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APPLICATION OF NON-EQUILIBRIUM MODELS TO EVALUATE FISHERY STATUS OF SQUIDS IN PAKISTANI MARINE WATERS

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ABSTRACT

Maximum sustainable yield (MSY) of squid fishery (including all species of squids) from Pakistani marine waters was calculated by using the catch and effort data from 1998 to 2010. Reported squid capture production totaled 40,390 metric tons (mt) during this period. The highest catch was 5,062 mt in 1999 while the lowest catch, 2,130 mt, was observed in 2003. Two specialized computer applications viz. CEDA and ASPIC were employed to statically evaluate the data. CEDA computer package includes three surplus production models (SPMs): the Fox, Schaefer and Pella Tomlinson models. Each model further uses three error assumptions i.e. log, log normal and gamma. An IP (initial proportion) of 0.6 was used because the initial catch was about 60% of the maximum catch. Computed MSY and CV values from the Fox model with log and log normal error assumptions were 2,401 mt (0.314) and 2,553 mt (0.250) correspondingly. However, for the Schaefer and Pella Tomlinson models, by using log and log normal assumptions, MSY and CV values remained 2,416 mt (0.235), 2,746 mt (0.072) and 2,416 mt (0.292) and 2,746 mt (0.063) in that order. All the SPMs with gamma error assumption did not produced interpretable result. In ASPIC, we used two models i.e. Fox and Logistic. Computed MSY with CV remained 2,659 mt (0.093) and 2,664 mt (0.065) respectively. CEDA computer package showed better fit to the data in terms of goodness of fit (R^2) values. CEDA results, for the Schaefer and Pella Tomlinson models with log assumption, both with high R^2 values (0.607), suggest that MSY of squid fishery in Pakistani marine waters is around 2,400-2,500 mt. Current of catch of this fishery resource is higher than its MSY. Thus, overall landing of this fishery resource must be reduced through some effective management measures in order to conserve this resource for future.

Keywords: squids, fishery status, CEDA, ASPIC, Pakistan.

INTRODUCTION

Among molluscan cephalopods, squids are the most captured category from the Arabian Sea (Anusha *et al*., 2014). Commercially important squids include *Loligo duvauceli*, *Sepioteuthis lessonia* and *Doryteuthis* sp. In most of the landings, cephalopods are mainly represented by the squid species *Loligo duvauceli*. This dominant species makes about 95% of the total squid catch from Indian waters. Squids are caught with trawl nets operating up to 100 meters depth and make about 85 % of the cephalopods landings (Meiyappan and Mohamed, 2003). In general, squids have high fecundity, up to more than 0.5 million eggs (Zuyev *et al*., 2002). Squids are gaining popularity in international sea food markets. Their meat is low in fats, rich in proteins and best alternative to fish protein (Lu, 2002). Major importers of squids include the European Union, USA, China, Japan, and countries of South East Asia and the Middle East. Due to commercial squid fishing, squid biodiversity assessment is urgently needed (Anusha *et al*., 2014).

Surplus production models (SPMs) are conventional tools frequently used in fishery resource assessment. Their popularity stems from their ease of use and their ability to compute exclusive parameters. Exclusive parameters are those which indicate very important aspects of the state of the fishery. These parameters include carrying capacity (K), maximum sustainable yield (MSY), catchability coefficient (q), intrinsic growth rate (r), replacement yield (R_{yield}), and final biomass. They require simple data on catch and effort, and use CPUE as an index of abundance. Their estimated parameters can be used to derive biological reference points or maximum sustainable yield. No doubt, they are less realistic than age structured models; however, they give us the direction in making harvest strategies for sustainable fishing (Jensen, 2002). A plethora of published literature indicates that SPMs have been used worldwide in fishery management (Ricker, 1975; Pitcher and Hart, 1982; Hilborn and Walters, 1992; Prager, 1994, 2005; Laloë, 1995; Walters and Parma, 1996; Quinn and Deriso, 1999; Panhwar *et al*., 2012).

Earlier versions of SPMs assumed that the fishery stocks are in a stable state which rarely occurs in natural fish population (Hilborn and Walters, 1992). However, now SPMs assume non-equilibrium state of the fishery stock. These SPMs are usually based on non-linear regression. Nowadays, various software have been developed which have the ability to estimate biomass dynamics of the exploited fishery stock e.g. A Stock Production Model Incorporating Covariates (ASPIC) (Prager, 2005) and Catch and Effort Data Analysis (CEDA) (Hoggarth *et al*., 2006). These computer packages are easily accessible and time saving tools.

In Pakistan, due to poor management and other policy reasons, fishery resources are under an open access regime (FAO, 2009). Thus, it is very important to evaluate status of every fishery stock in Pakistani marine waters. Research regarding the fishery stock assessment of *Argyrops spinifer* has concluded that this creature has consistently been overexploited in the past and some effective management is needed to conserve this resource (Memon *et al*., 2015). A study conducted on *Pampus argenteus* also ended up with similar results (Sial *et al*., 2013). Thus, various researchers have worked on fishery stock assessment in Pakistani marine waters and found that most of the fish stocks have been overexploited (Mohsin *et al*., 2016; Kalhoro *et al*., 2015; Kalhoro *et al*., 2013; Panhwar *et al*., 2012).

Therefore, overall the current status of fishery stocks in Pakistani marine waters is alarming and further research on particularly commercially important species is direly needed. In Pakistan few studies have done on squids which involve their biology (Khaliluddin and Haq, 1998; Bano *et al*., 1992). Available literature on fishery stock assessment in Pakistani marine waters is devoid of squids. This pivotal project is the first attempt to evaluate fishery status of squids (including all species of squids) in Pakistani marine waters. It is envisaged that this may not only provide better understanding of this fishery resource but also it will give direction to fishery managers and help them to achieve sustainable exploitation of this fishery resource.

MATERIALS AND METHODS

Data acquisition: Published catch and effort data, 1998 to 2010, of squids (including all species of squids) from Pakistani marine waters (Fig. 1) was used in this study. Regional office of FAO in Pakistan was contacted for data procurement and its suitability for proposed study. Specialized fishery software viz. FishStatJ – FAO Global Fishery and Aquaculture Statistics Software (FAO, 2008) was also used for data garthering. Catch data is in the form of metric tons (mt) while effort is in the number of fishermen per annum (Fig. 2). Computed CPUE (catch per unit effort) is presented in Fig. 3.

Data analysis: SPMs were used to analyze the fishery status of squids in Pakistani marine waters. For this purpose, time series data of squids from 1998 to 2010, a 13 year period, was statistically evaluated by applying two specialized software used in fishery resource management viz. "catch and effort data analysis" and "a stock production models incorporating covariates", abbreviated as CEDA and ASPIC, respectively. These specialized fishery computer applications are developed by the fishery researchers from USA and UK (Prager, 2005, Hoggarth *et al*., 2006). Although, both of aforementioned software are developed on non-equilibrium assumption of the fishery stock, yet they have some technical differences. The aim of using both the software together in this study was to increase the reliability of obtained results as each model may have structural uncertainty. Sometimes, surplus production models are termed as biomass dynamics models (BDMs). Common BMDs include the Fox, Schaefer and Pella Tomlinson models. Fox (1970) model is built on Gompertz growth equation:

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

Among all of the three models, the most frequently employed BDM in fishery management is Schaefer (1954) model, mathematically represented below, which is based on the logistic model of population growth:

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

Finally Pella Tomlinson (1969) model uses generalized population production equality described as:

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

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

CEDA (version 3.0.1) (Hoggarth *et al*., 2006): This fishery software is menu driven and capable of fitting all the SPMs stated above to evaluate catch and effort data. It can estimate customized parameters by using confidence intervals through bootstrapping. It has very useful tools such as goodness of fit and residual plots. Another very important feature of this computer program is that it considers three alternative error assumptions viz. log, log normal and gamma, for each of the three SPMs. This computer package is based on an assumption that fishery stock is in non-equilibrium state. Output key parameters computed by using this computer program include carrying capacity (*K*), maximum sustainable yield (MSY), catchability coefficient (*q*), intrinsic growth rate (*r*), replacement yield (R_{yield}), and final biomass. This software can also compute CV of the estimated MSY by using output confidence intervals.

ASPIC (version 5.0) (Prager, 2005): This computer package uses two SPMs viz. Fox model, which is a special case of GENFIT, and Schaefer model, also known as the Logistic model. This fishery software is also based on non-equilibrium state of the fishery stock. Important parameters estimated by using this computer package include *q*, MSY, *K*, R^2, B_{MSY} and F_{MSY} which represent catchability, maximum sustainable yield, carrying capacity, goodness of fit, biomass giving MSY and fishing mortality at MSY correspondingly.

IP (initial proportion) Requirement: Use of IP (B_1/K) is necessary for CEDA. It is obtained by dividing initial catch value by the maximum catch value. When IP is set at or near zero, it means exploitation started from virgin population. However, when IP is set at or near 1, it means fishery started from heavily exploited population. Sometimes, starting biomass may be fixed at $B_1 = C_1/(qE_1)$ where C represents catch, q represents catchability, E represents fishing effort or by some programmers $B_1 = K$ is also used.

RESULTS

Results obtained by using CEDA and ASPIC computer software were evaluated by considering three output parameters i.e. MSY, R^2 and CV values. Very large or small estimated MSY values, as compared to data values, were neglected as these were considered unrealistic. Only models in which R^2 value was higher than 0.5 and CV values fell into an acceptable range were considered.

ASPIC estimates: Table 1 presents the results obtained by using ASPIC fishery application. Two non-equilibrium ASPIC models viz. Fox and Logistic were applied. We used IP as 0.6, as the initial catch was nearly 60% of the maximum catch. Computed MSY along with their CV values by using Fox and Logistic models were 2,659 mt (0.093) and 2,664 mt (0.065), respectively. Carrying capacity (K) and goodness of fit (R^2) values obtained for both models were 55,200 mt, 43,900 mt and 0.155, 0.159 in that order. Thus, estimated value of K computed for the Fox model was higher as compared to value obtained for the logistic model. F_{MSY} and B_{MSY} were calculated as 0.131 yr^{-1}, 0.121 yr^{-1} and 20,300 mt, 21,900 mt for both the models correspondingly. Estimated parameters for IP ranging from 0.1 to 0.9 are given in Table 2. It can be noted that for different IP values output parameter values vary which conclude that ASPIC shows sensitivity towards IP values.

CEDA estimates: Table 3 illustrates various parameters anticipated by using CEDA software. It can be noted that CEDA software showed different results in response to different input values. It frequently produced a minimization failure for the gamma error assumption in all the three SPMs used. Parameters computed by using CEDA for IP 0.6 are listed in Table 4. For the Fox model by using log and log normal error assumptions, computed MSY with CV values were 2,401 mt (0.314) and 2,553 mt (0.250) correspondingly. In this model, gamma error assumption showed MF (minimization failure). MSY estimates for the Schaefer and Pella Tomlinson models by using all the error assumptions viz. log, log normal and gamma, remained same i.e. 2,416 mt, 2,746 mt and 1.47E+09 mt respectively. However, calculated CV values were different for these two models along with their all error assumptions i.e. 0.235, 0.072, 0.309 for Schaefer model and 0.292, 0.063, 0.063 for Pella Tomlinson model. Fox model showed lower computed MSY estimates as compared to other models used. For IP 0.6, observed and estimated catches are graphically represented in Fig. 4. From visual inspection, there exists no significant difference between all the presented graphs, however, in detail the values differ from each other.

Table 1. Computed parameters for squid fishery by using ASPIC software for IP 0.6 because the starting catch was about 60% of the maximum catch.

Model	IP	MSY	K	q	F_{MSY}	B_{MSY}	R^2	CV
Fox	0.6	2,659	55,200	2.91E-07	0.131	20,300	0.155	0.093
Logistic	0.6	2,664	43,900	3.70E-07	0.121	21,900	0.159	0.065

Table 2. MSY estimates of Fox and Schaefer models of ASPIC software by using IP 0.1-0.9.

Model	IP	MSY	K	q	F_{MSY}	B_{MSY}	R^2	CV
	0.1	5,182	17,100	5.78E-07	0.082	62,900	0.185	0.041
	0.2	3,489	99,300	4.95E-07	0.096	36,500	0.175	0.042
	0.3	2,927	75,100	4.34E-07	0.106	27,600	0.168	0.048
	0.4	2,692	63,900	3.81E-07	0.115	23,500	0.163	0.059
Fox	0.5	2,618	58,400	3.32E-07	0.122	21,500	0.159	0.059
	0.6	2,659	55,200	2.91E-07	0.131	20,300	0.155	0.093
	0.7	2,809	54,600	2.52E-07	0.140	20,100	0.151	0.160
	0.8	3,078	56,100	2.14E-07	0.149	20,700	0.149	0.449
	0.9	3,546	60,300	1.76E-07	0.160	22,200	0.146	0.934

	0.1	10,210	111,000	9.01E-07	0.184	55,400	0.229	0.025
	0.2	5,493	66,400	7.51E-07	0.165	33,200	0.208	0.041
	0.3	3,965	52,100	6.36E-07	0.152	26,100	0.190	0.044
	0.4	3,241	46,300	5.33E-07	0.140	23,200	0.177	0.045
Logistic	0.5	2,860	43,800	4.48E-07	0.130	21,900	0.167	0.051
	0.6	2,664	43,900	3.70E-07	0.121	21,900	0.159	0.065
	0.7	2,605	45,800	3.02E-07	0.114	22,900	0.153	0.077
	0.8	2,668	49,800	2.41E-07	0.107	24,900	0.149	0.118
	0.9	2,894	56,000	1.90E-07	0.103	28,000	0.146	0.330

Table 3. MSY estimation for squid fishery in Pakistani marine waters by using CEDA software for IP 0.1-0.9.

IP	Models								
	Fox			Schaefer			Pella Tomlinson		
	Log	Log normal	Gamma	Log	Log normal	Gamma	Log	Log normal	Gamma
0.1	4,865	5,165	MF	9,806	10,315	MF	9,806	10,315	MF
	0.105	0.048		0.040	0.010		0.040	0.003	
0.2	2.94E+09	5,688	MF	5,207	5,688	MF	5,207	5,688	MF
	0.310	0.010		0.068	0.105		0.064	0.007	
0.3	2,713	2,921	2,857	3,716	4,189	MF	3,716	4,189	MF
	0.130	0.070	0.090	0.090	0.020		0.090	0.020	
0.4	2,478	2,679	MF	3,009	3,074	3.56E+08	3,009	3,074	3.56E+08
	0.180	0.080		0.100	0.080	0.400	0.108	0.078	0.351
0.5	2,390	2,561	MF	2,625	2,976	1.60E+09	2,625	2,976	1.60E+09
	0.230	0.140		0.140	0.060	0.306	0.130	0.057	0.294
0.6	2,401	2,553	MF	2,416	2,746	1.47E+09	2,416	2,746	1.46E+09
	0.270	0.240		0.235	0.072	0.309	0.292	0.063	0.328
0.7	2,497	1.17E+06	MF	2,322	2,593	2,526	2,322	2,593	2,526
	0.370	0.750		0.320	0.130	0.540	0.300	0.161	2.012
0.8	2,688	3,095	MF	2,326	2,663	2,584	2,326	2,663	2,584
	0.840	9.090		0.730	8.340	14085.240	0.580	3.909	6.557
0.9	3,016	55,982	MF	2,433	2,872	1.46E+09	2,433	2,872	MF
	714.200	11.050		8455.340	12.290	0.240	0.720	8.442	

Notes: MF represents minimization failure.

Table 4. Various parameters estimated for squid fishery in Pakistani marine waters by using CEDA with IP 0.6 because starting catch was about 60% of the maximum catch.

Model	*K*	*q*	*r*	MSY	R_{yield}	CV	R^2	*B*
Fox (Log)	79,400	2.02E-07	0.082	2,401	2,330	0.314	0.606	36,400
Fox (Log Normal)	67,100	2.36E-07	0.103	2,553	2,480	0.250	0.570	31,000
Fox (Gamma)	MF	-	-	-	-	-	-	-
Schaefer (Log)	66,000	2.44E-07	0.146	2,416	2,400	0.235	0.607	30,400
Schaefer (Log Normal)	33,100	5.23E-07	0.332	2,746	2,700	0.072	0.569	14,400
Schaefer (Gamma)	2.56E+09	3.37E-12	2.290	1.47E+09	-1.24E+09	0.309	0.530	30,200
Pella Tomlinson (Log)	66,000	2.44E-07	0.146	2,416	2,400	0.292	0.607	30,400
Pella Tomlinson (Log Normal)	33,100	5.23E-07	0.332	2,746	2,700	0.063	0.569	14,400
Pella Tomlinson (Gamma)	25,600	3.37E-12	2.290	1.46E+09	-1.24E+09	0.063	0.530	30,200

Fig. 1. Map showing major landing sites (circles) along the coastline of Pakistan.

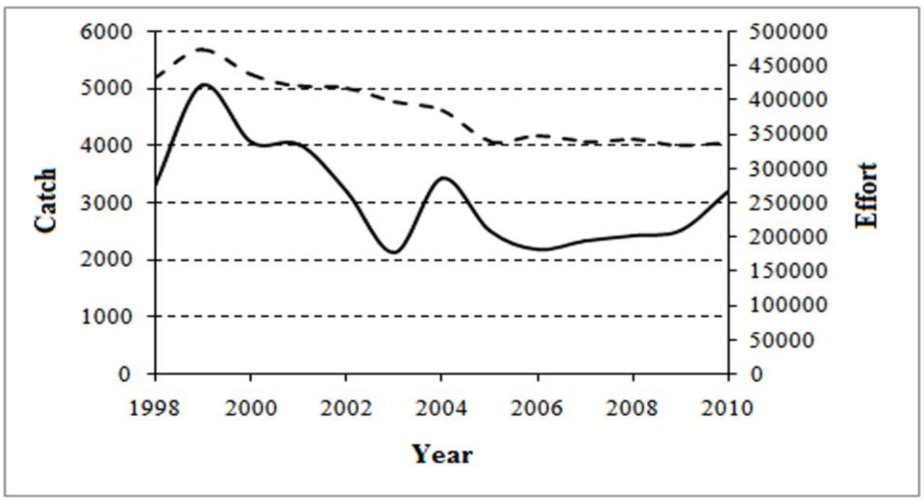

Fig. 2. Graphical representation of catch and effort for squid fishery (1998-2010). Catch is in the form of metric tons (mt) whereas effort is in the form of no. of fishermen year^{-1}.

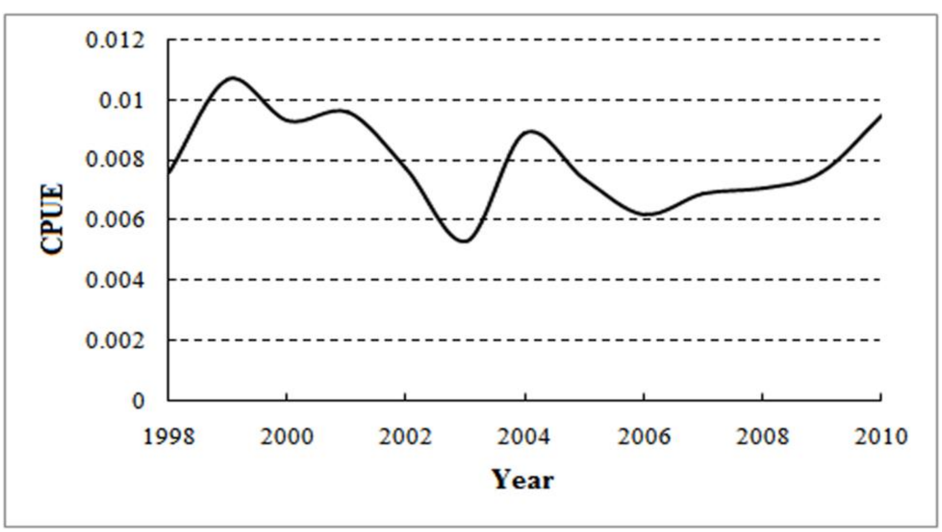

Fig. 3. Computed CPUE (catch per unit effort) for squid fishery (1998-2010).

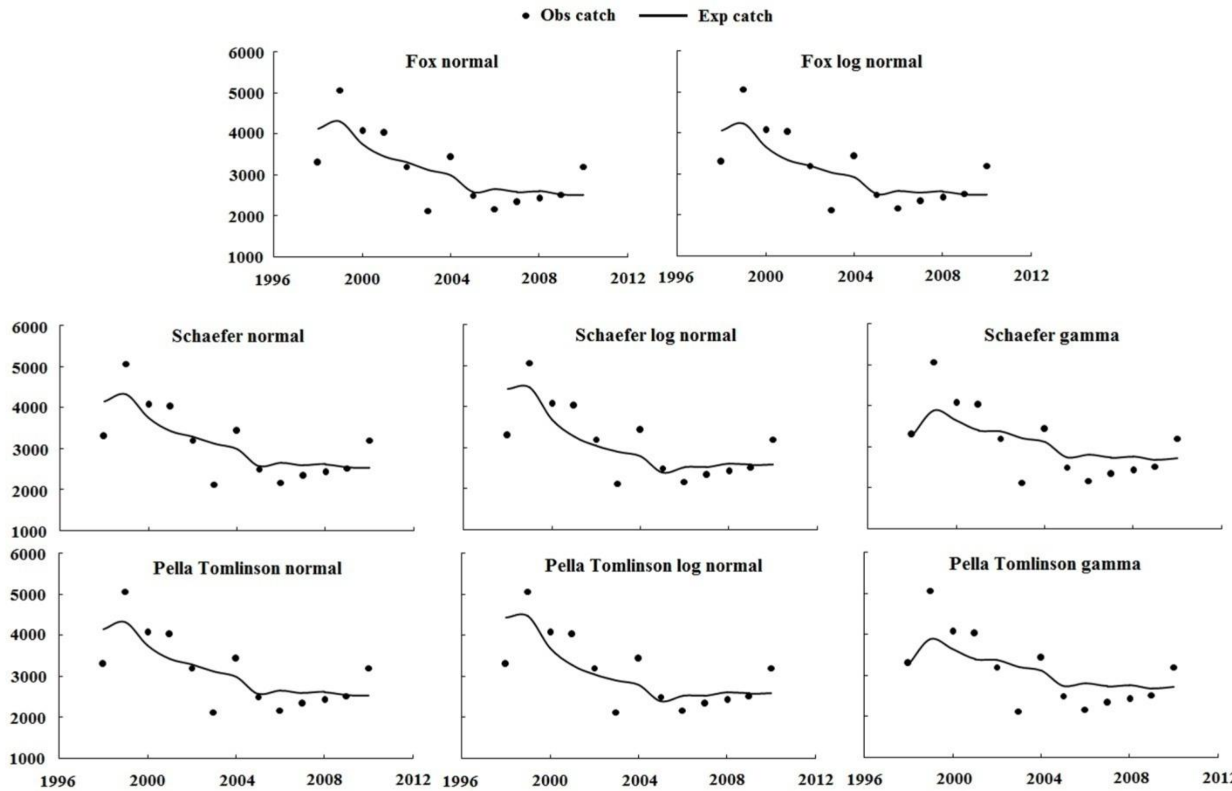

Fig. 4. Observed (dots) and expected (lines) catches computed by using CEDA for squid fishery in Pakistani marine waters, IP 0.6.

DISCUSSION

The concept of maximum sustainable yield (MSY) is central in fishery resource management. It describes the theoretical maximum catch up to which fishing remains sustainable. That is why occasionally, it is also treated as a biological reference point (BRP) and is used basis for long term fishery management (Hilborn and Walters, 1992). This BRP is the predicted highest possible sustainable catch, and corresponds to a certain fishing mortality, another potential BRP (Cadima, 2003). SPMs used in fishery management forecast fortune of the exploited fishery stock by estimating BRPs. They don't require complicated data, such as of age structure etc, rather just need an input of catch and effort data or CPUE (Mehanna and El-Gammal, 2007). Computed values of BRPs indicate state of fishery resource. In a mature fishery, when calculated value of MSY is lower than the series of actual catch values, it means fishery stock is overexploited. On the other hand, if its value is higher than the series of catch then it indicates that fishery resource is underexploited. However, when both equal each other then the fishery stock is at highest possible equilibrium.

Fishery resource assessment is very essential. If fishing is done blindly is may confer ecological as well as economic losses. If the fish stock is overexploited we harm the ecological system and if underexploited we will suffer from an economic loss (Mohsin *et al*., 2015). Thus in both the cases we shall suffer. Hence, it is of utmost importance to evaluate fishery resource for long term prosperity. Fishery resource management is not simple, rather it involves many elements. In best fishery management type of collected data, type of statistical technique and management proposals play central role. SPMs compute MSY on which further fishery management proposals can be made (Prager, 2005).

ASPIC: Estimated MSY figures, IP = 0.1 to 0.9, by using ASPIC are given in Table 2. Obtained figures indicate that the fishery resource of squids have been exploited in most of the study years. Although, ASPIC computer package shows sensitivity to IP values yet its sensitivity is low as compared to CEDA. For IP 0.6, estimated value of R^2 for Fox model was 0.155 while for Logistic model it remained 0.159. R^2 determines goodness of fit. Its higher value means better fit and vice versa. Hence, low values of R^2 obtained from ASPIC do not validate this result when compared to CEDA in which we got higher R^2 values.

CEDA: Reported squid capture production (1998-2010) totaled 40,390 mt. Highest, lowest and average annual production of squids form Pakistani marine waters were 5,062 mt (1999), 2,130 mt (2003) and 3,107 mt yr^{-1}. It can be noted from Fig. 2 that squid production has decreased with the passage of time. The decrease in capture production is probably a result of overexploitation of this fishery resource. CV was calculated by using bootstrapping confidence limit method. When IP other than 0.6 was used, CEDA sometimes calculated very large values of MSY or CV. Even for IP 0.6, gamma assumption did not produced realistic results. This assumption either showed minimization failure or gave unacceptable MSY values. Estimated values of R^2 for the Fox model with log and log normal error assumption were 0.606 and 0.570 in that order. By using the Schaefer model for all error assumptions i.e. log, log normal, and gamma, output computed values of R^2 remained 0.607, 0.569 and 0.530 respectively. Calculated values of R^2 for the Pella Tomlinson model for all error assumptions were similar to the estimates for the Schaefer model. Highest value of R^2 was obtained from normal error assumption for the Schaefer and Pella Tomlinson models, indicating this result more accurate and acceptable as compared to all others.

From above discussion, it can be concluded that estimated MSY of squid fishery in Pakistani marine waters, from all SPMs used with all error assumptions, i.e. log, log normal and gamma, is 2,401 – 2,746 mt. However, MSY computed through Schaefer or Pella-Tomlinson model by using normal assumption, due to high value of $R^2 = 0.607$, seems to be more valid. Thus, we conclude that the MSY of squid fishery resource is likely to be about 2,400–2,500 mt in Pakistani marine waters. Current study indicates that, this fishery resource has been overexploited in the past. Vigilance is required regarding its harvest beyond its MSY in future. To control overfishing, fishery managers must play their role. We suggest that trawlers with small mesh size should be banned. Nursery grounds should be protected so that this precious fishery resource is conserved. It is very important to mention that this analysis is based upon non-equilibrium state of fishery resource. The SPMs are based upon some assumptions such as: (a) population is not affected by environmental factors (b) *r* does not depend upon age composition (c) *q* remains constant (d) natural and fishing mortality go hand in hand (e) fishing vessel performance remains the same (f) catch data is reliable and (g) fishery stock represent single population (Musick and Bonfil, 2004). Thus, the results may be wrong if one or more assumptions are not met so caution is required in making further fishery management practices.

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