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Assessment approach of production models to commercial pelagic catch and effort data of Indian mackerel (*Rastrelliger kanagurta*, Cuvier, 1816) in the Arabian Sea

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Globally, Reference Points (RPs) indicators are usually lifted in the science of fisheries management for the alternative running objectives and tracking the condition of fisheries. The Fox Model (FM) and Logistic Model (LM) in A Stock Production Model Incorporates Covariates (ASPIC) estimated F = 0.062 – 0.132 and F = 0.059 – 0.126 from 2003 to 2018 with F/F_{MSY} showing an increased inclination from 0.628 to 1.346 and 1.027 to 2.179, respectively. Estimated Starting Biomass (B) = 520800 – 263100 MT and B = 541000 – 277000 MT from population trajectory (Non-bootstrapped) sharply decreased to the ratio of biomass to B_{MSY} (B/B_{MSY}) 2.810 – 1.420 and 2.075 – 1.063, respectively. Furthermore, the uncertainties reported in Maximum Sustainable Yield (MSY) (18210 – 15050 MT), F_{MSY} (0.098 – 0.058) and B_{MSY} (185300 – 260700 MT) from FM and LM was also estimated in ASPIC using 0.8 Initial Proportion (IP) of starting Maximum Catch (MC) that was 80 %. According to Target Reference Points (TRPs), CEDA and ASPIC (11000 – 18000 MT and 15000 – 18000 MT) range also indicate overexploitation of the Indian mackerel in the Arabian Sea of Pakistan. Estimated Predicted Yield (PY) of 28841 MT in 2003 and even Recent Catch (RC) of 19421 MT in 2018 is far away from harvested yield values of 31126 and 33658 MT and even MC of 38504 MT, pinpointing this research in a questionable and overexploitation state. Ideally, Fishing Effort (FE) should be reduced at the level of PY which is approximately 12000 fishing vessels (19421 MT) against the current engaged FE of about 19000 fishing vessels (33658 MT) in 2018 for the Indian mackerel fishery in Pakistan. In order to prevent this huge economic loss and to reduce the efforts of fisheries, it is suggested that strict and immediate measures should be followed by the policy makers and law enforcement organizations against the mesh size and illegal nets for this type of commercially important fishery.

[**Keywords**: Economic measures, Fishery management, Pakistan, *Rastrelliger kanagurta*, Surplus production models]

Introduction

Undoubtedly, most living marine resource fisheries have collapsed and been depleted by heavy fishing in recent decades. This situation has demonstrated and contributed to irreversible socio-economic disruption and reduced sustainability of the marine environment in many fishing industries worldwide leading to overfishing[1]. Marine fishery resources are in serious trouble under open access regimes that seem to be unresolved in Pakistan due to improper monitoring and supervision of destructive fishing practices[2-4]. The marine fisheries, showing the best strategies in the history of overfishing, have proven to be largely inadequate in any type of fishing. Currently, Pakistan's comprehensive assessment Report of Stock Assessment 2015 on Marine Fishery Resources reveals thirty years of fishing activity reflecting the overexploitation of many species and influencing fish stocks in Pakistan's seawater[3].

Marine fishing is very diverse, with around 150 different species of fish of commercial and economic importance in Pakistan. Some of them such as *Rastrelliger kanagurta* (Indian mackerel), *Scomberomorus commerson* (narrow-barred Spanish mackerel), *Pampus argenteus* (White pomfrets), *Lutjanus* spp. (Snappers), *Sardinella* spp. (Sardinellas), *Arius* spp. (Catfishes), Lethrinidae (Emperors), Penaeidae (Shrimps), Carcharhinidae (Sharks) and Sparidae (Seabreams) are species of relatively high dominant economic value[3,4]. The country has a long coastline of 1120 km (Fig. 1), which is ideal for the economic development of fishing since it contributes around 70 % in terms of landing and more than 90 % in exports[5]. In the coastal areas of Pakistan, fishing is the main activity and about 90 % of the families rely on fishing and other related activities[6]. Commercial subsistence artisanal fisheries in Pakistan are estimated to contribute approximately 40 % of the total annual marine catch[4]. The fisheries sector's role in Pakistan is very important because it provides direct employment to approximately one million people in coastal communities, 4,00,000 (0.4 million) fishermen and 6,00,000 (0.6 million) people in related industries[4].

The fisheries sub-sector of livestock has the largest capacity and productivity potential in Pakistan, which plays a vital position in the economy of the nation. Fishing has positioned itself first in the coastal economy, the share of the fishing sector of 0.39 % in GDP, providing approximately a tenth of 2.10 % of agricultural GDP. The share of fishing in GDP, although miniscule, substantially increases national income through export earnings. During 2018-19, the total production of marine fish was estimated at 390000 MT, out of which 130830 MT of fish and fishery products were exported to European and Asian countries with a value of USD 293.887/million (Pak Rs. 39245 million). Stocks of quality fishery products have significantly depleted in Pakistan's waters due to overfishing and the use of destructive nets[4,7]. The Pakistani government is taking many steps to improve the fisheries sector and its exports by implementing the law.

In almost all the marine water bodies of the world, the Scombridae family is represented by 15 genera

Fig. 1 — Map represents the Sindh and Baluchistan, a provincial coastal boundary for Indian mackerel (*Rastrelliger kanagurta*) and international boundaries with India and Iran

and 54 fish species[8]. Mackerels, tunas and bonitos are included in the Scombridae family[9]. Scombroid fish are most commonly found in schools from South Africa to the Indo-West Pacific, the Seychelles and east of the Red Sea to Indonesia and North Australia to Melanesia, Samoa, China and the island of Ryukyu entering the Eastern Mediterranean Sea through the Suez Canal[10]. The Indian mackerel is also the main component of small pelagic catches in Pakistan[3,4]. The fish of the Scombridae family is also regarded as the fastest swimming in the world[11]. The small Indian Mackerels live in rough shallow waters close to shore, while many other Indian mackerels travel to deeper waters often in extensive migration patterns[12]. The Indian mackerels spawn in the spring and early summer along the shoreline in the water[13] and are considered predators[14]. In Pakistan, this family is represented by the genus *Rastrelliger* with only one species *R. kanagurta*[3,4].

The English name for *R. kanagurta* is Rake-gilled mackerel[15] and according to the FAO, this species is commonly referred to as Indian mackerel, while it is locally known as Bangra in Pakistan[15,16]. It is the commercially essential fishery for the coastal regions of South and Southeast Asia[17-19]. Indian mackerel is a coastal pelagic shoal and school fish found in neritic waters in Pakistan, generally reaches up to 25 – 35 cm in length, believed to last about 4 years, the oceanodromous migratory fish passes all their life in seawater and is planktivorous feeder[3,15,16]. This small pelagic fish is consumed directly, sold fresh in the local market and also exported in frozen or cured form[4] and stated to get a good price, at from 70 cents to more than 2 USD.

Fish stock assessment is a key tool for conservation, protection and management[20]. Of all the resources that natural animals exploit, fishing is the largest. The results of fish stocks present an important, enormous and foremost challenge, which requires better management of the most recent and positive information on the assessment of their sustainability, potential, capacity, reach, scope, growth and stock of the population[1]. Compiling existing management strategies for sustainable fisheries and ecosystems, Surplus Productivity Models (SPM) are among the simplest models used to assess fish stocks[20] and acknowledged Biomass Dynamics Models (BDM) which are built up to maximize best fishing effort and determine Maximum Sustainable Yield (MSY). MSY studies are the key and important fundamental tools in the evaluation and assessment of the marine fishery stock and facilitate the understanding of large-scale stock exploitation[1,20]. The MSY is frequently considered Biological Reference Point (BRP) through which a permanent, sustainable exploitation objective can be achieved[20]. For the long term sustainable exploitation of the stocks, BRP is defined as the mortality rate or the biomass level of fishing for the excellent catch[1].

The Karachi-based Department of Marine Fisheries (MFD) is credited with implementing deep-sea fishing policies. This Federal Sector Department was founded in 1951 and operates within the federal jurisdiction of the Port and Shipping Ministry. Its primary responsibility is to manage and develop fishery resources for the benefit of the country beyond the 12 nautical miles (nm) of territorial waters in the Exclusive Economic Zone (EEZ). This is the only public sector that evaluates the assessment of marine fish stocks, inspects and manages the quality control of fishery products exported from Pakistan, compiles and monitors national fishery statistics, and observes marine, oceanographic and technical research related to fishing as per International Standard Statistical Classification of Aquatic Animal and Plant Groups (ISSCAAP) defined by FAO. However, no information is available on Catch Per Unit Effort (CPUE) and Age composition[5]. The published statistics of the entire marine fishery need special permission to distribute and use data for scientific research purposes by the Ministry of Maritime Affairs (MoMA), Government of Pakistan. There have been some studies on the status of fish populations living in the marine waters of Pakistan. However, each fishery resource should be specifically assessed and evaluated to gain access to its stock position since population dynamics and catch data samples are dissimilar for different fish stocks[1].

Consequently, the current state of Pakistan's seawater fish stock is a serious and terrifying concern on a larger scale and there is an urgent need for more research, especially on commercially important species. So far, three studies have been conducted on the Indian mackerel in Pakistan, one on the biology of two population dynamics and three on morphometric properties[21-23]. Different studies of the Indian mackerel have been reported in various parts of the world, some of which are evaluated with stock assessment and others on biological aspects[17-19,24]. From a stock review standpoint, Indian mackerel fishing stocks are unique here in Pakistani seawater. Although, for the exclusive stock of this fishery, the literature is limited. This essential key task is the first attempt to assess the condition and status of the Indian mackerel fish stocks in Pakistan's seawater. It is foreseeable that this study would provide a better understanding and guide fisheries administrators and managers to achieve the sustainable development and exploitation of this fishery resource.

Materials and Methods

Data

Indian mackerel fishing effort

Time-series Data of Catch and Effort of Indian mackerel (*R. kanagurta*, Curvier, 1816)[25] were obtained for the period from 2003 to 2018 (16 years) from the Northern Arabian Sea Coast of Pakistan (Fig. 1) compiled through the Department of MFD, Government of Pakistan (Table 1). The respective fishing vessels in the territorial waters of Pakistan's EEZ are flying. The fleets of mechanized and semi-industrial vessels, *i.e.* trawlers and gillnets in the Pakistani EEZ are compromised of four types of fishing vessels[5]:

a) Gillnet launch/trawler/fish carrier (over 55 ft. 16.76 m length)
b) Gillnet launch/trawler/fish carrier (under 55 ft. 16.76 m length)
c) Mechanized boats (boat fitted with outboard engine)
d) Non-mechanized boat

However, the effort has been taken as the total number of registered and operational trawlers, gillnets, sailboats equipped with outboard motors and fishing boats (mechanized and mechanized cum-sailboats) in the maritime regions of Pakistan. The total annual catch is presented in the form of catch weight in Metric Tons (MT). The total production of Indian mackerel off the northern Arabian Sea coast of Pakistan was 460582 MT. The maximum, minimum and average catches were 38504 MT (2006) and 19329 MT (2011) measured with an average of Standard Deviation (SD) 28786±5850 and Coefficient of Variation (CV) 0.20, respectively. The highest and lowest CPUE unit values were estimated at 2.89 and 1.26, respectively, with an average cost of CPUE at 1.29±0.5 SD. During the study period, the average effort of SD was 15367±2196.44 and CV was 0.14 per year.

Indian mackerel catch and effort data relationship

The catch, effort and catch per unit effort trend from 2003 to 2018 showed that the increase of the

Table 1 — Input file of *Rastrelliger kanagurta* (Cuvier, 1816) Indian mackerel fishery from the Northern Arabian Sea coast of Pakistan analyzed by using non-equilibrium SPM (Surplus Production Model), CEDA based on 16 years (2003-2018) catch and effort data

IP Parameter	Effort Fishing vessels/a	Yield Weight in MT/a	CPUE Catch/a	Predict yield Catch/a	Observations Year
0.8	12838	31126	2.425	28841	2003
	13002	34552	2.657	28783	2004
	13145	28129	2.14	28723	2005
	13308	38504	2.893	28645	2006
	13426	37079	2.762	28583	2007
	13522	28671	2.12	28527	2008
	13879	34906	2.515	28290	2009
	14619	23015	1.574	27634	2010
	15349	19329	1.259	26773	2011
	15937	20584	1.292	25925	2012
	16426	24643	1.5	25114	2013
	16908	24031	1.421	24221	2014
	17518	24428	1.394	22957	2015
	18319	28291	1.544	21072	2016
	18727	29636	1.583	20014	2017
	18945	33658	1.777	19421	2018
	245868	460582	30.857	413522	Sum
	15367	28786	1.929	25845	Average
	18945	38504	2.893	28841	Maximum
	12838	19329	1.259	19421	Minimum
	14984	28481	1.68	27204	Median
	2196.44	5849.89	0.567	3346.98	Standard deviation
	0.143	0.203	0.294	0.13	Coefficient of Variation
	6107	19175	1.634	9420	Range
	4824344	3.4E+07	0.322	1.1E+07	Sample variance
	549.11	1462.47	0.142	836.744	Standard Error
	-0.727	-0.34	0.61	#N/A	Correlation
	1170.4	3117.19	0.302	1783.48	Confidence level (95.0 %)
	14196	25669	1.626	24062	Lower confidence level (95.0 %)
	16537	31904	2.231	27629	Higher confidence level (95.0 %)
	16	16	16	16	Count

catch could be achieved by increasing efforts with fluctuating CPUE. Observations of the landing of the boats showed that the greatest effort could be to maintain the maximum production level that is estimated in this study at 33658 MT in 2018 (Fig. 2).

Production model (PM) for Indian mackerel

The basis for deterministic PM is that the net change in biomass from one year to the next is the result of the catch for the current year and the stock for that year. The combination of the production stock influences the growth of population recruitment and natural mortality, which is considered a divergent function of the current or recent storage volume of stock[1].

The use of CPUE in the evaluation of fish stocks, the so-called CPUE is used in the present study based on the explanation given by Hoggarth *et al.*[1]. Surplus Production Models (SPMs) are also occasionally called Biomass Dynamics Models (BDMs) and contain three diverse versions by three dissimilar scientists (Fox 1970[ref. 26], Schaefer 1954[ref. 27] and Pella Tomlinson 1969[ref. 28]) who stand on various important hypotheses.

The CEDA software contains three production models:

1) Schaefer Production Model (SPM-Schaefer, 1954)
2) Fox Production Model (FPM-Fox, 1970)
3) Pella Tomlinson production Model (PTM-Pell and Tomlinson, 1969)

Schaefer production model

The SPM assumes that there is an asymmetric relationship between the size of the stock and production (yield), which is a function of the size of the unexploited population of carrying capacity (K),

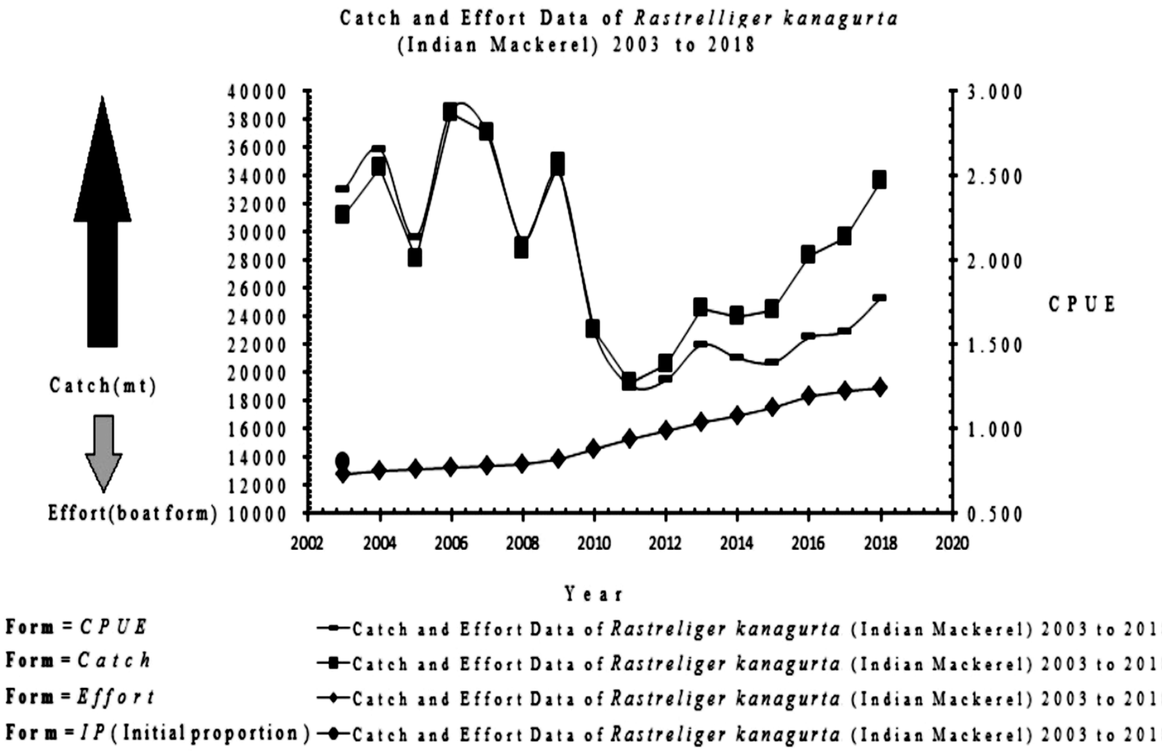

Fig. 2 — Relationship of catch and effort of Indian mackerel (*Rastrelliger kanagurta*) in the Arabian Sea (2003-2018)

and intrinsic growth rate (*r*). For Schaefer models, sustainable yield curves are symmetric and all have an MSY that occurs at a biomass of *K/2*. To obtain reliable estimates of *r* and *K*, the data should be available in a wide range of stock sizes. Schaefer's[26] model is based on logistical population growth and is the most widely used model.

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

Fox production model

FPM is quite similar to the Schaefer model as stock production is associated with *r* and *K*. Though the association between stock volume and production has a somewhat different shape, being flatter to the right of the top rather than symmetric. Fox's model proposed that the study is based on the Gompertz growth equation[27].

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

Pella-Tomlinson model

The generalized PTM specifies a similar relationship in mathematical form to the SPM. The difference between the two is that the PTM has a supplementary parameter (*z*), which allows the symmetry of the SPM to be distorted. The PTM and SPM are identical when $z = 1$, with the peak at *K/2*, the peak occurs to the left of *K/2* when $z < 1$, as z tends to 0, the shape not the height of the function approaches that of the FM. The peak occurs to the right of *K/2* when $z > 1$. The use of a generalized production equation is proposed by the PTM[28].

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

Where, *B* represents the biomass of the fish population, *n* indicates the shape parameter, *t* stands for time (year), B_∞ signifies the carrying capacity (*K*), and *r* corresponds to the intrinsic rate of the growth population.

Statistical analyses

Evaluation software

The time-series data of the catch and effort of the Indian mackerel for the period between 2003 and 2018 (16 years) were statistically analyzed using Surplus Production Models (SPM). Two specialized tools for the stock assessment of Indian mackerel have been used in this research paper:

1) Catch and Effort Data Analysis (CEDA)[1] downloaded from the Marine Resources Assessment Group (MRAG)[29] website: https://mrag.co.uk/resources/ceda-version-30

2) A Stock Production Model Incorporates Covariates (ASPIC)[30] downloaded from the website http://www.mhprager.com/aspic.html (Accessed May 11, 2020).

These fishing computer toolkits have been used for stock assessment in the world and Pakistan, developed by the UK and US renowned Fisheries Scientists. These stock appraisal tools assume that the fishing stocks are in a state of inequality and disequilibrium. The purpose of utilizing these two packages concurrently in this research study is to get better assurance in the results since each analysis may be uncertain.

Models

Analysis of Catch and Effort Data Model-CEDA-Version 3.0.1

CEDA software package is a menu-based data modifier that can estimate custom parameters and a 95 % confidence interval is used by the boot technique. It also makes three Error Assumptions (EAs) (log, normal log and gamma) for all SPMs and has extremely excellent tools including the residual plots and quality fit goodness and only involves IP or B_1/K for input. Initil Proportion (IP) is calculated by dividing the initial catch by the maximum available catch existing output Catch and Series Data of Effort. In addition, different values of IP were operated to reach a sensitivity in Indian mackerel stock. When the value of the IP input is 0, CEDA calculates the parameters assuming the stock of virgin fish. Conversely, when the value of the IP input is 1 of the fish stocks, it is assumed fishing is ongoing from an already highly exploited state. Occasionally, the initial biomass is designated $B_1 = C_1 / (qE_1)$. The parameters C (Catch), q (Catchability coefficient), and E (Fishing effort) represent in this mathematical statement and some programmers also use B_1 as K (Carrying capacity). The CV (Coefficient of Variation) is estimated using confidence intervals and other vital parameters using CEDA, and ASPIC are estimated including MSY, K, q, r (Intrinsic growth rate), RY (Replacement yield) and B (Final biomass).

A stock production model incorporates covariates-ASPIC-Version-5.0

Conversely, ASPIC also needs an IP value for the entry in contrast to CEDA and requires separate input files for each IP value. Two fishing software of SPMs (Fox a special case of GENFIT) and the Logistic model (Schaefer model) are used. The program modes fitting mode (FIT) and bootstrap mode (BOT) are prepared for all the IP values in ASPIC. There is a technical disparity between FIT and BOT. FIT mode estimates interest parameters to the administration, whilst the BOT mode employs bootstrap confidence intervals with many tests to calculate the parameters. Consequently, the BOT model run time is much longer than the FIT model. By calculating the MSY for each IP value, 500 tests are completed. This model can estimate other important parameters, *i.e*. MSY, K, q, B_1K, R^2, F_{MSY}, B_{MSY}. In these models due to unreliable results using IP values from 0.1 to 0.9 (Tables 2, 3), the sensitivity analysis is also performed. For the reliable results, various parameters are also considered with R^2 values and visual inspection graphs are compared to obtain dependable results for the model selection.

Results

Based on the results of the 16 years (2003 – 2018) assessment of the fisheries of Indian mackerel, the total production of Indian mackerel from the Northern Arabian Sea Coast of Pakistan was 460582 MT. The maximum, minimum and average catch in 2006 and 2011 was 38504 MT (8.36 %) and 19329 MT (4.20 %) measured with an average of (6.25 %) 28786±5850 SD and 0.20 CV, respectively. The highest and lowest CPUE unit values were estimated at 2.89 and 1.26, respectively, with an average cost of CPUE at (6.25 %) 1.93±0.57 SD with 0.29 CV. During the study period, the average effort was (6.25 %) 15367±2196 SD and 0.14 CV per year (Table 1).

The trend of the catch production was seen fluctuating for the Indian mackerel throughout the 16 years of study with the highest Indian mackerel fisheries production contributing 8.36 % in 2006 in the form of catch, while an increase of 7.308 % was observed in 2018 (33658 MT) from the production 6.758 % in 2003 (31126 MT). Over the 16-year study, the total number of boat inventory of mechanized, non-mechanized trawlers, gillnetters fishing crafts within EEZs of Pakistani waters have been operated by 245868 fleet vessels during the study period. The trend of increase in the total effort used in the form of boats was observed from 5.222 % (12838) in 2003 to 7.705 % (18945) in 2018. On the other hand, the CPUE showed a decreasing trend of 5.758 % (1.777) in 2018 than the highest CPUE of 9.376% (2.893) in 2006 and 7.857 (2.425) in 2003.

Table 2 — The calculated range of MSY and CV values from 0.1 to 0.9 using the non-equilibrium surplus production model (CEDA) for *Rastrelliger kanagurta* (Cuvier, 1816) fishery from the Northern Arabian Sea coast of Pakistan based on 16 years (2003-2018) data

B_1/K	FMN	FMLN	FMG	SMN	SMLN	SMG	PTMN	PTMLN	PTMG	SUM	% (IP)
					MSY						
0.1	0.16	45993	MF	MF	1331	88444	MF	1331	88444	225543	22.22
0.2	0.5	29200	MF	MF	351	MF	MF	351	MF	29902	2.95
0.3	56727	22397	MF	0.12	21906	36602	0.12	21906	36602	196140	19.32
0.4	1	19679	MF	0.08	19556	32934	0.08	19556	32934	124660	12.28
0.5	9125	18318	MF	1	13739	30196	1	13739	30196	115316	11.36
0.6	12794	17534	MF	0.27	12138	MF	0.27	12138	MF	54605	5.38
0.7	13921	17374	MF	6017	13132	MF	6017	13132	MF	69594	6.86
0.8	14506	17637	MF	10910	14213	MF	10910	14213	MF	82388	8.12
0.9	14970	17872	MF	11880	15859	14360	11880	15859	14360	117042	11.53
Sum	122045	206005		28808	112224	202537	28808	112224	202537	1015188	100
MSY	328051 (G.T of FM)			343568 (G.T of SPM)			343569 (G.T of PTM)			1015188	-
%	37.2	62.8		8.38	32.66	58.95	8.38	32.66	58.95	-	-
% (SPMs)		32			34			34		-	-
% MSY of SPMs in TY	71			75			74				
Max	56727	45993		11880	21906	88444	11880	21906	88444	-	-
Min	0.16	17374		0.08	351	14360	0.08	351	14360	-	-
Range	56727	28619		11880	21555	74084	11880	21555	74084	-	-
					CV						
0.1	0.83	0.04	MF	MF	30.39	0	MF	30.11	0	61.38	0.04
0.2	33453.9	0.08	MF	MF	64.17	MF	MF	56.4	MF	33574.5	24.37
0.3	0.39	0.15	MF	0.69	0.3	0.02	0.61	0.29	0.02	2.47	0
0.4	14559.9	0.18	MF	0.68	0.28	0	0.66	0.28	0	14561.9	10.57
0.5	0.91	0.21	MF	23198.4	0.51	0	24049.1	0.52	0	47249.6	34.3
0.6	0.48	0.21	MF	1.45	0.59	MF	42282.9	0.6	MF	42286.2	30.7
0.7	0.39	0.22	MF	1.66	0.48	MF	1.64	0.47	MF	4.85	0
0.8	0.4	0.24	MF	0.66	0.38	MF	0.71	0.38	MF	2.76	0
0.9	0.41	0.23	MF	0.56	0.3	0.4	0.56	0.3	0.39	3.14	0
Sum	48017.5	1.56		23204.1	97.4	0.43	66336.1	89.34	0.41	137747	0
CV	48019.07 (G.T of FM)			23301.94 (G.T of SPM)			66425.89 (G.T of PTM)			137747	-
%	100	0		99.58	0.42	0	99.86	0.13	0	-	-
% (SPMs)	34.86			16.92			48.22				
Max	33453.9	0.24		23198.4	64.17	0.4	42282.9	56.4	0.39	-	-
Min	0.39	0.04		0.56	0.28	0	0.56	0.28	0	-	-
Range	33453.5	0.2		23197.9	63.89	0.4	42282.3	56.12	0.38	-	-

Table 3 — Fox and Logistic model: the estimation, management and derived key parameters (non-bootstrapped) using IP 0.1 to 0.9 by ASPIC software for *Rastrelliger kanagurta* (Cuvier, 1816) fishery in Pakistan

					Fox Model				
Parameters IP	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
R-squared	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54
K	498300	504100	499000	499100	497700	498500	498400	503800	496900
Q	5.45E-06	5.37E-06	5.44E-06	5.44E-06	5.45E-06	5.45E-06	5.45E-06	5.37E-06	5.47E-06
MSY	18310	18180	18320	18290	18370	18360	18330	18210	18380
B_{MSY}	183300	185500	183600	183600	183100	183400	183400	185300	182800
F_{MSY}	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
CV	0.12	0.14	0.12	0.14	0.1	0.14	0.1	0.12	0.14
Sum of MSY of FM (0.1 to 0.9)	164750	-	-	-	-	-	-	-	-
Sum of CV of FM (0.1 to 0.9)	1	-	-	-	-	-	-	-	-
% of MSof FMTY	42.478	-	-	-	-	-	-	-	-
% of MSY in TY	35.770	-	-	-	-	-	-	-	-

(Contd.)

Table 3 — Fox and Logistic model: the estimation, management and derived key parameters (non-bootstrapped) using IP 0.1 to 0.9 by ASPIC software for *Rastrelliger kanagurta* (Cuvier, 1816) fishery in Pakistan (*Contd.*)

	Logistic Model								
R-squared	0.52	0.54	0.53	0.54	0.54	0.54	0.54	0.54	0.54
K	261300	522500	216500	517300	523500	523300	522200	521400	523200
Q	5.60E-05	5.07E-06	5.89E-05	5.13E-06	5.06E-06	5.06E-06	5.08E-06	5.09E-06	5.07E-06
MSY	62320	15010	55600	15190	14960	14970	15010	15050	14990
B_{MSY}	130700	261300	108200	258600	261800	261600	261100	260700	261600
F_{MSY}	0.48	0.06	0.51	0.06	0.06	0.06	0.06	0.06	0.06
CV	14.668	0.131	22.73	0.14	0.16	0.11	0.1	0.13	0.12
Sum of MSY of LM (0.1 to 0.9)	223100	-	-	-	-	-	-	-	-
Sum of CV of LM 0.1 to 0.9	38	-	-	-	-	-	-	-	-
% of MSY of LMTY	57.522	-	-	-	-	-	-	-	-
% of MSY in TY	48	-	-	-	-	-	-	-	-
Sum of MSY (FM & LM)	387850	-	-	-	-	-	-	-	-
% G.T MSY of FM & LM (TY)	84.209	-	-	-	-	-	-	-	-

The calculated result of both software ASPIC and CEDA are more observed considering the output parameters of MSY, CV, R^2, and residual graph of Observed and Expected catches. The calculated values of MSY are evaluated with the figures' data and very huge or small MSY values are ignored. SPMs of all models are compared based on R^2 and visual residual graphs, the value of higher R^2 (0.5) is a better fit model and values of CV fell in an acceptable range were considered and accepted.

Results of CEDA

Table 2 showed sensitivity toward IP input values as a calculated range of MSY and CV values from 0.1 to 0.9 in CEDA all EAs models and as usual gamma model showed MF. From 0.1 to 0.2 IP values in Schaefer Normal Model (SNM) and the Pella Tomlinson Model Normal (PTMN) only produced minimization failures. The calculated MSY and CV values for FM, SPM and PTM with their EAs: FMN, FMLN and FMG, SMN, SMLN and SMG, and PTMN, PTMLN and PTMG could not produce normal results except for 0.8 IP values. The CV values are calculated by the bootstrapped confidence limit method. The total MSY calculated for the Fox Model (FM) was 328051 (32 %) MT and the total MSY calculated value was 343568 MT (34 %) for SPM and PTM, respectively. Here SPM and PTM showed more sensitivity than FM in all three types of SPM. The maximum and minimum range of MSY for FM was from 0.16 to 45993 MT, while the range was observed from 0.08 to 88444 MT for SPM and PTM, respectively. In the sum of the IP values of 0.1 to 0.9 for the Indian mackerel, the highest calculated MSY of 22.22 % was observed with an IP value of 0.1, and the lowest calculated MSY of 2.95 % was found with the IP value of 0.2. The higher MSY values are observed with lower IP input values in CEDA.

Based on a 16-year study (2003 – 2018) of the *R. kanagurta* (Indian mackerel) fishery from the Northern Arabian Sea Coast of Pakistan, the non-equilibrium SPM Catch and Effort Data Analysis (CEDA) is used. The input IP value 0.8 is used because the initial catch is approximately 80 % of the Maximum Catch (MC). Table 4 consists of the Fox model with EAs (FMN, FMLN and FMG) with an input IP value of 0.8, the MSY and CV estimated values are 14506 MT and 17637 MT with CV 0.40 and 0.24, respectively. In the Schaefer and Pella-Tomlinson models with EA (SMN, SMLN and SMG) and (PTMN, PTMLN and PTMG), the calculated values of MSY were 10910 MT, 14213 MT and remained the same with a little difference in CV (0. 66 and 0.38) and (0.71 and 0.38), respectively. The FMEAG, SMEAG, and PTMEAG maximization failure occurred in all SPMs. The residual plot of observed and expected catch values can be recognized in Figure 3. For all EAs models, the observed and expected catch values are close to each other but fluctuate from each other in detail.

The R-squared (R^2) values for FMN and FMLN EAs using IP 0.8 for *R. kanagurta* were 0.8, whereas in SMN and SMLN and PTMN and PTMLN EAs were same *i.e.* 0.6, respectively (Table 4). The FMG, SMG, and PTMG showed minimization failure here also. It is very important to take into account the

Table 4 — Initial proportion (IP) 0.8 for *Rastrelliger kanagurta* (Cuvier, 1816) fishery from Northern Arabian Sea coast of Pakistan analyzed using non-equilibrium SPM (Surplus Production Model), CEDA

Parameters	FMN	FMLN	FMG	SMN	SMLN	SMG	PTMN	PTMLN	PTMG	SUM
R-squared	0.08	0.08	MF	0.06	0.06	MF	0.06	0.06	MF	0.40
K	6.36E+05	5.25E+05	MF	7.22E+05	6.06E+05	MF	7.22E+05	6.06E+05	MF	3.82E+06
Q	5.38E-06	6.54E-06	MF	4.64E-06	5.49E-06	MF	4.64E-06	5.49E-06	MF	3.22E-05
R	0.06	0.09	MF	0.06	0.09	MF	0.00	0.09	MF	0.40
MSY	14506	17637	MF	10910	14213	MF	10910	14213	MF	82389
Final Biomass	242366	199109	MF	277501	233748	MF	277501	233748	MF	1463973
R_{YIELD}	14496	17629	MF	10325	13474	MF	10325	13474	MF	79723
CV	0.400	0.240	MF	0.660	0.380	MF	0.710	0.380	MF	2.770
BMSY	234036	193292	MF	361093	302750	MF	361093	302750	MF	1755014
Sum of MS (FM, SPM, PTM)	32143			25123			25123			82389
Sum of CV (FM, SPM, PTM)	0.640	-	-	1.040	-	-	1.090	-	-	2.770
% MSY (FM, SPM, PTM)	45	55	-	43	57	-	43	57	-	-
% CV (FM, SPM, PTM)	62.500	37.500	-	63.462	36.538	-	65.138	34.862	-	-
% MSY (Grand total of SPMs)	39.014	-	-	30.493	-	-	30.493	-	-	100
% CV (Grand total of SPMs)	23.105	-	-	37.545	-	-	39.350	-	-	100
G.T % of MSY of TY	6.98	-	-	5.45	-	-	5.45	-	-	17.89

goodness of fit values (R^2) since it informs us about the fit of the best model. Here FM showed the best model than SPM and PTM. The total of the calculated MSY and CV for FM was 32143 MT with a value of CV 0.64 and the same value of MSY 25123 MT was calculated for SPM and PTM with 1.04 and 1.09 values of CV. In the total of the calculated MSY of SPMs, 39 % was from FM followed by 30 % from SPM and PTM, and FM showed more sensitivity here (Table 4). It is also found from the calculated total percentage of MSY of Total Yield (TY) of Indian mackerel in Pakistani waters that FM showed also more sensitivity producing 6.98 % MSY than SPM and PTM 5.45 %.

Results of ASPIC

Table 3 shows all the IP values from 0.1 to 0.9 produced by various parameters from ASPIC software; this software contains two models: Fox Model (FM) and Logistic Model (LM). The calculated parameters for SPMs with different IP values estimated different values. Larger MSY values were estimated when using smaller IP input values, showing sensitivity to different IP input values. The total sum of the calculated MSY and CV from 0.1 to 0.9 are 387850 MT and 39 for FM and LM, respectively. FM calculated MSY and CV 164750 MT with 1and 223100 MT with 38 were from the LM. The 42 % and 3 % estimated MSY and CV were from FM, whereas 58 % and 97 % were from LM, respectively from the total yield estimated. While from the total yield of Indian mackerel from Pakistani waters 36 % was estimated from the FM and 48 % from the LM. From the above results, it is observed that ASPIC software (LM) shows more sensitivity than the FM similar to CEDA in Table 2.

Table 5 shows various parameters calculated for an IP value of 0.8 in the ASPIC software. The MSY and CV values for FM and LM were calculated as 18210 (0.543) MT and 15050 (0.538), respectively. The R-squared (R^2) was estimated as greater 0.543 in FM

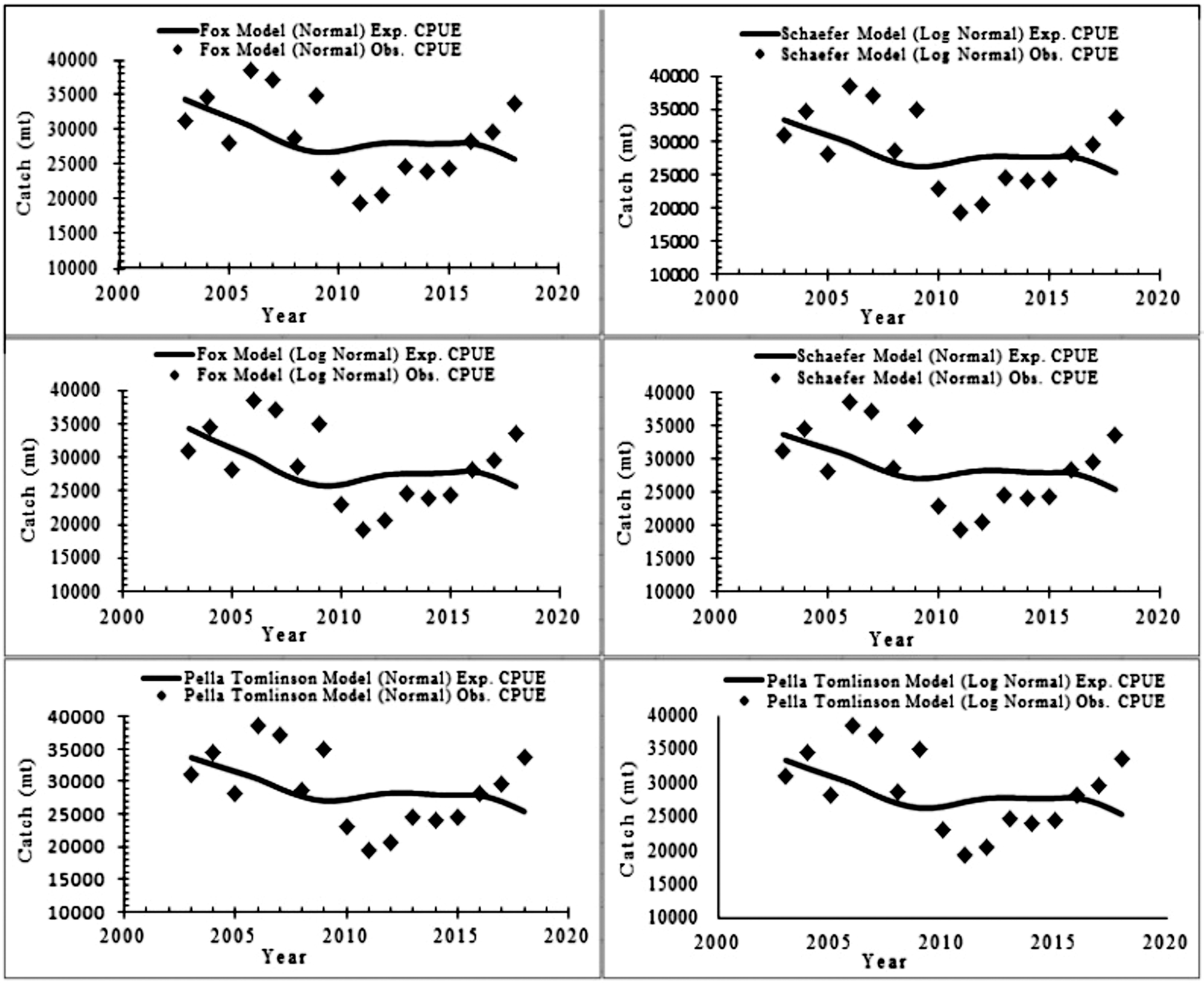

Fig. 3 — Annual observed (points) and expected (lines) catch (MT) of Indian mackerel (*Rastrelliger kanagurta*) fishery from Pakistan using IP = 0.8 in CEDA

than the calculated R^2 value of 0.538 in LM, showing a better fit model as in CEDA Table 4. In FM and LM, the *K*, B_{MSY} and F_{MSY} are estimated at 503800, 185300 MT, 0.10 and 521400, 260700 MT, 0.06, respectively.

The estimated total MSY sum of IP 0.8 in FM and LM was 33260 MT, 55 % (18210 MT), and 45 % (15050 MT), respectively. From the total yield of Indian mackerel point of view in Pakistani waters, the FM produced 3.954 % of MSY and LM estimated 3.268 % (Table 5) and showing more authenticity and sensitivity of our results obtained from CEDA in Table 4 as 6.98 % of MSY than SPM and PTM 5.45 %. The estimated range of MSY and CV from using CEDA and ASPIC software was about 11000-18000 (0.24-2.77) MT and the values from ASPIC were 15000 – 18000 (0.12 – 0.13) MT. Overall the results suggest that ASPIC software was more sensitive than CEDA for Indian mackerel in Pakistani waters with a total estimated MSY of 6.98 % in CEDA (Table 4) and 7.221 % in ASPIC (Table 5).

Table 6 showed the trend of increasing and decreasing observations of Indian mackerel values of estimated between estimated total fishing mortality and estimated starting biomass relationship, by using ASPIC of the SPMs, the FM and LM. The trend of F (estimated total fishing mortality) is indicated as the increasing trend from 0.062 to 0.132 and 0.059 to 0.126 during 2003 – 2018, respectively in FM and LM. While the trend of B (estimated starting biomass) is indicating a decreasing trend from 520800 to 263100 MT and 541000 to 277000 in that order, respectively as referred above for both models. The trend of F/F_{MSY} (ratio of fishing mortality to F_{MSY}) also

Table 5 — Management, model and derived parameter estimates (Non-bootstrapped) by ASPIC software using Initial proportion (IP) 0.8 for *Rastrelliger kanagurta* (Cuvier, 1816) fishery in Pakistan

Parameters	Main estimated and calculated values		
	Fox Model		Logistic Model
IP	0.8		0.8
R-squared	0.543		0.538
K	503800		521400
Q	5.37E-06		5.09E-06
MSY	18210		15050
B_{MSY}	185300		260700
F_{MSY}	0.098		0.058
CV	0.121		0.133
Sum of MSY (FM & LM)		33260	
Sum of CV (FM & LM)		0.254	
% of MSY (FM & LM)	54.750		45.250
% of the CV (FM & LM)	47.788		52.212
% of MSY of TY (FM & LM)	3.954		3.268
G.T % of MSY of TY		7.221	

Table 6 — Estimated population trajectory (Non-bootstrapped) for Fox model and Logistic model

Fox model						Logistic model					
Obs.	Year or ID	Estimated total fishing mortality	Estimated starting biomass	The ratio of fishing mortality to F_{MSY}	The ratio of biomass to B_{MSY}	Obs.	Year or ID	Estimated total fishing mortality	Estimated starting biomass	The ratio of fishing mortality to F_{MSY}	The ratio of biomass to B_{MSY}
1	2003	0.062	520800	0.628	2.81	1	2003	0.059	541000	1.027	2.075
2	2004	0.073	489500	0.743	2.641	2	2004	0.07	510000	1.213	1.954
3	2005	0.063	457800	0.642	2.47	3	2005	0.06	478000	1.044	1.834
4	2006	0.092	435000	0.935	2.347	4	2006	0.088	456000	1.516	1.748
5	2007	0.095	404000	0.968	2.18	5	2007	0.09	425000	1.562	1.63
6	2008	0.078	376700	0.794	2.032	6	2008	0.074	398000	1.276	1.527
7	2009	0.1	359400	1.021	1.939	7	2009	0.095	381000	1.638	1.46
8	2010	0.069	337100	0.705	1.819	8	2010	0.065	358000	1.129	1.374
9	2011	0.059	327600	0.606	1.768	9	2011	0.056	348000	0.969	1.336
10	2012	0.065	322300	0.657	1.739	10	2012	0.061	343000	1.052	1.314
11	2013	0.079	316000	0.807	1.705	11	2013	0.075	336000	1.293	1.287
12	2014	0.08	306100	0.811	1.652	12	2014	0.075	325000	1.301	1.247
13	2015	0.083	297300	0.849	1.604	13	2015	0.079	315000	1.364	1.209
14	2016	0.1	288500	1.02	1.556	14	2016	0.095	305000	1.642	1.171
15	2017	0.11	276200	1.119	1.49	15	2017	0.104	292000	1.806	1.119
16	2018	0.132	263100	1.346	1.42	16	2018	0.126	277000	2.179	1.063

indicated an increasing trend as same as in FM and LM from 0.628 to 1.346 and 1.027 to 2.179 from 2003 to 2018, respectively. The B/B_{MSY} trend (ratio of biomass to B_{MSY}) indicates a decreasing trend from 2.81 to 1.42 and 2.07 to 1.06, respectively, for both models. Therefore, both parameters F/F_{MSY} and B/B_{MSY} point out the overexploitation of the Indian mackerel fishery in Pakistani waters.

Discussion

Pakistan's EEZ is classified into three zones (Fig. 1); under Pakistan's (deep-sea fishing policy 1982), following the United Nations Convention on the Law of the Seas. For the first time, the convention defined the territorial zones and EEZs of all coastal states in the world[31]. Described as Zone-1, starting from the coastline to 12 nm is under provincial government supervision and can be used for small-scale fishing activities. While Zone-2 starts from 12 nm up to 35 nm and remains reserved for fishing through medium-sized vessels, the area between 12 and 20 nm is left as a buffer zone between the local and industrial fishing area. Similarly, Zone-3 (35 to 200 nm) will be under use for fishing activities with medium and large fishing vessels (industrial fishing). Therefore, both zones are under the governance of the Federal Government (A government body on a national level) and are responsible for all fisheries within 12 to 200 nm. Here, the fishing trawlers and local fishing launches are free to operate for the management of deep-sea trawl fisheries[4,5,31].

The gillnet is the most predominant and important gear to catch the Indian mackerel in Pakistan, whose mesh size is (2 cm) up to the bottom set gillnet called "Thukri"[16]. It has been witnessed that most commonly Indian mackerel catch in Pakistan is exploited by gillnet or encircling net[4,15,16,22]. A modification of "Thukri" called "Plastic net" or monofilament surface gillnet has got popularity and is used nowadays for catching Indian mackerel along with the shallow coastal waters (Baluchistan and Sindh) Pakistan. Such fishery was nonexistent before 2002. The estimated commercial landings quantities of Indian mackerel from the Pakistani coast of the Arabian Sea was 7.308 % (33658 MT) in 2018, showing an increasing trend in the total yield from 2003 (6.758 %; 31126 MT) with the annual average catches of Indian mackerel 6.25 % (28786 MT; Table 1). The catch composition of small pelagic fish (Indian mackerel) in Pakistan's coastal waters was 33 % of the total catch in 2010 and this species dramatically dropped from 8.360 % (38504 MT) in 2006 to 7.308 % (33658 MT) in 2018 due to overfishing. The concern should be raised about the sustainability of this decreased fishery trend over the last decade in the marine waters of Pakistan[4,22]. These small pelagic Indian mackerel fishes are generally available and affordable throughout the year at low prices and are commonly consumed in local communities. These small pelagic fishes are considered valuable sources of nutrients, particularly are rich in proteins which are health-beneficial and are reported in alleviating diseases/disorders related to malnutrition and ageing[32]. Because these fish have been recognized as an important component of the diet of humans, provide nutrients for the human body to function properly[33]. These are rich in vitamin D which strengthens our bones, and vitamin B-12 which helps in making our DNA and red blood cells and also have a lot of omega-3 fatty acids that enhance brain function.

Production models[26-28] were fitted to pelagic catch and effort data of Indian mackerel using the methods described in CEDA and ASPIC packages[1,30]. Although, the production models in the past have been built on equilibrium techniques means fishery stock is in a stable state, which required a linear regression for the easy way to implement, this approach has largely been discontinued[20]. Currently, the non-equilibrium techniques have been interpreted meaning fishery stock is in an unstable state and requires non-linear regression which is relatively very difficult to implement in natural water bodies and these models provide robust estimates of relative parameters[1,34]. This methodology has mostly been used in various parts of the globe[20,30,35-39]. Production models are used herein to estimate three key fishery management stock parameters, MSY, F_{MSY}, and B_{MSY}. The current state of the stock parameter for Indian mackerel in Pakistan is estimated relative to a target or limit reference level such as MSY, B_{MSY}, and F_{MSY}. With these methods, the stock ratios of model parameters can be estimated more reliably, which are always enclosed in the hypothesis[1].

To calculate proprietary parameters the status and popularity come from their specific criteria and simplicity of the practice and usage[37]. To achieve the statistical property of estimated parameters, the bootstrapped methods have been performed through Confidence Intervals (CIs) to know the real and exact precise data of a fishery that fits well in the sensitive analysis[1]. The biomass of the fishery that can be developed and grown without fishing is referred to by surplus production models[38]. Therefore, it is possible to continue fishing by maintaining and sustaining fish stock volume at a certain and constant level. The SPMs models are based on the depletion concept and reduction of fishery resources. The concept of depletion refers to a decrease in abundance indicators due to the reduction of fishery resources. The complete and comprehensive capture and effort data on SPMs needs to be continuously recorded[39]. Each unit effort (CPUE) can be used to predict different parameters[1,39].

Corresponding goals (target points) and limitations (limit points) are normally raised in the fisheries management science for the choice of objectives and tracking fisheries status[1]. These reference points are also known as Technical Reference Points or Biological Reference Points (TRPs) and are categorized into two main management global instruments[40]. Ideally, these reference points were determined by FAO's Code of Conduct for Responsible Fisheries in 1992 and become part of it nowadays[41]. The conventional concept of MSY target, which stands as an outstanding level on fisheries production models, is commonly seen to be a risk-prone strategy, instead of both Target Reference Points and Limit Reference Points (TRPs and LRPs) biological reference points targets based on the desirable and undesirable state of fishery or fish stock means higher and lower values of F_{MSY} and B_{MSY} should be based and adopted on the management level strategy. The RPs act as indicators by guiding specific values and fishing regulators that can act as a mediator between fishermen and stakeholders to make decisions[40]. For example, if the fishing mortality rate (F_{MSY}) is set and supersedes the B_{MSY} limit point, the fishing may be stopped. However, fishing can be continued in case of low or below the B_{MSY}. This simple rule of thumb is known as "pulse fishing" in the science of fishing management[40].

For fisheries management, strategies for Indian mackerel in Pakistan using catch and effort data on these simple production models can be useful. Depending on the performance estimates, measures from production models can be easily interpreted based on biological reference points such as MSY, B_{MSY}, and F_{MSY}. The model in Table 6 has estimated total fishing mortality (F = 0.062 to 0.132) and (F = 0.059 to 0.126) from 2003 to 2018, the ratio of fishing mortality to F_{MSY} (F/F_{MSY}) also showing an increased inclination 0.628 to 1.346 and 1.027 to 2.179, respectively. Whereas estimated starting biomass has decreased (B = 520800 to 263100 MT) and (B = 541000 to 277000 MT) with the ratio of biomass to B_{MSY} (B/B_{MSY}) 2.81 to 1.42 and 2.075 to 1.063. Furthermore, the analyses account for the uncertainty of fishing mortality rate under MSY (F_{MSY}) and B_{MSY}, which was also estimated from the production model using an initial proportion (IP) of 0.8, due to starting catch was approximately 80 % of the maximum catch. The estimated fishing mortality rate at MSY (F_{MSY}) was 0.098 and 0.058 with biomass given MSY (B_{MSY}) 185300 and 260700 MT, respectively (Table 4). B_{MSY} is the stock size of MSY referred to as fishing mortality (F_{MSY}). In the case of the Schaefer production model, this is half of the unfished stock size[1].

Another important reference point MSY was the first embedded during 1982, in the UNCLOS. Where it was defined as “to guide fisheries” specified as a standard target for fisheries resources exploitation. Later, it was defined LRPs and TRPs entirely in terms of the biological reference points related to maximum sustainable yield B_{MSY} and F_{MSY} in the 1995 UN Fish Stock Agreement[41]. It has been the single reference point used in marine fisheries policy in Pakistan[3]. Because, Pakistan did not develop specific reference to the current fisheries policies so the stock assessment results of Indian mackerel are based on the indicators that are specified by UNCLOS. These reference points are the precautionary approaches, suggesting sustainable fisheries targets in the best interest of the national level. The production models estimation of MSY values in terms of RPs for the Indian mackerel fishery in Pakistan is estimated as 14960-18380 MT (FM and LM-ASPIC) (Table 3) and 10910 to 17637 MT (FM and LM-CEDA) (Table 4). Thus, production models are representing over-exploitation based on TRPs and LRPs for Indian mackerel fishery in Pakistani waters. Due to dramatically increase in the number of mechanization fishing vessels and size, the demand and necessity of seafood export, the marine aquatic resources are being exploited without long-term ecological and economic sustainability of fisheries in Pakistan[3-5,7]. In the case of overfishing, the ecological change can also be natural or anthropogenic[7]. The fish stock size and distributions can fluctuate widely in a naturally/ unexploited state due to the discrepancy in environmental factors and effects of other species with which they interact[1]. The reference points can be specified by F_{MSY} and B_{MSY} and the MSY, and each can be used as a reference point to manage a fishery at the point where yield will theoretically be maximized[1]. Because stock estimates to the reference, point TRPs and LRPs are often framed on the possibilities or probabilities. Reference points provided the specific values to aim at TRPs and avoid from LRPs for the indicators adopted in the fishery. Several reference points can be related to more than one indicator. Where, MSY adopted as an objective for instance, in Pakistan the long-standing fisheries managing approaches are built around the concept of maximum sustainable yield (MSY) and often is taken as a standard target derived from the surplus production models.

Marine resources of Pakistan are now facing massive pressure these days and need sustainable enforcement measures in the preservation of fish stock, the overfishing reflects a shortage of management and regulation in fisheries. According to the FAO, Pakistan’s fisheries stock assessment report (2015) “The marine resources of Pakistan are over-fished and have been dwindling as the ever-increasing fishing effort continues to take unsustainable harvests in an ongoing ecological

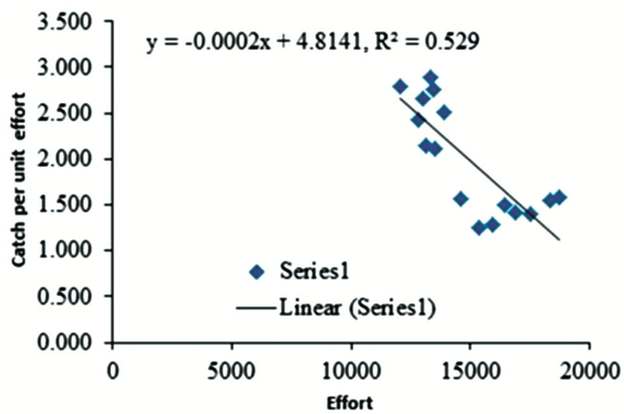

Fig. 4 — CPUE for Indian mackerel (*Rastrelliger kanagurta*) from the Arabian Sea

disaster"[3]. That is seen and proved in our study that more fishing vessels effort (18945) in 2018 harvested more yield (33658 MT) that is also highest from MC, RC, and even PY as compared to fishing effort 12838 (31126 MT) in 2003 (Table 1). The theoretical point is that as effort increases, the CPUE decreases (Table 1; Figs. 2, 4), so when there are lots of boats around, each boat or each unit effort does not catch many fish, when there are few boats around then each boat or each unit effort catch lots of fish, but when there is an only small number of boats around each unit effort catches most fish[1]. The theoretical kind of the point here is that if only one boat around with a very small amount of effort (12838 in 2003) catch even more fishes (31126 MT in 2003). However, even though the maximum catch 38504 MT in 2006 in the TY series is quite low (Fig. 4), the catch per unit effort (CPUE = 2.900) could be as high as possible testifying (CPUE = 2.893 in 2006) in our current study (Table 1, Figs. 2, 4). From the prediction point of view for Indian mackerel in Pakistani marine waters the estimated values 28841 MT in 2003 and even RC 19421 in 2018 are much far from harvested yield values (31126 MT and 33658 MT) (Table 1), respectively. The pinpointing of this scientific research is in an overexploitation state. Ideally, fishing efforts should be reduced at the level of predict yield which is approximately 12000 fishing vessels (19421 MT) against the engaged fishing effort of about 19000 fishing vessels in 2018 for the Indian mackerel fishery in Pakistan.

According to a report by IUCN (2011), the main reason for the decline in the catch of commercially targeted species in artisanal fishing is overfishing[3,4,22,42]. By definition, when the catch of a certain population is higher than the limit fishing mortality specified for a given fishery is called overfishing. Similarly, if the biomass of a group or stock is lower than the specified limit reference point, the group or stock is said to be overfished. If the population is larger, but the fishing activity is too fishy and arduous, overfishing may occur and the population has not been overfished. In the same way, depleted populations may be rebuilt and can only be fished slightly, so they may be overfished without overfishing. Overfishing is causing a rapid decline in the catch of Indian mackerel at the coast of the Arabian Sea, locally known as Bangra[15,16], which is major commercial targeted specie emerged in the country's[3,4]. The Indian mackerel fishing season starts in September in Pakistan. The data show that the total landing of Indian mackerel increased from 23000 MT in 2010 to 33000 MT in 2018 (Table 1). However, this dramatic increase in their catches has lost the economic benefit over the past decade. With the whole term overfishing, the good quality Indian mackerel catches are significantly being lost. The economic cost of resources is relative to size as larger stocks take larger price[1].

The necessity and status of this research depend on fishing stocks in Pakistan's seawater, and since most of the fisheries stocks have been exaggerated and overexploited, leading to a decline in the production of marine fishing output[3,4]. Therefore, it is, enormously important to examine the status of important commercial fish stocks in Pakistan's coastal waters. Many researchers have worked on other fisheries in Pakistan and adopted several regulatory measures to maintain a single fishery resource. The evaluation of the fishery stock assessment of *Megalaspis cordyla* is in a state of excessive exploitation in Pakistani seawater[43]. The estimated MSY range of *M. cordyla* in Pakistan's seawater was 1300 – 3300 MT per year, which should be considered as TRP, the projected LPR is 4048 MT, and it is recommended to reduce the catch to MSY level. Mohsin *et al.*[7] pointed out that over time, Pakistan's seafood exports have been increasing, so maximum efforts are being made to catch commercially important fish[4]. Therefore, in this situation, it becomes extremely important to assess the fishery stocks of commercially valuable fish on a global scale. There have been no written records of the world for Indian mackerel fishing status on the catch and abundance index as well as in Pakistan. This shows the importance of evaluating this study and the economic impact management measures, which is the first attempt by Pakistani waters fisheries.

Conclusion and management implications for the Indian mackerel

Conclusion

In line with the conclusion, delivered results for the 16-year assessment of the Indian mackerel fishery (2003 – 2018), by international stock evaluation tools CEDA and ASPIC with relative corresponding errors in SPMs, the obtained and managed results of the main key parameter estimates (non-bootstrapping) are 10910 – 17637 (MT) and 14960 – 18380 (MT). The scope of EAs agrees to be overfished due to the maximum catch of 38504 MT in 2006 and the most recent catch of 33658 MT in 2018, indicating that fishery stock of Indian mackerel in Pakistan's seawater is overexploited. Besides, it can also be determined according to TRP that CEDA and ASPIC estimate the range of MSY results to be approximately 11000 – 18000 MT and 15000 – 18000 MT. However, the fishing of 28786 MT of this fishery resource should be regarded as LRP, based on these reasons of reference points fishing rates significantly high F_{MSY} than B_{MSY} is considered unfavourable economically and ecologically to their fishing industry and resources, which will cause huge economic losses.

Management implications

Considering the importance of the fisheries sector, there are about 150 varieties of commercial fish stock in Pakistan. Most of them are exported, Indian mackerel, shrimps, ribbon-fish, tuna, sole, crabs, etc. (USD 293.887 million in 2018 – 19), as well as for use as feed-in poultry locally. Pakistan has a greater capacity for fishing in the northern waters, while this capacity remains poor in the deep sea, which prevents the country from utilizing its total capacity. The FAO concluded a report on Pakistan's maritime resources, adding that all findings of the study were of considerable concern. During the past 30 years, almost all economically valuable stocks have declined in biomass. This was partly due to the widespread exploitation of fisheries resources. The study recommended a 50 % reduction in fishing efforts from the current level on a sustainable basis. This is not an easy task in case of over-exploitation of the fisheries resource. Immediate restrictions may be imposed for new entrants and alternative vessel strategies can be adopted to modernize and reduce the fleet to the desired extent and limit. Such catches and fishing efforts should be managed in such a way that the stock can be kept at the level of biomass and MSY can be harvested without damaging the stock. Therefore, there is a need to involve fisheries managers in a special way to restore Pakistan's fisheries, since long-term economic component can protect fish resources of Pakistan. To avoid large national economic losses, try to take advantage of fishing and exploit a fair amount of fish, against mesh size and illegal nets, policy frameworks, and law enforcement regulations. The hard and fast steps must be taken for the commercial and economic value of the fisheries.

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Conflict of Interest

The authors declare that they have no competing or conflicts of interest to influence the work reported in this paper.

Author Contributions

Conceptualization, formal analysis, funding acquisition, investigation, resources, software, supervision, roles/Writing - original draft, and writing: AM & MY; Review & editing: MTK, SBH, MSC, MRM, OK & MAM.

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