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Estimation of Maximum Sustainable Yield of Bombay Duck, *Harpodon nehereus* Fishery in Pakistan Using the CEDA and ASPIC Packages

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Abstract.- Maximum Sustainable Yield (MSY) of Bombay duck *Harpodon neherus* fishery from Pakistan was estimated from the catch and effort data during 1995 – 2009. The average landing from fifteen years of Bombay duck fishery was 66 t. The highest catch was 101 t in 1996 and the lowest catch was recorded at 43 t in 2008. The CEDA and ASPIC non-equilibrium surplus production models were used in this study. CEDA includes three surplus production models of Fox, Schaefer and Pella-Tomlinson with three different error assumptions of normal, log-normal and gamma. Here we use initial proportion (IP) value of 0.9 because the starting value of the catch was roughly 90% of the maximum catch. The estimated MSY values from Fox model and three error assumptions were 25.57 t (R^2 = 0.900), 31.42 t (R^2 = 0.916), 29.11 t (R^2 = 0.909), respectively, while from Schaefer and Pella-Tomlinson models were 27.34 t (R^2 = 0.895), 36.64 t (R^2 = 0.911), 32.54 t (R^2 = 903) from three different error assumptions respectively. The MSY values from Schaefer and Pella-Tomlinson models were the same. The MSY values from ASPIC when IP = 0.9, for the Fox and logistic models were 34.4 t (R^2 = 0.926), 30.5 t (R^2 = 0.931) respectively. Therefore we may suggest that CEDA and ASPIC estimated the MSY of the Bombay duck fishery from Pakistan at 25 – 35 t, which were lower than the current catch, and therefore we would recommend a reduction of fish landing for this fishery.

Keywords: *Harpodon nehereus*, surplus production models, MSY

INTRODUCTION

Marine fisheries sector plays an important role in the Pakistan national economy and fish is an important protein source for the common people. Pakistan has a rich fish resources and about 70% of fish resources come from marine sector (FAO, 2009). But recently the fish catch is gradually decreasing due to water pollution, increased fishing efforts, illegal, unreported and unregulated fishing nets.

Pakistan coastal line is 1120 km and divided into two parts of Sindh coast about 348 km along Indian border and Baluchistan coastline about 772 km along Iranian border (Fig. 1). The Baluchistan coast is steep, rough and narrow *i.e.* between 12 - 32 km wide, on the other hand Sindh coast has sandy and muddy bottom and the area extended 40 - 120 km shelf area and mostly flat and provides better trawling ground. Further due to freshwater flow from Indus River the Sindh coast have network of creeks with mangroves which creates good habitat for finfish and shellfish resources (FAO, 2009).

Harpodon nehereus (Hamilton, 1822) belongs to the family Synodontidae commonly called as Bombay duck is one of the important fish resources along the coast of Pakistan. The average landing catch was 66 t at Karachi fish harbor the maximum catch was recorded 101 t in 1996 and the minimum catch was recorded 43 t in 2008. Due to overexploitation the catch of this fish is decreasing. *H. nehereus* is mostly found throughout the year at offshore deep waters on sandy and muddy bottom but also gathers at mouth of the river mostly during monsoon season (Frimodt, 1995; Yamada *et al.*, 1995). This is why the *H. nehereus* catch is only from Sindh coast (Table I). The freshwater flow from Indus River creates good habitat and provides good atmosphere for nurseries for finfish, shrimps and other marine life (Snead, 1967; Ahmed et al., 1999; Ahmed and Abbas, 199a).

Early work has been done on Bombay duck fishery such as from Indian waters (Zafar Khan,

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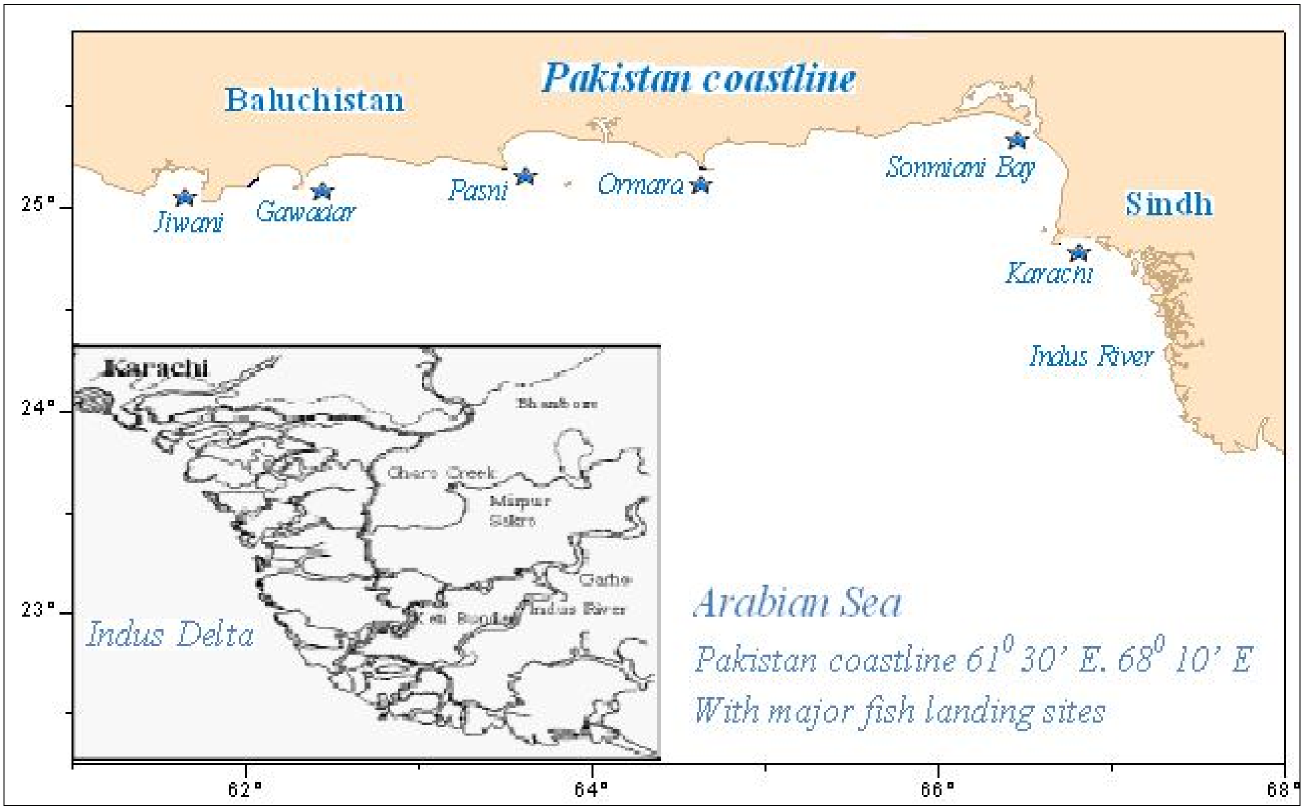

Fig. 1. Pakistan Coastline map and Indus delta with major fish landing sites.

Table I.- Catch and effort data of Bombay duck *Harpodon nehereus* fishery in the Pakistan from 1995 - 2009.

Year	Catch (t) *	Effort	CPUE
1995	98	11066	0.0089
1996	101	11061	0.0091
1997	95	10983	0.0086
1998	91	11444	0.0080
1999	72	11768	0.0061
2000	65	12114	0.0054
2001	58	12618	0.0046
2002	55	12695	0.0043
2003	67	12838	0.0052
2004	55	13002	0.0042
2005	51	13145	0.0039
2006	50	13308	0.0038
2007	45	13426	0.0034
2008	43	13522	0.0032
2009	44	13897	0.0032

*catch in tones only from Sindh

1989; Zafar Khan *et al.*, 1992; Kurian and Kurup, 1992; Fernandez and Devaraj, 1996; Ghosh *et al*., 2009; Balli *et al*., 2011; Kumar, 2012). But there was no work reported on maximum sustainable yield (MSY) of Bombay duck from Pakistani waters. In this study we use catch and effort data of Bombay duck fishery from Pakistan to estimate the MSY and other population parameters by using surplus production models. Those results can be useful for management of the Bombay duck fishery from Pakistan.

Surplus production models also called biomass dynamic models require only catch and effort data and are important when age structured data were not easily available (Haddon, 2011). Earlier work has been reported on different production models (Pitcher and Hart, 1982; Hilborn and Walters, 1992; Prager, 1994; Walter and Perma, 1996; Quinn and Deriso, 1999; Maunder *et al*., 2006). Because fish stock always remain in non-equilibrium state due to the ever changing biological and environment factors affecting the fish stock therefore the equilibrium models have been failed.

In this study we will estimate MSY and other population parameters from the non-equilibrium surplus production models (Polacheck *et al*., 1993). Recently some work has been done on MSY of different fish species from Pakistani waters and East China Sea (Panhwar *et al*., 2012a, b; Siyal *et al*., 2013; Wang and Liu, 2013) but there is no published work available on Bombay duck fishery from Pakistani waters. Therefore, MSY of Bombay duck fishery from Pakistani waters is estimated using catch and effort data using CEDA and ASPIC computer software packages in an attempt to help the fishery managers to manage the fishery in a sustainable manner.

MATERIALS AND METHODS

Data source

Catch and effort time series data of Bombay duck fishery from 1995 – 2009 were taken from Handbook of fisheries statistics of Pakistan complied by the Marine Fisheries Department (MFD) at Karachi, Pakistan. For the Bombay duck fishery the only catch was from Sindh coast (Table I) because Sindh coastline is more productive and rich with species biodiversity due to freshwater flow from Indus River and muddy and sandy bottom. The catch of Bombay duck fishery from Pakistani waters was gradually decreasing due to overexploitation on the fish resources. The catch was in the weight in metric tons (mt) and efforts were taken in number of powered fishing boats.

Surplus production models

Three surplus production models (SPMs) of Schaefer, Fox and Pella-Tomlinson model were used in CEDA package. The Schaefer model has been most commonly used which are based on the logistic growth model:

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

Later work of Fox (1970) put forward a Gompertz growth equation, and another work from Pella-Tomlinson (1969) reported a generalized production equation:

$$\frac{dB}{dt} = rB(InB_\infty - InB) \quad \text{(Fox, 1970)}$$

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

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

CEDA (catch and effort data analysis, Hoggarth et al*., 2006)*

Catch and Effort Data Analysis (CEDA v. 3.0.1) software package were used which is capable to give three non-equilibrium production models which are Schaefer (1954), Fox (1970) and Pella and Tomlinson (1969) with three error distribution assumption (normal, log-normal and gamma). The key output parameters were MSY , q (catchability coefficient), K (carrying capacity), r (intrinsic growth rate), replacement yield, final biomass, where CV (coefficient of variation) of estimated MSY values were calculated from the computed confidence intervals.

ASPIC (a surplus-production model incorporating covariates, Prager, 2005)

The ASPIC is also commonly used for fish stock assessment which is based on the non-equilibrium surplus production model. This software has two types of surplus production models Logistic (Schaefer) and Fox (special case of GENFIT). The key output parameters are: ratio of starting biomass over carrying capacity ($B1/K$), MSY, catchability coefficient (q), carrying capacity (K), optimum fishing efforts (f_{MSY}) and coefficient of determination (R^2). These all parameters are the key parameters for fish stock assessment.

CEDA and ASPIC need an input value of initial proportion (IP, ratio of starting biomass over carrying capacity) from the user. When the IP is near zero which indicates that the data started from a virgin population and when it is near 1 then it means the data started from the serious exploitation population. Sometime starting biomass if fixed at $B_1 = C_1/(qE_1)$ (C = catch, q = catchability, E = fishing efforts) or $B_\infty = K$ by some programmers.

RESULTS

CEDA results

Table II showed that the CEDA package is sensitive with the input IP values. In CEDA package sometimes gamma error assumption gives the minimization error. In Table III we used initial proportion IP = 0.9 because the starting catch was roughly 90% of the maximum catch then the estimated MSY with R^2 value from the Fox model with three different error assumptions were 25.57 t (R^2 = 0.900), 31.42 t (R^2 = 0.916) and 29.11 t (R^2 = 0.909), respectively, and the MSY with R^2 value from Schaefer and Pella-Tomlinson with three error assumptions were 27.34 t (R^2 = 0.895), 36.64 t (R^2 = 0.911) and 32.54 t (R^2 = 0.903), respectively. The MSY values from Schaefer and Pella-Tomlinson were the same. Using IP = 0.9 then the coefficient of variation (CV) range from all those error assumption models were from 0.1 – 0.29. The estimated and observed catches were also shown in Figure 2 when IP = 0.9, the observed catches were close to the estimated catches from Fox and logistic models. From Table III, we may suggest the MSY for this fishery to be about 25 - 30 t.

ASPIC results

Two non-equilibrium surplus production models of Fox and Logistic have been estimated from ASPIC package. The estimated non-bootstrapped values were shown in Table IV, when IP = 0.2 – 0.9. The MSY values from Fox model were at 34.4 t, the fishing effort at maximum sustainable yield (f_{MSY}) was 6520, and coefficient of variance was 0.1, with R^2 = 0.926. From logistic model the MSY estimated values were 30.5 t, fishing effort MSY (f_{MSY}) was 7890, coefficient of variance (CV) was 0.1, with R^2 = 0.931. Table IV shows that ASPIC package is not sensitive with IP value. Therefore we may suggest that the estimated values from Fox and Logistic model were more stable and the MSY value of Bombay duck fishery in Pakistan is about 30 - 35 t.

DISCUSSION

CEDA

CEDA only requires the series of catch and effort data and limited to three surplus production models with three different error assumptions (Hoggarhth *et al*., 2006) from which we can estimate the MSY, and other related population parameters which can be helpful for fishery management. The surplus production models do not include the age-structured models and do not explain about the related environmental factors. Overall CEDA is a useful tool to give a MSY values from simple data from different error assumptions and does not assume that the population is at equilibrium state. When we use initial proportion (IP) ranging from 0.2 – 0.9 Table II shows that CEDA package is sensitive to the IP values. When IP values were low, the estimated MSY values were higher and when IP values were high the estimated MSY values were lower (Table II). When the IP were from 0.4 - 0.9, the estimated MSY values from Fox, Schaefer and Pella-Tomlinson production models were lower than the catch data. The estimated parameter values from the Schaefer/Pella-Tomlinson models were the same. When we use IP = 0.9 because the starting catch was roughly 90% of the maximum catch in Table III, then the MSY values from those three models with three different error assumption were in the range from 25 - 30 t (Table I) and R^2 values all near or above 0.9 which shows the better fit of the model (see also Figure 2). The confidential interval is also easier to estimate from CEDA by bootstrapping method which provides 95 % confidential interval. When using IP value 0.9 the coefficient of variations range from 0.1-0.3 also show in Table III. Because the estimated MSY values were lower than the recent catch, we may assume that the Bombay duck fishery from Pakistani waters is over-exploited.

ASPIC

ASPIC (Prager, 2005) including the non-equilibrium surplus production models was also used to estimate the MSY and related parameters from time series data of catch and fishing efforts of the Bombay duck fishery from Pakistan. The non-equilibrium surplus production models were frequently used because the stocks are seldom in equilibrium state due to some biology, environmental and fishing factors which affect the population. The MSY values and other parameters estimated were shown in Table IV which indicates

Table II.- **Estimates of MSY for the Bombay duck *Harpodon nehereus* fishery in the Pakistan (coefficient of variation is in brackets) using CEDA package, with the initial proportion (IP) ranging from 0. 2 - 0.9.**

IP	Fox			Schaefer			Pella-Tomlinson		
	Normal	**Log-normal**	**Gamma**	**Normal**	**Log-normal**	**Gamma**	**Normal**	**Log-Normal**	**Gamma**
0.2	74.894 (0.111)	72.059 (0.024)	102.111 (0)	146.145 (0.0005)	145.805 (0)	145.769 (0)	146.145 (0.0005)	145.805 (0)	145.769 (0)
0.3	54.845 (0.135)	72.059 (0.035)	MF MF	108.293 (0.003)	108.078 (0)	108.495 (9.8E-06)	108.293 (0.003)	108.078 (0	108.495 (9.8E-06)
0.4	44.372 (0.163)	50.495 (0.085)	48.433 (0.135)	85.02 (0.019)	79.706 (0.0006)	MF MF	85.02 (0.019)	79.706 (0.0006)	MF MF
0.5	37.846 (0.193)	37.382 (0.162)	41.713 (0.15)	60.534 (0.131)	69.156 (0.003)	67.466 (0.072)	60.534 (0.131)	69.156 (0.003)	67.466 (0.072)
0.6	33.367 (0.212)	40.489 (0.108)	37.101 (0.164)	47.182 (0.198)	62.814 (0.008)	53.610 (0.149)	47.2 (0.198)	62.814 (0.008)	53.610 (0.149)
0.7	30.1 (0.228)	37.858 (0.116)	33.735 (0.162)	38.402 (0.254)	42.516 (0.198)	44.386 (0.149)	38.402 (0.254)	42.516 (0.198)	44.386 (0.149)
0.8	27.564 (0.246)	34.355 (0.149)	31.142 (0.197)	32.10 (0.291)	38.307 (0.149)	37.666 (0.22)	32.10 (0.291)	38.307 (0.149)	37.666 (0.22)
0.9	25.60 (0.27)	31.417 (0.161)	29.113 (0.20)	27.336 (0.33)	36.643 (0.176)	32.540 (0.245)	27.336 (0.33)	36.643 (0.176)	32.540 (0.245)

Cells with (MF) indicates the minimization failure

Table III.- **Estimated parameters for Bombay duck *Harpodon nehereus* fishery using CEDA (Catch and effort data analysis) initial proportion was set at 0.9 because the starting catch was roughly 90% of the maximum catch.**

Model	*K*	*q*	*r*	MSY	*Ryield*	R^2	CV
Fox(Normal)	1029.08	1.10E-05	0.067	25.57	24.21	0.900	0.275
Fox(Log-normal)	911	1.28E-05	0.093	31.42	29.83	0.916	0.161
Fox(Gamma)	961.82	1.20E-05	0.082	29.11	27.68	0.909	0.200
Schaefer/Pella-Tom(Normal)	975.55	1.16E-05	0.112	27.34	20.29	0.895	0.330
Schaefer/Pella-Tom(Log-normal)	795.28	1.47E-05	0.184	36.64	27.52	0.911	0.176
Schaefer/Pella-Tom(Gamma)	877.63	1.31E-05	0.148	32.54	24.48	0.903	0.245

K (carrying capacity), *q* (catchability coefficient), *r* (intrinsic growth rate), MSY (maximum sustainable yield), replacement yield, final biomass, R^2 (coefficient of determination), CV (coefficient of variation).

that the ASPIC package is not sensible with IP values. The Fox model produced higher values than the Logistic model. The MSY values from Fox and Logistic models were relatively close to the annual catch of Bombay duck fishery, when IP = 0.2 – 0.9 the values were the same and range from 30 – 35 t. The R^2 values in both models were above than 0.9 and show the better fit of the models to data. Because the estimated MSY values were lower than the recent catch, we may assume that the Bombay duck fishery from Pakistani waters is not in a safe condition.

The surplus production models were frequently used for the fisheries management from the last decades and also recently were used in Pakistani waters by Panhwar *et al*. (2012a, b) and Siyal *et al*. (2013). If the MSY estimated from models are greater than the recent catch data then it

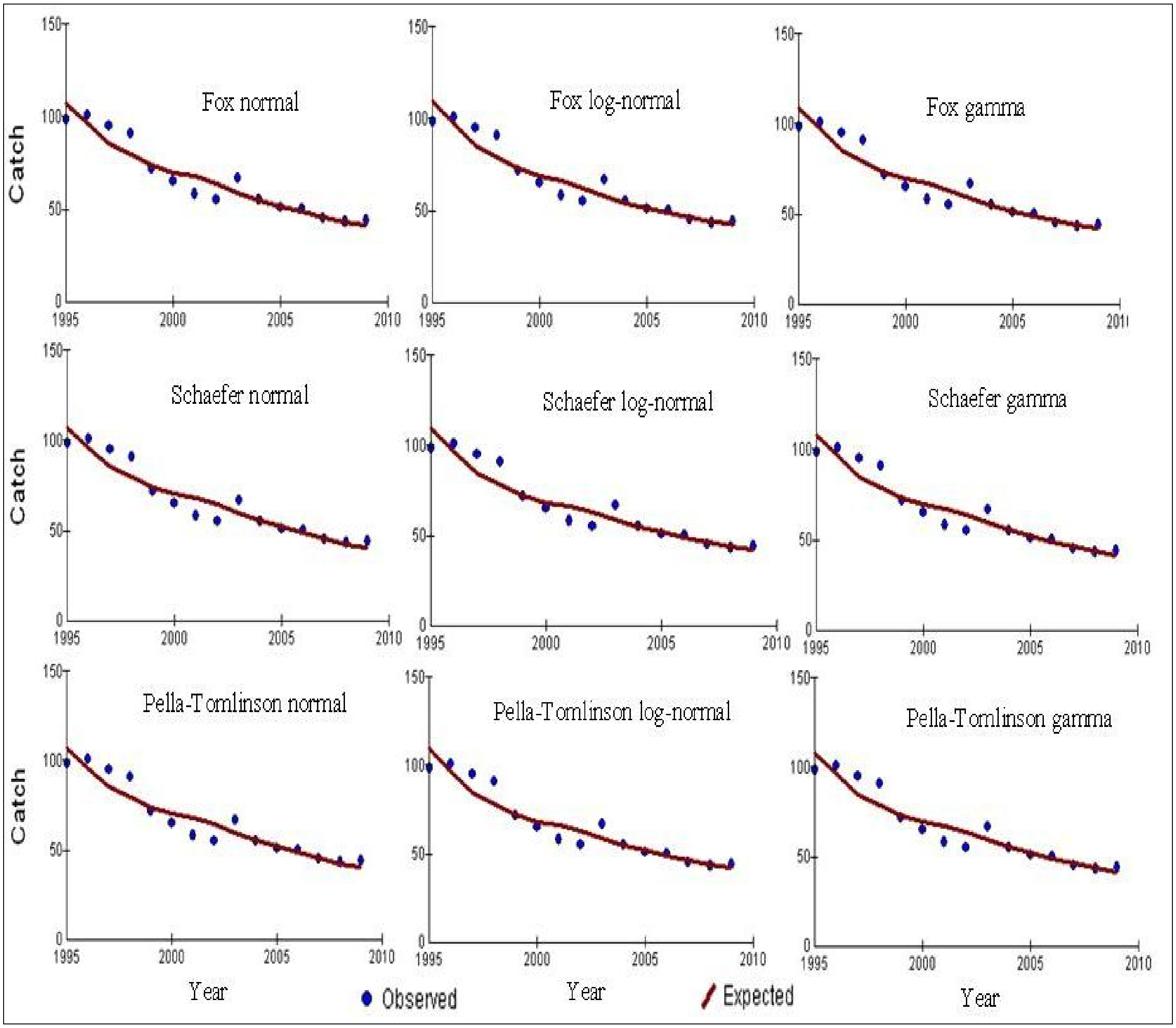

Fig. 2. Using IP = 0.9 the observed (dots) and expected (lines) catches from three production models (Fox, Schaefer and Pella-Tomlinson) and three error distribution assumptions (normal, log-normal and gamma) from the CEDA computer package for the Bombay duck *Harpodon nehereus* fishery from Pakistan during 1995-2009.

indicates that the population is in a safe condition. When annual catch of the fish is equal to the estimated MSY results from surplus production models then it may assume that the fish stock is in a sustainable state. But if the catch is greater than the estimated MSY results that it shows that the fish stock is going to be in decline state. MSY results were frequently considered as biological reference points from which we can carry out the fishery management (Hilborn and Walters, 1992; Prager, 2002; Musick and Bonfil, 2004).

The estimated MSY results from CEDA and ASPIC were generally reasonable with regard to the annual catch data, so we may suggest that the MSY of Bombay duck fishery in Pakistan range from 25–35 t. Pakistan fisheries resources are open accessed and there is no any effective planning to maintain the fish stock, and Bombay duck fishery is one of those resources and is mainly caught from Sindh. Because the estimated MSY values were lower than

Table IV.- Comparison of ASPIC parameters estimates for Bombay duck *Harpodon nehereus* fishery from Fox and Logistic models by changing the starting initial proportion (0.2 - 0.9) level.

Model	IP	*B1/K*	*K*	*q*	MSY	*fmsy*	CV	R^2
Fox	0.2	1	759	1.39E-05	34.4	6520	0.193	0.926
	0.3	1	760	1.39E-05	34.4	6520	0.192	0.926
	0.4	1	760	1.39E-05	34.4	6520	0.235	0.926
	0.5	1	759	1.39E-05	34.4	6530	0.161	0.926
	0.6	1	760	1.39E-05	34.4	6520	0.198	0.926
	0.7	1	759	1.39E-05	34.4	6520	0.145	0.926
	0.8	1	759	1.39E-05	34.4	6520	0.187	0.926
	0.9	1	759	1.39E-05	34.4	6520	0.187	0.926
Logistic	0.2	1	852	1.23E-05	30.5	7890	0.165	0.931
	0.3	1	852	1.23E-05	30.5	7890	0.145	0.931
	0.4	1	853	1.23E-05	30.5	7880	0.152	0.931
	0.5	1	852	1.23E-05	30.5	7880	0.173	0.931
	0.6	1	854	1.23E-05	30.5	7870	0.126	0.931
	0.7	1	853	1.23E-05	30.5	7870	0.122	0.931
	0.8	1	853	1.23E-05	30.5	7880	0.156	0.931
	0.9	1	853	1.23E-05	30.5	7880	0.156	0.931

B_1/K (ratio of starting biomass over carrying capacity), MSY (maximum sustainable yield), q (catchability coefficient), K (carrying capacity), f_{MSY} (optimum fishing effort), CV (coefficient of variation) and R^2 (coefficient of determination)

the recent catch, therefore we may assume that the Bombay duck fishery from Pakistani waters is over-exploited. Hence we may suggest that the fishery managers will take some serious steps to reduce the catch to the MSY level. These measures may be the control on fishing efforts and trawl mesh size that can save the small fish at least they can grow and can breed one time in their lifespan, closing area to protect the nursery grounds to maintain the natural process, and stopping the discard. 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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