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Assessment of Black-spotted croaker (*Protonibea diacanthus*) fishery stock status in Pakistan using Surplus Production Models

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Abstract. This study features the estimates of MSY (Maximum Sustainable Yield) of the commercial high-priced Spotted croakers (*Protonibea diacanthus*, Sciaenidae) of Pakistan by evaluating year-wise catch and effort data. Catch and effort data analysis (CEDA) and a surplus production model incorporating covariates (ASPIC) was applied to analyze data from 24 years (1986 to 2009) of catch and effort. The *MSY* was assessed using the initial proportion (*IP*) value of 0.9 because the starting catch was about 90% of the maximum catch. The calculated *MSY* values for the Fox model with three error assumptions of least square, log-transfer, and gamma were 4481 MTs, 4215 MTs, and 4443 MTs. In contrast, the results of MSY were the same in Schaefer and Pella-Tomlinson models as 7265 MTs and 7373 MTs, respectively. Except for Fox models, the gamma error assumption was presented with minimization failure for all models. The calculated *MSY* results from ASPIC analysis with the two surplus production models of Fox and Logistic were 4609 MTs and 8445 MTs when using an IP value of 0.9. The estimated output values of the Fox model from the CEDA packages, which were lower than the recent catch, indicate that the stock is in over-fished condition, but other analyses from Schaefer and Pella Tomlinson showed higher values than the recent catch indicate safer stock. Similarly, the *MSY* estimated values from the Logistic model were greater than the current catch. In contrast, from the Fox model of ASPIC analysis, they were also higher than the recent catch, revealing the stock is not under control. However, it is necessary to initiate specific managerial measures to maintain the current fishing effort of this species in Pakistani waters to protect the decreasing trend of the existing stock of *P. diacanthus*.

Keywords: *Protonibea diacanthus*, maximum sustainable yield, ASPIC (a surplus production model incorporating covariates), CEDA (catch and effort data analysis); Pakistan.

Introduction

Pakistan has been blessed with vast marine fisheries resources, which are not only a source of valuable animal protein but also contribute to the country's national economy and take part in human development and employment (FAO 2009). Pakistan's vast and rich marine fisheries diversity comprises some commercially important fisheries and about 250 bottom-dwelling (demersal) fish species, 20 small pelagic species, 15 medium-sized, and 20 large pelagic fish species (FAO 2009). The Sciaenidae are a large group of demersal fishes found in the Arabian Sea, Persian Gulf, Indo-West Pacific waters, Papua New Guinea, and northern Australian waters. The common names are Spotted Croaker, locally known as 'Sua' in Sindhi, and 'Kir and Soli' in Balochi. The spotted croakers, *Protonibea diacanthus,* are primarily coastal inhabiting fishes, mostly found in muddy bottoms or off the sea-bed, and frequently occur with forming shoals or schools in depths between 20-100m (Fishbase 2015). They feed commonly on crustaceans, squids, and small schooling fishes (especially anchovies), and these are generally caught with trawl nets or by bottom trawling (Bianchi 1985). It is a high-priced fish because it is less consumed locally, but it is being exported as frozen fillets or whole fish to countries such as China, Europe, and the Middle East. This fish is a reward for the fishermen if they catch it. With its great taste, it is also used for medicinal purposes in different countries. In the meantime, the bladder of *P. diacanthus* in dried form is also exported to China, Hong Kong, and other Asian countries, where it is in high demand for its medicinal value.

Some earlier studies were mainly based on some biological aspects. Mok et al. (2009) reported on the spawning season and breeding sites in the Taiwan waters; Phelan et al. (2008) conducted a survey of its biological management in the Northern Cape-York Peninsula waters of Australia and also worked on its feeding biology; Jakhar et al. (2012a, 2012b) worked on gelatin extraction from the skin of *P. diacanthus*. However, no study has been found about its population biology, demographic trends, stock assessment, or estimated maximum sustainable yield. This work may be the first attempt to analyze the catch and effort data of Pakistan's spotted croakers (*P. diacanthus*) to evaluate the MSY (maximum sustainable yield).

Several models, commonly known as surplus production models, have been demonstrated in the fish stock assessment textbooks and published papers (e.g., Pitcher & Hart 1982, Prager 1994, Hilborn & Walters 1992, Quinn & Deriso 1999, Maunder et al. 2006). This work aimed to estimate the stocks of spotted croakers *(P. diacanthus)* fishery in Pakistan. For this reason, surplus production models (Schaefer 1954, Fox 1970, Pella & Tomlinson 1969) with different error assumptions through CEDA packages (Hoggarth et al. 2006) are used to assess maximum sustainable yield (MSY). Hopefully, the estimated values may assist in illustrating the desired fisheries' rules and regulations for the sustainable management and utilization of this fishery resource in the country.

Material and Methods

Data source:

The time series catch and effort data of spotted croakers (*P. diacanthus*) from the period 1986 to 2009 (24 years) were taken from the booklet of Fisheries Statistics of Pakistan accumulated by the Marine Fisheries Department (MFD), Karachi, Pakistan. Fishing effort is attainable by the number of operational fishing boats in the maritime region of Pakistan (Fig. 1), and the per annum catch (total) was shown in the form of catch weight (Metric tons). The average catch of spotted croakers (*P. diacanthus*) from Pakistani waters in 1986-2009 was 7831 MT. The highest catch was observed in 1988 at 11746 MT, while the lowest catch was found in 2005 at 4069 MT (Fig. 2).

Surplus production models:

The fishery catch and effort data of *P. diacanthus* were analyzed with a computer software package developed by some British fisheries scientists (Hoggarth et al. 2006). The three surplus production models (SPMs) (also called biomass dynamic models, BDMs) used in the CEDA package are Schaefer (Schaefer 1954), Fox (Fox 1970), and Pella-Tomlinson (Pella & Tomlinson 1969). The most frequently used model is Schaefer (1954), which is based on the logistic population growth function:

$$\frac{\mathrm{d}B}{\mathrm{d}t} = rB(B_\infty - B)$$

Then, Fox (1954) proposed a study based on the Gompertz population growth equation,

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

At the same time, Pella and Tomlinson (1969) proposed the use of generalized production equations,

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

where B is fish stock biomass, t is time, $B\infty$ is carrying capacity, and r is intrinsic rate of population increase.

Catch and effort data analysis (Hoggarth et al. 2006) (version 5.0.1):

The software package, CEDA (Catch and Effort Data Analysis), contains three non-equilibrium surplus production models, i.e., Schaefer (1954), Fox (1970), and Pella-Tomlinson (1969) with three error assumptions (normal, log-normal, and gamma). The package can compute the subsequent key parameters: *MSY* (maximum sustainable yield), r (intrinsic growth rate), K (carrying capacity), q (catchability coefficient), final biomass, and replacement yield, whereas *CV* (coefficient of variation) of the estimated *MSY* values can also be calculated. The package requires an input value of initial biomass (B_1) over the carrying capacity (K) by the user. When the *IP* (initial proportion) value is fixed at zero, it points out that the fishery started from a virgin population, and if the *IP* value is close to 1, it specifies that the fishery initiates from a severely captured population. However, in some cases, starting biomass is fixed by the user, i.e., B_1=K.

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

The *ASPIC* package is generally used to assess fish stock based on the non-equilibrium surplus production models. This software comprises two types of surplus production models- Logistic (Schaefer) and Fox (a special case of GENFIT). The proportion of starting biomass over carrying capacity (B1/K), coefficient of determination (R2), catchability coefficient (q), maximum sustainable yield (MSY), and optimum-fishing efforts (FMSY) are vital output parameters of this package that are significantly used in fish stock assessment. Like CEDA, ASPIC also needs an input value of initial proportion (IP, ratio of starting biomass over carrying capacity) to function the packages.

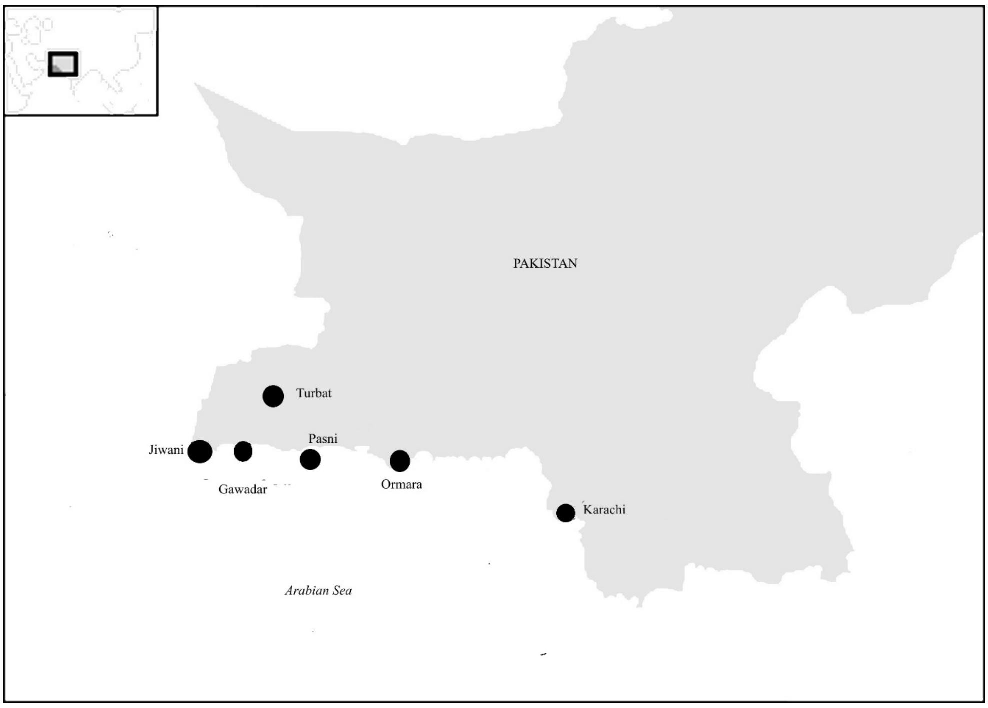

Figure 1 Map showing the major landing sites along the coasts of Sindh and Baluchistan, in Pakistan

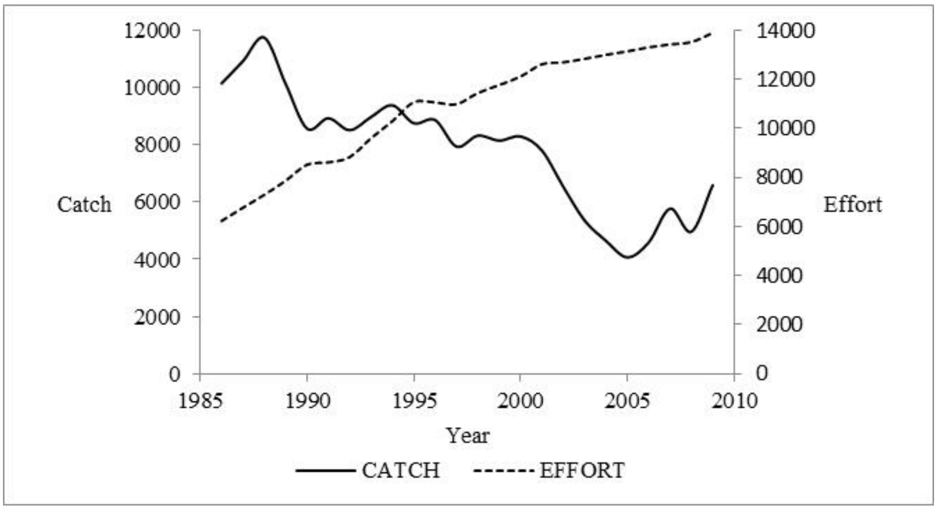

Figure 2 Catch and effort data of *Protonibea diacanthus* from marine waters of Pakistan

Results

During the study period, the capture of *P. diacanthus* in the marine waters of Pakistan reached 187948 metric tons. The maximum and minimum catch was observed at 11746 MTs in 1988 and 4069 MTs in 2005, with an average catch of 7831 metric tons annually. In 1986, the highest capture per unit effort (CPUE) value was examined at 1.629, and the lowest value was analyzed in 2005 as 0.310 (Fig. 3), with an average of 0.802 annually. The results of CEDA and ASPIC were further scrutinized by considering four factors: MSY (Maximum sustainable yield), R2 (goodness of fit), observed and expected traces of residual maps, and CV (coefficient of variation). The MSY values were compared with the data statistics and did not consider very large or small MSY values. The models were compared according to visual inspection of R^2 values and residual graphs. The better model fit is represented by the higher values of R2, and the result is accepted with the appropriate CV values.

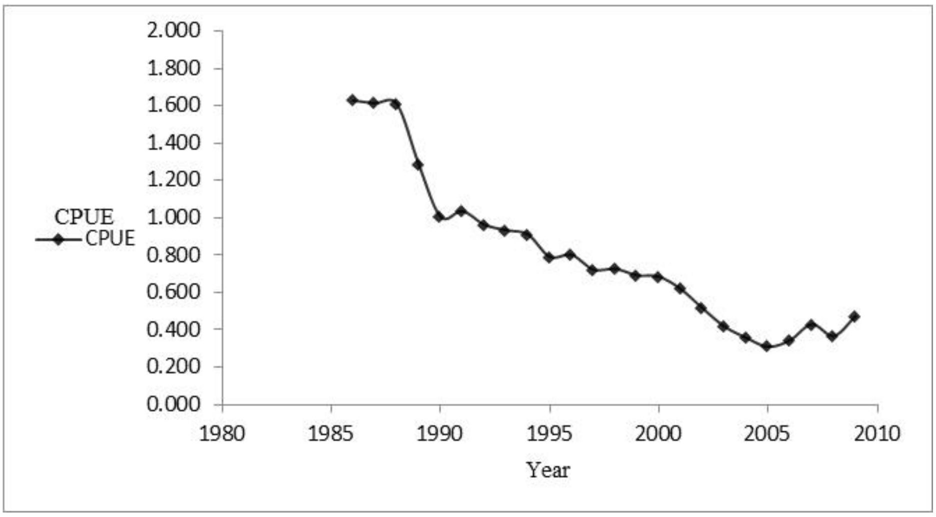

Figure 3 Analysis of CPUE of the *Protonibea diacanthus* during 1985 to 2009 (24 years) of catch data

CEDA results:

The bootstrapping confidence limit technique was used to calculate the CV (coefficient of variation), shown in Tables 1 and 2. The results from the CEDA package are highly responsive to the input IP (initial proportion) values. The MSY values were inversely proportional to the IP values. When IP values were low, the estimated MSY values were higher; when IP values were high, the estimated MSY values were lower (Table 1). Table 2 shows the CEDA results with an IP of 0.9 because the initial capture was about 90% of the maximum catch. Using the IP value 0.9 for Schaefer and Pella-Tomlinson with normal and log-normal error assumptions produces the MSY results, while the gamma error assumption produces common minimization failure. The estimated values of MSY with CV (coefficient of variation) from the Fox model with three error assumptions were produced at 4481 MT (CV= 0.130), 4215 MT (CV= 0.151), and 4443 MT (CV= 0.124), respectively. Similarly, the estimated values of MSY for Schaefer and Pella-Tomlinson with two error assumptions of normal and log-normal were 7265 MT (CV= 0.056), 7373 MT (CV= 0.006), and 7265 MT (CV= 0.056), 7373 MT (CV= 0.009) (Table 2). The values of MSY were the same as Schaefer and Pella-Tomlinson, but CV was somehow different from each other. The Fox model produced R^2= 0.804, 0.776, and 0.795, whereas Schaefer and Pella Tomlinson models produced R2= 0.815 and 0.795, respectively, and the estimated R^2 values show a good fit to the data. The coefficient of catchability (q), the intrinsic growth rate of population (r), and carrying capacity (K) values of Fox were higher than that of Schaefer and Pella-Tomlinson model. These values were equivalent for Schaefer and Pella-Tomlinson. The values of maximum sustainable yield of the biomass (B_{MSY}) of the Fox model with three error assumptions were 49536 MT, 52018 MT, and 49731 MT, respectively, while Schaefer and Pella-Tomlinson produced the same values of B_{MSY}, 32066 MT, and 31183 MT. Fig. 4 shows the observed and estimated catches using the IP value of 0.9; the observed catches from all models were approximately near the estimated catch.

Table 1. MSY estimates for *P. diacanthus* fishery of Pakistan using CEDA with IP from 0.1 to 0.9

B_1/K	Model								
	Fox			***Schaefer***			***Pella Tomlinson***		
	Normal	Log normal	Gamma	Normal	Log normal	Gamma	Normal	Log normal	Gamma
0.1	2.59E-01	14676	MF	225619	21766	327863	225619	21766	327863
	2.70E+04	**0.001**	**MF**	**1.68E+03**	**0.033**	**2.38E+02**	**2.32E+03**	**0.03**	**3.73E+02**
0.2	53401	9524	70781	0	121	MF	0	121	MF
	0.044	**0.002**	**7.95E+02**	**0.493**	**31.084**	**MF**	**8.956**	**2.85E+01**	**MF**
0.3	1.06E+10	7592	MF	123938	3723	57589	123938	3723	57589
	0.318	**0.011**	**MF**	**6.44E+03**	**0.34**	**0.184**	**0.312**	**0.33**	**0.605**
0.4	9.32E+09	6646	MF	41296	5196	37640	41296	5196	37640
	0.418	**0.042**	**MF**	**1.30E+04**	**0.081**	**0.26**	**1.42E+04**	**0.088**	**0.394**
0.5	6885	6162	MF	MF	8739	8799	MF	8739	8790
	0.072	**0.051**	**MF**	**MF**	**0**	**0**	**MF**	**0**	**0.001**
0.6	6008	5690	6023	8165	8166	8166	8165	8166	8166
	0.101	**0.068**	**0.09**	**0.025**	**0**	**0**	**0.022**	**0**	**0**
0.7	5366	5395	MF	21922	7766	7813	21922	7766	7813
	0.112	**0.071**	**MF**	**2.43E+04**	**0.004**	**0**	**2.36E+04**	**0.004**	**0.001**
0.8	4873	4975	21050	7864	7583	19309	7864	7583	19309
	0.121	**0.101**	**0.047**	**0.027**	**0.003**	**0.011**	**0.025**	**0.003**	**0.008**
0.9	4481	4215	4443	7265	7373	28406	7265	7337	28406
	0.13	**0.151**	**0.124**	**0.056**	**0.006**	**0.17**	**0.056**	**0.009**	**0.178**

Table 2. Estimated parameters for *P. diacanthus* using CEDA when IP was set at 0.9 because the starting catch was roughly 90% of the maximum catch

Model	*K*	*q*	*r*	*MSY*	*R yield*	*CV*	R^2	*B*	B_{MSY}
Fox (Normal)	134652	1.41E-05	0.090	4481	3805	0.130	0.804	**24950**	49536
Fox (Log Normal)	141400	1.33E-05	0.081	4216	3523	0.139	0.776	25216	52018
Fox (Gamma)	135183	1.41E-05	0.089	4443	3740	0.135	0.795	24525	49731
Schaefer (Normal)	64132	3.24E-05	0.453	7265	3968	0.057	0.815	10465	32066
Schaefer (Log Normal)	62366	3.33E-05	0.471	7337	3955	0.010	0.795	10011	31183
Schaefer (Gamma)	MF	MF	MF	MF	MF	MF	MF	MF	MF
Pella Tomlinson (Normal)	64132	3.24E-05	0.453	7265	3968	0.054	0.815	10465	32066
Pella Tomlinson (Log Normal)	62366	3.33E-05	0.471	7337	3955	0.009	0.795	10011	31183
Pella Tomlinson (Gamma)	MF	MF	MF	MF	MF	MF	MF	MF	MF

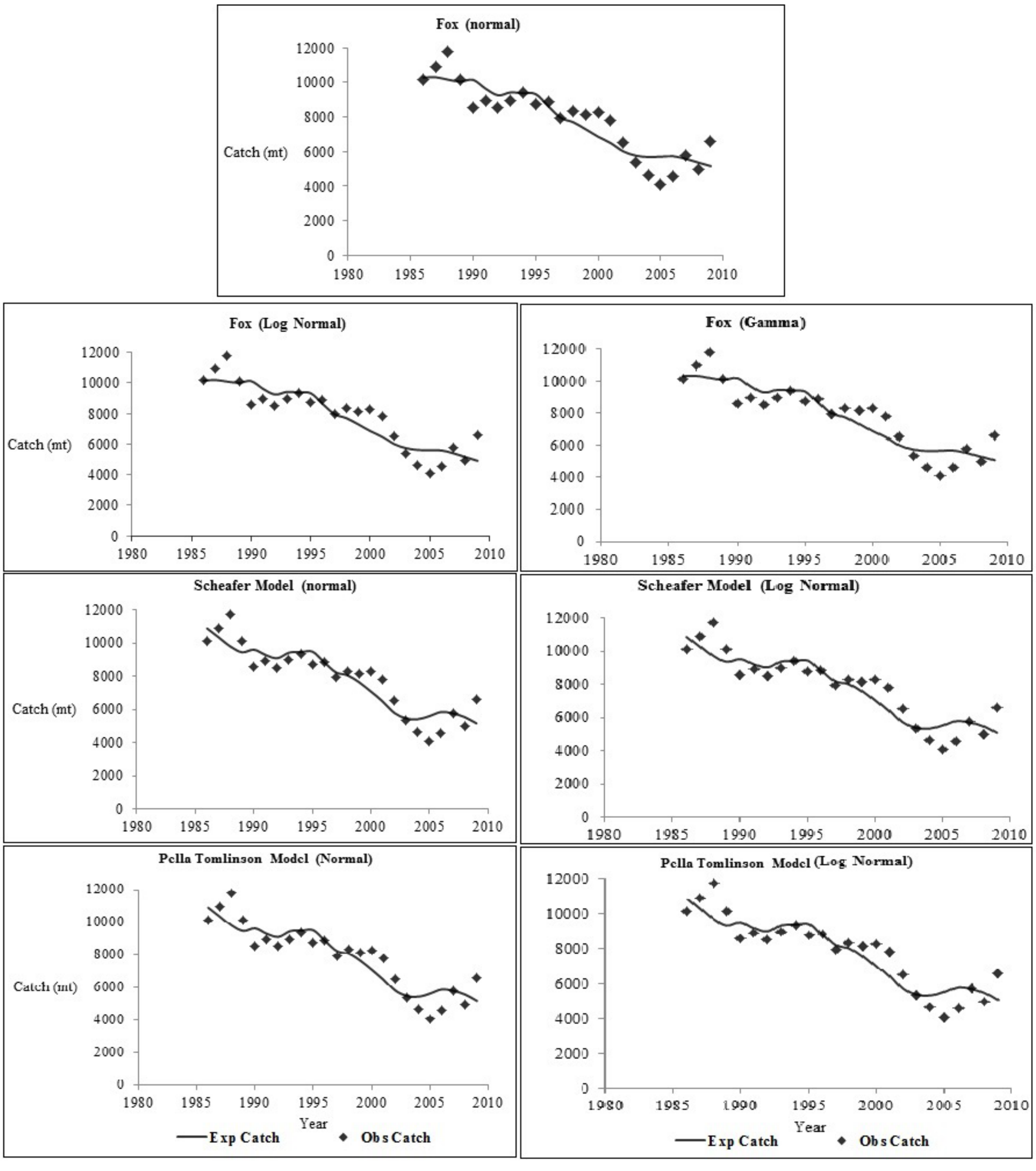

Figure 4 Annual expected (lines) and observed (points) catch (MT) of *Protonibea diacanthus* fishery of Pakistani waters using CEDA for Fox, Schaefer and Pella-Tomlinson models. Note: Gamma error distribution produced minimization failure for all models except Fox model.

ASPIC results:

In the ASPIC package, two non-equilibrium surplus production models of Logistic and Fox were used to evaluate maximum sustainable yield. The estimated non-bootstrapped values are shown in Table 3 when *IP* was 0.9. The estimated *MSY* value from the Fox model was 4609 MT (*CV*= 0.092), the fishing effort at maximum sustainable yield (F_{MSY}) was 0.098, and B_{MSY} was 47230 MT, with R^2= 0.950. From the logistic model, the estimated MSY value was 8445 MT, fishing effort at MSY (FMSY) was 0.504, and the coefficient of variance (*CV*) was 0.141, with R^2= 0.935. Table 4 shows that the ASPIC package is somehow sensitive to the *IP* value. Therefore, we found that the estimated *MSY* value from the Fox model was higher than the recent catch when the *IP* ranged from 0.1-0.5, indicating the over-exploited condition of this fishery in Pakistan, whereas IP values ranged from 0.6-0.9 for the Fox model showed the safer condition of that fishery. In the logistic model, IP values range from 0.1-0.9, indicating a safer state of the *P. diacanthus* fishery of Pakistan than the recent catch of 6587 MTs in 2009 (Table 4).

Table 5 shows the estimated mortality rates (F) and biomass (B) values using the ASPIC. The data obtained from the Fox and Logistic models showed that F has increased over time and B has been reduced. For the study period, F/FMSY increased, and B/BMSY decreased, and they both indicated excessive overuse of fishery resources (F/FMSY and B/BMSY).

Table 3. Model parameters estimates by non-bootstrapped method

Model	B_1/K	*MSY*	*K*	*q*	B_{MSY}	F_{MSY}	R^2	*CV*
Fox	9.00E-01	4609	128400	1.49E-05	47230	0.098	0.95	9.22E-02
Logistic	9.00E-01	8445	33530	6.54E-05	16760	0.504	0.935	1.41E-02

Table 4. MSY estimates for *P. diacanthus* fishery of Pakistan using ASPIC with IP from 0.1 to 0.9

Model	B_1/K	*MSY*	*K*	*q*	B_{MSY}	F_{MSY}	R^2	*CV*
	1.00E-01	8210	91460	4.45E-05	33650	0.2440	0.9360	0.0762
	2.00E-01	8616	80560	5.33E-05	29640	0.2907	0.9340	0.0572
	3.00E-01	8533	82550	5.14E-05	30370	0.2810	0.9350	0.0651
	4.00E-01	8497	84040	5.04E-05	30920	0.2748	0.9350	0.0684
Fox	5.00E-01	8519	84260	5.05E-05	31000	0.2748	0.9340	0.0736
	6.00E-01	6203	118200	2.39E-05	43490	0.1426	0.9470	0.0562
	7.00E-01	5546	123800	1.97E-05	45540	0.1218	0.9480	0.0679
	8.00E-01	5037	126600	1.69E-05	46560	0.1082	0.9490	0.0921
	9.00E-01	4609	128400	1.49E-05	47230	0.0976	0.9500	0.0922
	1.00E-01	8366	33240	6.44E-05	16620	0.5034	0.9320	0.0143
	2.00E-01	8365	33170	6.45E-05	16580	0.5044	0.9310	0.0139
	3.00E-01	8367	33250	6.44E-05	16630	0.5033	0.9320	0.0132
	4.00E-01	9382	105700	3.07E-05	52860	0.1775	0.8360	0.0003
Logistic	5.00E-01	8480	31190	6.97E-05	15590	0.5438	0.9300	0.0085
	6.00E-01	9023	36880	6.83E-05	18440	0.4893	0.8910	0.0117
	7.00E-01	8834	32600	7.32E-05	16300	0.5419	0.9160	0.0090
	8.00E-01	8707	30690	7.48E-05	15340	0.5675	0.9280	0.0083
	9.00E-01	8445	33530	6.54E-05	16760	0.5037	0.9350	0.0141

Table 5: Estimated population trajectory through non-bootstrapped of fishing mortality and biomass in ASPIC software using initial proportion (*IP* = 0.9) (1986-2009) (F= total fishing mortality, B= starting biomass, F/F_{MSY}= ratio of fishing mortality to FMSY, B/B_{MSY}= ratio of biomass to BMSY)

No of Obs.	Year	Model							
		Fox				Logistic			
		F	*B*	*F/F*F/F_{MSY}	B/B_{MSY}	*F*	*B*	F/F_{MSY}	B/B_{MSY}
1	1986	0.091	115600	0.936	2.447	0.373	30180	0.740	1.800
2	1987	0.107	107000	1.092	2.265	0.474	25120	0.942	1.499
3	1988	0.125	98270	1.285	2.081	0.604	21440	1.200	1.279
4	1989	0.118	89390	1.209	1.893	0.598	17890	1.186	1.067
5	1990	0.107	82620	1.096	1.749	0.531	16190	1.055	0.966
6	1991	0.119	77730	1.217	1.646	0.566	16060	1.123	0.958
7	1992	0.121	72720	1.238	1.540	0.550	15550	1.091	0.927
8	1993	0.136	68330	1.394	1.447	0.594	15430	1.179	0.920
9	1994	0.154	63640	1.574	1.348	0.661	14820	1.311	0.884
10	1995	0.155	58680	1.587	1.243	0.657	13680	1.304	0.816
11	1996	0.170	54450	1.739	1.153	0.710	13020	1.409	0.776
12	1997	0.164	50170	1.678	1.062	0.665	12040	1.320	0.718
13	1998	0.185	46830	1.898	0.992	0.726	11850	1.441	0.707
14	1999	0.197	43120	2.022	0.913	0.762	11130	1.512	0.664
15	2000	0.221	39540	2.261	0.837	0.867	10320	1.722	0.615
16	2001	0.229	35750	2.351	0.757	0.974	8905	1.934	0.531
17	2002	0.209	32360	2.145	0.685	0.990	7236	1.966	0.432
18	2003	0.181	30130	1.857	0.638	0.933	6037	1.852	0.360
19	2004	0.161	29010	1.654	0.614	0.853	5472	1.693	0.326
20	2005	0.142	28570	1.456	0.605	0.701	5422	1.391	0.323
21	2006	0.161	28690	1.650	0.607	0.699	6189	1.388	0.369
22	2007	0.210	28290	2.154	0.599	0.857	6916	1.701	0.413
23	2008	0.190	26650	1.943	0.564	0.727	6566	1.444	0.392
24	2009	0.270	25750	2.768	0.545	1.043	7077	2.071	0.422

Discussion

Ecosystem-based effective management approaches are mostly dependent on stock assessment results. Therefore, fisheries scientists must provide managers with a reliable depiction of stock dynamics and stock status (Lynch et al. 2012). The major apprehension of this paper was to estimate the maximum sustainable yield (*MSY*) of *P. diacanthus* in Pakistan by Surplus Production models. The results obtained from CEDA were generally dependable among the three surplus production modeling approaches, i.e., Schaefer, Fox, Pella, and Tomlinson. The computed output values from Schaefer's (1954) approach, which was higher, disclosed that the Fox model is more conservative than others. Similar patterns have also been seen in ASPIC results, in which Fox showed closer and more conservative results than Logistic approaches.

Modeling Approach

In fisheries stock assessments, CPUE (Catch per unit of effort) is often considered proportional to the fish population abundance and referred to as the relative abundance index. Several population dynamic models were used to predict the relative abundance index to obtain the future values of predicted absolute abundance by multiplying with a constant catchability coefficient (Hinton & Maunder 2004). There are two basic mathematical approaches in fisheries science, i.e. (1) Surplus production models are considered to be the first approach, initially proposed by Schaefer (1954) and later by Fox (1970), and (2) the yield-per-recruit analysis is the second approach (Beverton & Holt 1957). The Surplus Production Models (SPMs), also called Biomass Dynamic Models (BDMs), are the reasonable approach due to their holistic or simple nature. The surplus production models can determine the level of effort at which a fishery sustainably produces a maximum yield of fish stock without changing the long-term productivity termed *MSY* (Sparre & Venema 1998).

Assumptions, limitations, and trends

The concept of *MSY* has played a significant role in fishery science over the decades. It is considered the target Biological Reference Points (Smith & Punt 2001), which serve as a standard of measurement of stock status from a biological point of view and also imitate the combination of stock dynamics such as growth, recruitment and mortality. These reference points are normally summarized under the three main fish stock dynamic models, i.e., dynamic pool models, stock-recruit models, and surplus production models (Gabriel & Mace 1999).

Fish stock sizes and distributions can vary extensively even in their unexploited state due to changes in environmental factors and interrelationships with other species (Garcia & Newton 1995). Some researchers have indicated that if the surplus production is higher than the catch, the population size increases; when the catch is greater than the surplus production, the population has a decreasing trend. When the surplus production outcomes and catch were equal, it indicated a constant trend in fish population size (Hilborn & Walters 1992, Prager 2002, Musick & Bonfil 2004).

The average catch of *P. diacanthus* from Pakistani waters during the 24 years 1986–2009 was 7831 MT. The contribution of the *P. diacanthus* fishery to the total marine production of Pakistan until 2007 was about 3% (FAO 2009). Fig. 2 shows that the *P. diacanthus* fishery was decreasing because the observed catch 1986 was 10146 MT, while in 2009, it was only 6587 MT. Pakistan has rich resources of fisheries but open access, and there is a deficiency of effective planning and management (FAO 2009). In Pakistan, the estimated *MSY* of demersal species was 213000 MT, while the exploitation level is 175674 MT (FAO 2009, Coastal and Marine Ecosystems Country profile - Pakistan 2009). Like other demersal fishery, this fishery is also based on trawl netting, which is now more vulnerable than pelagic capture fishery. The size ranges from 50-229 cm, and the dominant size is 90-115 cm from Pakistani water (Moazzam 2010). However, no work has been reported on the *MSY* of Spotted croakers *P. diacanthus* separately. This may be the first attempt to investigate the MSY of spotted croaker fisheries from Pakistani waters using a surplus production model.

CEDA

In Table 1, the *CV* (coefficient of variation) values were obtained using the bootstrapping confidence-limit method. The outcomes of the Fox model using the CEDA package were when the IP values ranged from 0.1 to 0.6, the estimated values of MSY were found to be greater than the recent catch, and when the IP ranged from 0.7 to 0.9, the estimated *MSY* values were smaller than the recent catch. When applying *IP*=0.9, with error assumptions of normal, log-normal, and gamma of the Fox model produced R2= 0.804, R2= 0.776, and R^2= 0.795, whereas the R^2 values from Schaefer and Pella-Tomlinson models with error assumptions of normal and log-normal were R^2= 0.815 and

R^2= 0.795 respectively which showed in Table 2. The estimated R^2 values from the Fox model of CEDA show a good fit to the data.

In conclusion, this study exposes that the CEDA is relatively easy to operate and suitable for MSY estimation. Still, its initial proportion is highly sensitive and requires catch-effort data. The Fox model estimates are close to the recent landings of the spotted croakers in Pakistan. These results point out that the *P. diacanthus* stock has overfished, and the current annual catch is close to the outputs of the Fox model estimation, which are more conservative and thus the best fits.

<u>ASPIC</u>

The *MSY* of both Logistic and Fox models in ASPIC packages under IP (initial proportion) values ranging from 0.1 to 0.9 are shown in Table 4. Similar trends like CEDA were also seen in Fox models of ASPIC analysis when *IP* ranged from 0.1 to 0.5, that reveals the fishery of *P. diacanthus* is in safe mode in Pakistani waters where no over-exploitation appeared, but when IP ranged from 0.6-0.9 that indicates over-exploitation. This computer package ASPIC does not show any sensitivity to initial proportion (*IP*) as compared to the Schaefer and Pella-Tomlinson models of the CEDA package because the estimated population parameter values of the Logistic model for *IP* values ranging from 0.1 to 0.9 appeared almost the same. The Fox and Logistic models produced R^2= 0.950 and R^2= 0.935, respectively (when IP= 0.9), which were higher than those from the CEDA package and showed excellent fitting to the data.

The estimated output values of the Fox model from the CEDA packages, which were lower than the recent catch, indicate that the stock is in over-fished condition, but other analyses from Schaefer and Pella Tomlinson showed higher values than the recent catch indicate safer stock. Similarly, the *MSY* estimated values from the Logistic model were more significant than the current catch, while from the Fox model of ASPIC analysis (when IP ranged from 0.1-0.5) were also higher than the recent catch, revealing the stock is not under control. However, it is necessary to initiate certain important managerial measures to maintain the current fishing effort of this species in Pakistani waters to protect the decreasing trend of the existing stock of *P. diacanthus*.

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