMs used. In addition to this, only for Schaefer model did normal assumption produce minimization failure for IP values of 0.1 and 0.2. CV values were obtained by using a special method called bootstrapping confidence limit method. For all the SPMs used along with their error assumptions either MSY or R^2 value did not produce rational results except for IP 0.8. For IP 0.8, values of R^2 by using normal and log normal assumption in Fox model were 0.709 and 0.72 respectively. For both the models i.e. Schaefer and Pella-Tomlinson R^2 values were the same as 0.703, 0.712 and 0.711 in that order. R^2 (the goodness of fit) values are very important to consider as they tell us about the fitting of the model.

Computed parameters for IP 0.8 are given in Table 3. Estimated values of MSY and their CV for the Fox model with normal assumption were 6 857 t and 0.204 correspondingly while for log normal their values remained 73 834 t and 0.211. Gamma error assumption showed minimization failure for the Fox model. Computed MSY values for all the error assumptions used in Schaefer and Pella-Tomlinson models remained the same. For both of these models, their values were 7 083 mt, 8 209 mt and 7 242 mt respectively. Calculated CV values for both of these models for all the error assumptions were 0.211, 0.084, 0.196 and 0.216, 0.095, 0.196 in that order. Figure 2 shows the graphical representation of observed and expected annual catch values. From visual inspection it can be recognized that observed and expected catch values are close to each other for all the error assumptions used in the Fox model, however in detail, they differ from each other. CEDA computed higher MSY values with lower IP values and vice versa.

3.2 ASPIC result

ASPIC software did not produce results for all the IP values. Only IP values 0.5–0.9 computed various

Table 3 Various parameters computed by using CEDA computer package for *P. stylifera* in Pakistani marine waters (IP=0.8, because the initial catch was about 80% of the initial catch)

Model	K	q	r	MSY	R_{yield}	CV	R^2	B	B_{MSY}
Fox (normal)	192 178	8.60E-07	0.097	6 858	6 855.851	0.204	0.709	72 359	70 698
Fox (log normal)	177 971	9.31E-07	0.113	7 384	7 379.514	0.149	0.72	67 725	65 472
Fox (gamma)	MF								
Schaefer (normal)	166 587	9.90E-07	0.170	7 083	6 615.408	0.211	0.703	61 899	83 293
Schaefer (log normal)	128 680	1.32E-06	0.255	8 209	7 593.941	0.084	0.712	46 724	64 340
Schaefer (gamma)	162 212	1.01E-06	0.179	7 242	6 776.863	0.196	0.711	60 548	81 106
Pella-Tomlinson (normal)	166 587	9.90E-07	0.170	7 083	6 615.408	0.216	0.703	61 899	83 294
Pella-Tomlinson (log normal)	128 680	1.32E-06	0.255	8 209	7 593.941	0.095	0.712	46 724	64 340
Pella-Tomlinson (gamma)	162 212	1.01E-06	0.179	7 242	6 776.863	0.196	0.711	60 548	81 106

MF: indicates 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 4 Various parameters estimated by using ASPIC software for *P. stylifera* in Pakistani marine waters (IP=0.8, because the initial catch was about 80% of the initial catch)

Model	IP	MSY	K	q	F_{MSY}	B_{MSY}	R^2	CV
Fox	0.8	7 219	177 400	9.332E-07	0.110 6	65 280	0.872	0.142
Logistic	0.8	7 720	144 200	1.15E-06	0.107 1	72 110	0.868	0.148

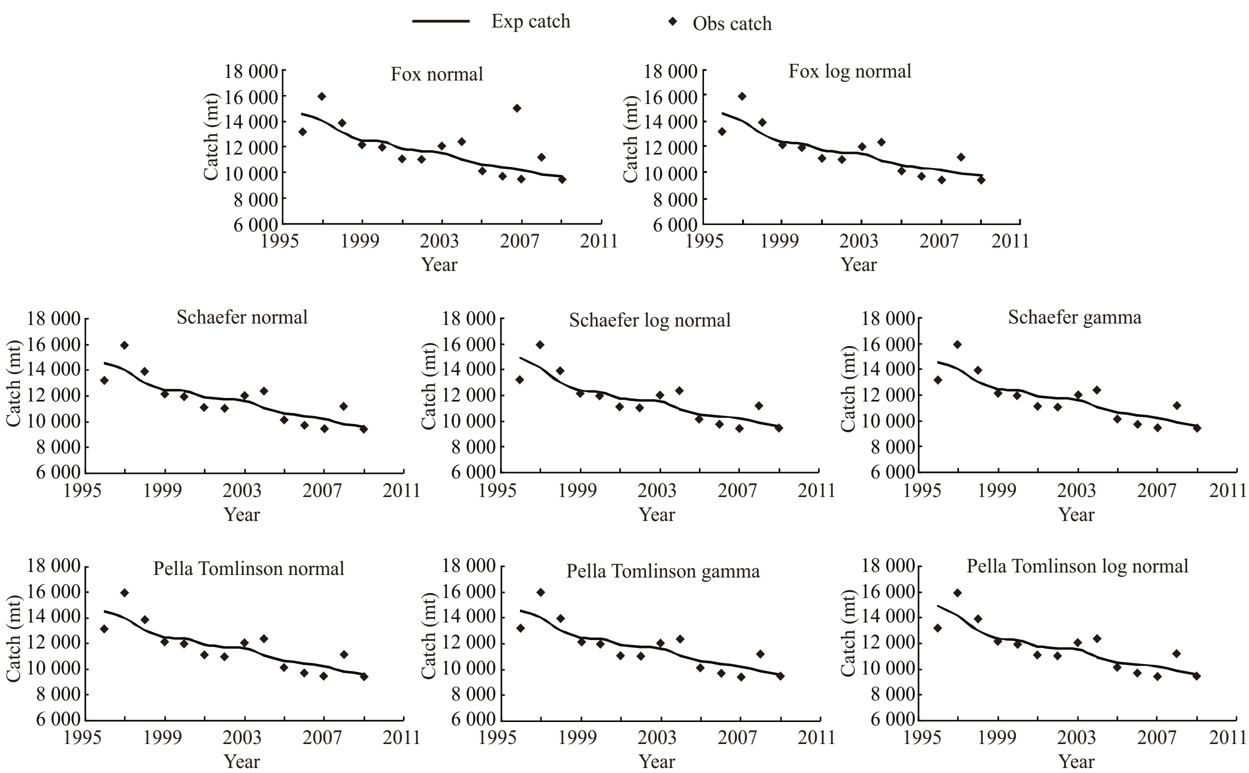

Fig.2 Annual observed (dots) and estimated (lines) catches (metric tons) for *P. stylifera* by using CEDA computer package in Pakistani marine waters (IP=0.9)

parameters through this software. The calculated parameters for IP 0.8 are listed in Table 4. MSY along with their CV (coefficient of variation) values for the SPMs, Fox, and Logistic models used in ASPIC, were estimated as 7 219 mt (0.142) and 7 720 mt (0.148) respectively. The Fox model showed better fit as its R^2

Table 5 ASPIC results for *P. stylifera* by using ASPIC software in Pakistani marine waters (IP=0.5–0.9)

Model	IP	MSY	K	q	F_{MSY}	B_{MSY}	R^2	CV
Fox	0.5	8 737	166 700	1.58E-06	0.142 4	61 340	0.869	0.096
	0.6	8 044	170 500	1.29E-06	0.128 2	62 730	0.87	0.095
	0.7	7 566	173 800	1.09E-06	0.118 3	63 930	0.871	0.114
	0.8	7 219	177 400	9.33E-07	0.110 6	65 280	0.872	0.142
	0.9	6 979	181 100	8.13E-07	0.104 8	66 620	0.872	0.144
Logistic	0.5	10 920	105 500	2.42E-06	0.207 1	52 740	0.857	0.061
	0.6	9 724	112 300	1.94E-06	0.173 2	56 140	0.863	0.090
	0.7	8 639	127 700	1.48E-06	0.135 3	63 850	0.866	0.112
	0.8	7 720	144 200	1.15E-06	0.107 1	72 110	0.868	0.148
	0.9	6 960	159 500	9.25E-07	0.087 27	79 750	0.869	0.164

Table 6 ASPIC estimates of fishing mortality (*F*) and biomass (*B*) (IP=0.8) (1996–2009)

Year	Model							
	Fox				Logistic			
	F	B	F/F_{MSY}	B/B_{MSY}	F	B	F/F_{MSY}	B/B_{MSY}
1996	0.163	83 280	1.145	1.358	0.255	52 730	1.233	1.000
1997	0.213	78 440	1.497	1.279	0.333	50 470	1.607	0.957
1998	0.203	71 070	1.422	1.159	0.317	45 380	1.531	0.861
1999	0.189	65 890	1.327	1.074	0.294	42 130	1.419	0.799
2000	0.196	62 500	1.378	1.019	0.302	40 410	1.459	0.766
2001	0.191	59 290	1.340	0.967	0.290	38 710	1.401	0.734
2002	0.197	56 930	1.385	0.928	0.296	37 720	1.427	0.715
2003	0.227	54 640	1.595	0.891	0.338	36 700	1.633	0.696
2004	0.251	51 270	1.760	0.836	0.376	34 440	1.814	0.653
2005	0.217	47 470	1.522	0.774	0.327	31 460	1.579	0.597
2006	0.215	45 830	1.513	0.747	0.324	30 400	1.567	0.577
2007	0.215	44 510	1.508	0.726	0.323	29 570	1.560	0.561
2008	0.266	43 420	1.870	0.708	0.407	28 880	1.963	0.548
2009	0.237	40 500	1.664	0.660	0.372	26 130	1.795	0.495

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.

value (0.872) was higher than the computed R^2 value (0.868) for the Logistic model. Calculated F_{MSY} (fishing mortality rate at MSY), B_{MSY} (stock biomass giving MSY) and K remained 0.111, 65 280 t, 177 400 and 0.107, 72 110 t, 144 200 for the Fox and the Logistic models respectively. Table 5 shows different factors computed for IP 0.5–0.9. Like CEDA, ASPIC also showed sensitivity to IP values as it estimated different output parameter values for different IP input values. ASPIC estimated larger MSY values for smaller IP values. However, parameters calculated by this software did not show higher variation as compared to CEDA. For example, MSY computed by ASPIC ranged in 6 500 mt–11 000 mt while for CEDA its estimated range was 6 500 mt–2.06E+10 mt. It means that ASPIC is sensitive to IP values but its sensitivity is less than CEDA. For IP 0.1–0.4, ASPIC did not compute required parameters because the data set was not suitable for computing all IP values. In contrast to CEDA, ASPIC models showed higher R^2 values indicating better fitting of the data.

Estimated fishing mortality (F) and biomass (B) values of *P. stylifera* by using ASPIC are listed in Table 6. Figures obtained indicate that F has shown an increasing trend with the passage of time whereas B has decreased. F/F_{MSY} has increased and B/B_{MSY} has decreased during the course of the study period. Both, F/F_{MSY} and B/B_{MSY} indicate overexploitation of the fishery stock.

4 DISCUSSION

Several studies have been conducted on the stock status of various fish resources inhabiting Pakistani marine waters (Panhwar et al., 2012; Panhwar and Liu, 2012; Siyal et al., 2013; Kalhoro et al., 2013, 2014; Memon et al., 2015). All of these studies involve the same SPMs used in our project. In fact, these models confer many advantages over the other routines used in fishery stock assessment. For example, these SPMs require simple input data of catch statistics to compute fishery parameters. Similarly, these models produce an estimate of unified biomass incorporating various population aspects such as growth, recruitment and mortality. In addition to this, estimated current population size can be employed to compute fishing mortality. Moreover, catchability coefficient (q) calculated directly forecasts fishery stock status. Other important fishery parameters which can be computed by using SPMs include B_{current}, B_{MSY}, F_{current} and F_{MSY}.

SPMs are based on statistical calculations by using certain assumptions. In nature, most of the assumptions may not be met. For example, the majority of the SPMs assume that there exists no inter- or intra-species interaction, which is impossible in the natural environment. Similarly, it is supposed that r does not depend on age composition, catchability coefficient remains constant, there is a single stock unit, fishing and natural mortality go hand in hand, gears and vessels remain equally efficient and gathered catch and effort statistics are perfectly true (Ewald and Wang, 2010). These models also assume no emigration or immigration in the fish population (Hoggarth et al., 2006).

Another drawback of these models is that they do not encompass age structure data. These models also do not use time delays between recruitment and reproduction. Furthermore, uncertainty is also associated with MSY estimation (Ewald and Wang, 2010). However, even despite deviation/s from these assumptions or uncertainties, the scientific method is not rejected. Instead, critical use of SPMs makes them powerful tools for initial fishery stock assessment (Musick and Bonfil, 2005).

Although less statistically simple consideration of catch, effort and CPUE data may also be used as an indicator of fishery status. For example, if both catch and effort show increasing trends and CPUE is fairly constant, it may be concluded that fish stock is not being disturbed by fishing. However, when effort remains constant but catch either increases or decreases, it may be due to quantitative changes in the fish stock. On the other hand, when the effort is increasing and catch is decreasing this may suggest that the fish stock is declining rapidly (Hoggarth et al., 2006).

Non-equilibrium SPMs have amazing flexibility and are reliable tools for fishery management advice as compared to traditional estimation of MSY. The use of CEDA is advantageous as this computer package assumes the non-equilibrium state of the fishery stock which occurs in nature. Thus, they give more accurate and reliable results as compared to earlier versions of SPMs which were based on the equilibrium assumption (Medley and Ninnes, 1997; Hoggarth et al., 2006). In CEDA, all the SPMs use the concept of depletion and require two types of data. First, it needs catch data to estimate sustainable exploitation of the fishery stock. Second, it requires an abundance index which must be proportional to the population size (Medley and Ninnes, 1997). Further, for catch per unit effort data, the non-equilibrium state of the fishery stock is important because if this assumption is not met the modeling approach may be wrong (Panhwar and Liu, 2013).

Selection of SPMs depends upon the available data and objective of the analysis. For annual catch and effort data production model may be fitted. It is usually better to test more production models to analyze data. Then, the results obtained may be compared to find the best fit. Commonly all the SPMs give almost the same parameter estimates, however, differences may exist due to the model assumptions. If two or more models compute the same estimates for parameters it means the results are not dependent of some un-testable biological assumptions. Once the best fitting of data is obtained by using model parameters, they can be used to estimate various reference points for fish stock (Hoggarth et al., 2006).

Model diagnostics are a very important component of the analysis. Goodness of fit depends upon two factors. First, it is reasonable to judge goodness of fit based upon the R-squared values obtained. However, R-squared values must not be used alone, but rather visual examination of residual plots, fit between observed and expected data points, is an essential element to use while selecting best model. High R-squared values should not be considered if the residual plots show poor fit (Hoggarth et al., 2006).

Fishery management is basically an integrated process. It involves data gathering, analysis, interpretation of results, consultation, planning and decision making (FAO, 1997) involving stakeholders (Die, 2002). In the science of fishery management, reference points are commonly used to set management objectives and track fishery status (Hoggarth et al., 2006). The concept of reference points (RPs) was introduced in 1992. Nowadays, they are a part of the FAO Code of Conduct for Responsible Fisheries (FAO, 1995). These reference points are broadly divided into two kinds: TRPs (target reference points) and LRPs (limit reference points). As the name implies, TRPs are the desirable fishery points. On the other hand, LPRs are undesirable fishery points which must be avoided or otherwise the fish stock will suffer. RPs serve as a signpost by providing specific values and guide fishery managers (Caddy and Mahon, 1995; Cochrane, 2002). RPs help fishery managers in decision making e.g. when fishing mortality is set at F_{MSY} the fishing will stop when it crosses B_{MSY} limit. However, when it is below B_{MSY} fishing may be continued. This simple decision making rule is known as "pulse fishing" in fishery management science (Caddy and Mahon, 1995).

Usually three RPs or indicators MSY, F_{MSY} and B_{MSY} are used in fishery management when the objective is to theoretically estimate highest possible fish catch. Among these RPs, MSY receive priority due to its projection in fisheries literature. Estimated MSY, by using SPMs, expresses fishery status. Generally, when computed MSY is higher than catch statistics, it means fishery stock is flourishing and, even more, fishing is allowed up to the estimated MSY. However, when computed MSY is lower than catch values it means that fishery resource is overexploited which must be controlled to conserve this resource for future. But, when both the estimated MSY and catch figures are equal the fishery stock is considered in equilibrium. MSY concept was coined for the first time in 1992. Later on, it was included in the UN Convention on the Law of the Sea. In 1995, UN Fish Stock Agreement defined MSY in terms of F_{MSY} and B_{MSY}. It was suggested that F_{MSY} should be taken as the lower bound of LRPs (Hoggarth et al., 2006). According to Gabriel and Mace (1999) F_{MSY} is the upper bound for LPRs. Thus, TRPs should be kept below the MSY level. TRPs for MSY should be indentified very carefully. If the MSY is overestimated the fishery stock will decline with the passage of time. On the other hand, underestimated MSY will cause economic losses. It should be remembered that RPs are indicators and do not specify constant quantities. Their indication does not allow constant yield but rather they should be considered as overfishing alarms (Rosenberg et al., 1993).

For effective management of a fishery resource, ecological as well as anthropogenic effects must be taken into consideration. Penaeid shrimps inhabit shallow waters where trawlers operate for their commercial catch. Published literature indicates that around the year two spawning peaks occur in *P. stylifera*. Usually, the spring spawning occurs from May to July whereas autumn spawning from November to February (Ayub and Ahmed, 2002). In Pakistan the closed season for shrimp fishing, according to Act 1975, SRO 329(1), is from June to July (Schmidt, 2014). However, this ban is during the spring spawning season of *P. stylifera*. During autumn spawning season fishermen catch a large proportion of the breeding stock resulting in the subsequent biomass production being less. The situation gets even more adverse when untreated effluents pollute the coastal waters. In this filthy water, the survival of this aquatic fauna becomes very difficult. Moreover, high salinity along the coastal belt of sea also hinders *P. stylifera* from maximum spawning. The most important factor responsible for decreased biomass production of this fishery resource is commercial catch. To restore and conserve this precious resource, fishing during the autumn breeding season must also be banned. The fishery managers should play their key role by keeping an eye over the other factors too which are affecting the stock of *P. stylifera* in Pakistani marine waters.

5 CONCLUSION

For CEDA and ASPIC the estimated value of MSY, IP 0.8, ranged from 6 500 mt to 8 500 mt and from 7 000 mt to 8 000 mt respectively. Thus, CEDA seems to be more conservative in terms of calculated MSY as compared to ASPIC. Higher values of R^2 for ASPIC indicate that its results are more reliable. The MSY ranges computed by the Fox and the Logistic models overlap, thus by considering the results of both these software packages and applying the pulse fishing rule, we recommend that the MSY TRP range of *P. stylifera* is from 7 000 mt to 7 500 mt in Pakistani marine waters. A capture production of 8 000 mt or more must be considered 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 noted that this fishery resource has consistently been overexploited in the past. Due to overfishing, *P*. *stylifera* stock is shrinking with the passage of time. Thus, immediate steps combining proper planning with legitimate implementation are urgently needed to conserve this fishery resource for the future.

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