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Research Paper

Comparative study of stock status and sustainable management of *Pomadasys olivaceus* fishery along Pakistan coast*

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Abstract Fish stock assessment is essential for ensuring the sustainable utilization of marine resources. We evaluated the stock status of the *Pomadasys olivaceus* along both the Balochistan and Sindh coasts of Pakistan using Catch-based Monte Carlo Maximum sustainable yield (CMSY), Bayesian Schaefer model (BSM), and a stock production model incorporating covariates (ASPIC) models based on catch and effort data from 2000 to 2022. Results from all models indicate the B/B_{MSY} (relative biomass) values were below 1.0 and F/F_{MSY} (fishery exploitation) values>1, indicating that the stock is severely overfished in both regions. The estimated maximum sustainable yield (MSY) from the CMSY and BSM methods ranged between 2 440–2 670 metric tons (mt) for Balochistan and 2 430–2 650 mt for Sindh. The ASPIC model (Fox and Logistic) also indicated overexploitation, with MSY estimates of 1 585 mt (Fox) and 1 379 mt (Logistic) for Balochistan, showing critical stock depletion. In contrast, MSY estimates from Sindh were 3 260 mt and 3 024 mt, suggesting stock condition was not over fished. These findings offer a scientific basis for the formulation of targeted management and conservation strategies by the government, particularly emphasizing urgent intervention for the Balochistan coast to ensure the long-term sustainability of the *P. olivaceus* fishery.

Keyword: maximum sustainable yield; *Pomadasys olivaceus*; Sindh; Balochistan; Catch-based Monte Carlo Maximum sustainable yield (CMSY); Bayesian Schaefer model (BSM); ASPIC

1 INTRODUCTION

Assessing the stock status and associated biological reference points (BRPs) is crucial to ensure their long-term sustainable utilization. BRPs serve as critical benchmarks for fisheries management, guiding decision-making processes aimed at maintaining fish populations at sustainable levels. To establish these reference points, fisheries scientists employ statistical models to evaluate the health and productivity of fish stocks (Afzaal et al., 2016, 2018; Al-Mamun et al., 2022). According to Food and Agriculture Organization of the United Nations (FAO, 2018), approximately one-third of the world's assessed fisheries are currently

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overfished. However, Lam and Pauly (2019) reported that nearly half of the global fish populations have either collapsed or are being excessively exploited. The primary objective of fisheries management is to achieve a balanced integration of ecological sustainability, economic profitability, and social welfare in the use of marine resources. The objectives require a comprehensive assessment of both the current status and future exploitation potential of fish stocks, using a combination of biological indicators and economic criteria (Albertsen and Trijoulet, 2020). Globally, fisheries have undergone various phases of development, yet mismanagement has resulted in nearly 50% of them being either overexploited or fully collapsed (Froese and Kesner-Reyes, 2002). These failures have led to significant socioeconomic consequences for millions of people who rely on fisheries for their livelihoods, which have negatively affected global food security and marine biodiversity. Increasing fishing pressure and indiscriminate exploitation have further exacerbated the situation, leading to adverse effects on fish populations and their habitats. Consequently, there is growing concern worldwide about the future viability of marine fisheries (Mora et al., 2009). The situation is particularly dire in developing countries, where a lack of regulatory and inadequate management measures, alongside widespread illegal exploitation of juvenile and breeding fish, prevail in fisheries (Froese et al., 2004; Jabado et al., 2017).

Pakistan's exclusive economic zone (EEZ) covers approximately 299 000 km^2 extending 350 nautical miles (~648.2 km) into the northern Arabian Sea, situated along the coastlines of Balochistan and Sindh (Pakistan Navy, 2016) (Fig.1). Pakistan coast stretches approximately 1 001 km from its southeastern border with India to

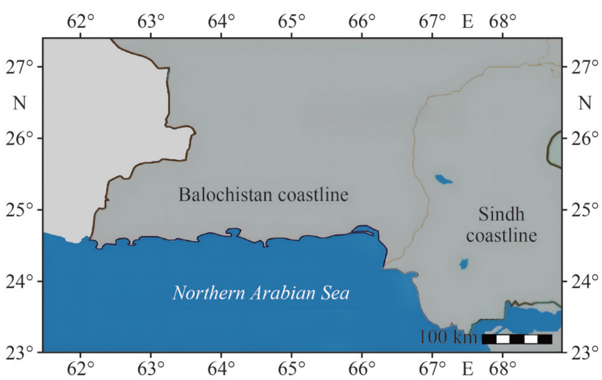

Fig.1 The map represents both coastlines of Balochistan and Sindh in Pakistani marine waters

the northwestern border with Iran (Pakistan Navy, 2016). The largest fish harbor in Sindh located is Karachi, which accommodates 80%–90% of the industrial fishing fleet, consisting of primarily trawlers and larger gillnetters. The remaining larger vessels and major landing sites are situated along the Balochistan coast, with Pasni and Gwadar contributing to over 75% of the provincial landings. Traditional gears such as gillnets, cast nets, handlines, and longlines are still widely employed by the small-scale artisanal fishing industry. Pakistan's marine fisheries are notably diverse, comprising approximately 150 commercially important fish species. Recent studies on several commercially important fish species, including tuna, mackerel, and croakers, have revealed that these stocks are heavily exploited and subject to significant fishing pressure (Baloch et al., 2020, 2025; Kalhoro et al., 2024a, b). In earlier assessments, various surplus production models were employed to evaluate individual fish stocks, leading to the formulation of specific management strategies (Afzaal et al., 2016, 2018; Kalhoro et al., 2017; Nadeem et al., 2017; Razzaq et al., 2019). Similar approaches have been applied to various fish species in different regions, including Bangladesh (Barua, 2019; Barua et al., 2023) However, significant expansion in fleet size and increased mechanization since the last stock assessments (2009–2016) have contributed to the depletion of marine resources. The continuous decline in fish stock strongly indicates a persistent state of overexploitation, underscoring the urgent need for improved management and conservation measures (Fanning et al., 2011; Kalhoro et al., 2025).

Despite contributing less than 0.4% to the nation's GDP, the maritime fishery industry holds significant economic importance for coastal communities in Sindh and Balochistan. Fish production peaked in the early 1990s, and it has steadily declined since 2000, with marine capture fisheries yielding around 360 000 metric tons (mt) by 2015. Unfortunately, except for a few species exhibiting low fishing mortality and potential for sustainable exploitation, most fish stock have been subjected to over-exploited (Patil et al., 2018). Sindh and Balochistan represent the two coastal provinces of Pakistan, each with distinct geographic and ecological characteristics. Sindh's coastal shelf, covering around 35 700 km^2, is broader and characterized by muddy and sandy, while Balochistan's coastal shelf, spanning about 14 500 km^2, is narrower and lacks estuaries (Roonjha et al., 2021). Sindh, a province in Pakistan, has formulated a fisheries policy aimed at sustainable management and development of its fisheries resources (Roonjha et al., 2021). The policy likely focuses on strategies to ensure sustainable utilization of fisheries resources, including measures to prevent overfishing and habitat degradation. Regulations governing fishing practices of licensing are used to maintain order and prevent illegal fishing activities. Similarly, Balochistan also has its fisheries policy tailored to its specific needs and challenges, key components may include seasonal closures and gear restrictions. Collectively, the fisheries policies of Sindh and Balochistan aim to balance economic development with environmental conservation, striving for sustainable fisheries management to benefit present and future generations (Khan and Khan, 2021).

The family Haemulidae consists of 138 species across 23 genera globally (Fricke et al., 2024). These species predominantly inhabit marine, brackish, and demersal environments, typically depths up to 50 m (Psomadakis et al., 2015). In Pakistani waters, the family is represented by several groups, including grunts, sweetlips, rubberlips, and hotlips. Among them 10 species of grunts have been recorded: *Pomadasys argenteus*, *P. bayanus*, *P. commersonni*, *P. kaakan*, *P. macracanthus*, *P. maculatus*, *P. multimaculatum*, *P. olivaceum*, *P. opercularis*, and *P. stridens* with the largest individuals reaching up to 100 cm in size (Fanning et al., 2015). These species fishes are typically associated with coral reef habitats, as well as muddy or weedy coastal areas, and are commonly captured using bottom trawls and gillnets (Bianchi, 1985; Moazzam et al., 2006). Grunts are benthic feeders, primarily consuming invertebrates and small fishes. They hold significant commercial value in Pakistan, both for local consumption and export markets particularly in the Middle East, Far East, and Europe (Fanning et al., 2015). The main fishing season for Haemulidae species in Pakistan spans from August to March, with reduced catches reported during the remaining months (Bianchi, 1985; Moazzam et al., 2006). Grunts contribute approximately 70% of the total Haemulidae catch, while sweetlips contribute for the remaining 30% (Fanning et al., 2015).

The Olive grunt (*Pomadasys olivaceus*) (Day, 1875) is a commercially significant demersal fish species in Pakistan, contributing around 5% of the total catch weight from 2008 to 2011 (Fanning et al., 2015). This fish geographically widespread in tropical waters, ranging from the southeast Atlantic to the Indian Ocean and the Malay Peninsula (Heemstra, 1995). This species inhabits marine, brackish, and reef-associated regions at depths ranging from 1 to 50 m (Jawad et al., 2014). It reaches maturity at 15 cm in length and can grow up to 55 cm (Roux, 1986). The species follows an oviparous reproductive strategy and typically spawns annually (Smith and McKay, 1986; Froese and Pauly, 2024).

This study aims to evaluate the maximum sustainable yield (MSY) of the demersal fish species Olive grunt (*P. olivaceus*) in the coastal areas of Balochistan and Sindh, Pakistan. While previous biological studies on *P. olivaceus* have been conducted in Spain (Pajuelo et al., 2003; Bañón et al., 2014) and Indonesia (Mous et al., 2020, 2021), comprehensive stock assessments for this species within Pakistan remain absent. Despite its considerable commercial importance both domestically and internationally, recent catch data indicate a decline trend, underscoring the need for rigorous stock evaluation. This research represents the first comprehensive assessment of the stock status of *P. olivaceus* in marine ecosystems of Pakistan. The lack of prior stock assessments presents significant challenges to sustainable management and conservation efforts in the region. The objectives of this study include estimating the MSY, biomass via the CMSY (catch-MSY) method, exploitation rates, and other BRPs for *P. olivaceus* in the target regions. To achieve these goals, three modeling approaches, CMSY, Bayesian Schaefer model (BSM), and a stock production model incorporating covariates (ASPIC) model were applied. The outcomes of this study provide essential information for fishery managers to implement sustainable harvesting strategies and ensure long-term conservation of *P. olivaceus* stocks. Notably, the advantage of the CMSY method lies in simplicity, enabling estimation of crucial parameters such as biomass, exploitation rate, and MSY solely from catch time series and qualitative information, without reliance on fisheries-independent datasets. Additionally, this research provides an opportunity to enhance understanding of the latest techniques for estimating fisheries reference points using catch and effort time series data in Pakistan.

2 MATERIAL AND METHOD

2.1 Study region

The coastlines of Sindh and Balochistan provinces show a notable variation in the extent of their continental shelf areas. The seaward coastal zone up to 12 nautical miles from the shoreline, is essentially under the jurisdiction of these two provinces. (Fig.1).

2.2 Data source

The time-series data of the catch and fishing effort of *P. olivaceus* from the eastern (Sindh) and western (Balochistan) Arabian Sea coast of Pakistan was collected from 2000 to 2017 through the Marine Fisheries Department (MFD), Government of Pakistan. Additional catch and effort data from 2018 to 2022 were obtained from Statistical year book compiled by both the Balochistan Fisheries Department, Government of Balochistan, and the Marine Fisheries Department, Government of Pakistan (MFD, 2017, 2021). The catch record is measured in metric tons-live weight (mt), and the fishing effort is quantified as the number of fishing vessels, including trawlers, gill netters, and trolling boats, operating within Pakistani waters. These fishing vessels are active in the territorial waters of Pakistan's EEZ. The fleet consist of mechanized and semi-industrial vessels (over 16.76 m in length), mechanized boats (fitted with outboard engines), and non-mechanized boats. Overall, this study utilizes 23 years of landing data (from 2000 to 2022) to analyze the catch and effort data of *P. olivaceus*, which is a major species in Pakistan (Fig.2).

2.3 Catch and effort data of *P. olivaceus* fishery

Catch and effort data of the *P. olivaceus* fishery in Pakistan from 2000 to 2022 are shown in Fig.2. The total number of registered and operational trawlers, gillnets, and sailboats equipped with outboard motors in the maritime regions of Pakistan has been recorded. From Balochistan and Sindh, the maximum catches of *P. olivaceus* were reported as 6 592 mt (2005) and 4 901 mt (2004) respectively. The average and minimum catch for Balochistan were 2 449±1 140 and 989 mt (2014), while for Sindh were 2 095±1 340 and 399 mt (2013) respectively. The highest, lowest and average CPUE (mt/boat) from the Balochistan and Sindh coasts were 4.998, 0.417, 1.669±0.997 mt/boat, and 8.141, 0.327, and 2.749±2.308 mt/boat noted respectively. Predict yields from Balochistan and Sindh were estimated using ASPIC model (Fig.2). Throughout the study period, the maximum, minimum and average effort (number of boats) were recorded

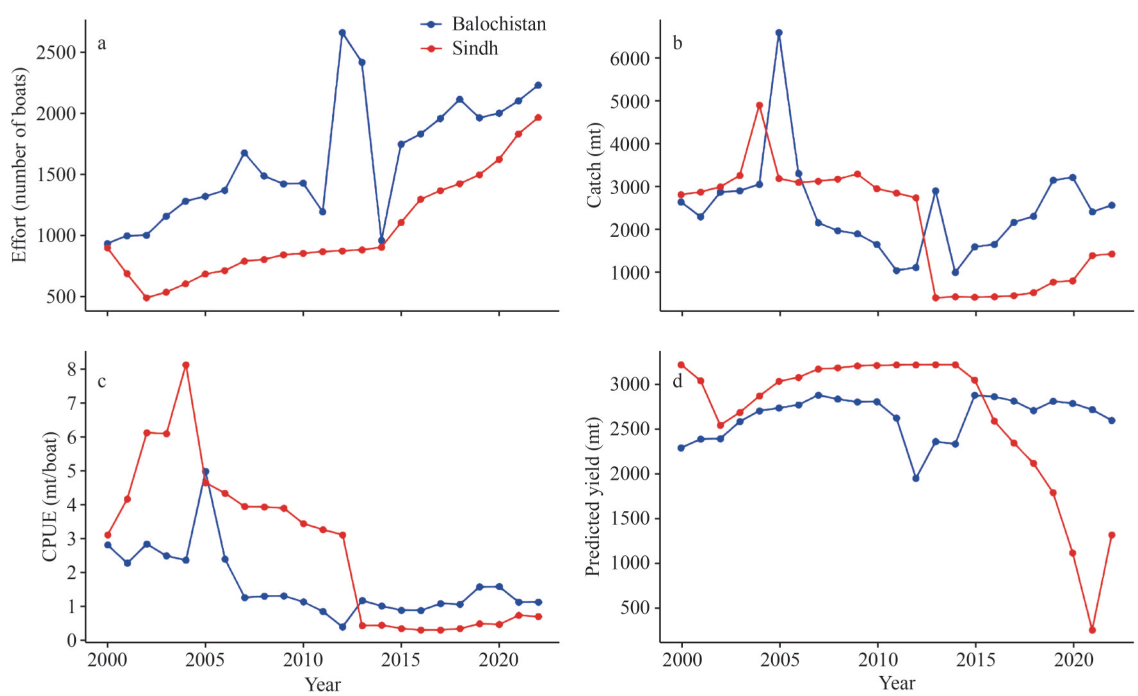

Fig.2 The *P. olivaceus* fishery showing variations in fishing effort (number of boats), catch (mt), CPUE (mt/boat), and predicted yield (mt) from 2000 to 2022 along Balochistan and Sindh, Pakistan

2 663 (2012), 932 (2000), 1 619±498 and 1 965 (2022), 487 (2002), 1 022±414 for Balochistan and Sindh coasts respectively.

The catch per unit effort (CPUE) or abundance index can be calculated by:

$$\text{Abundance index (CPUE)}=C/f, \tag{1}$$

where C is the weight of fish catches and f the number of fishing boats.

2.4 Catch-based Monte Carlo method (CMSY)

The CMSY approach (Martell and Froese, 2013; Froese et al., 2017), is a modified version of the catch-at-MSY method, inspired by the modeling framework of stock reduction analysis (SRA) (Kimura, 1985). Although SRA does not formally fall under production models, it employs a similar methodology. By applying annual catches that are reported in terms of species weight and catch equations in exponential form, SRA offers a unique approach to estimating the sustainability curve (Kimura et al., 1984). The often-used techniques for evaluating and managing fishery stocks are surplus production models. Due to their simplicity of use, these models only needed a small amount of data to estimate the important fisheries reference points such as MSY, biomass, depletion level, and optimal fishing effort (Bonfil et al., 2005). The CMSY method, based on species catch data and resilience information, offers an alternative tool for estimating of the technical reference points. In this study, the CMSY approach was employed to assess the stock status of *P. olivaceus* fishery and evaluate its sustainability in Pakistan.

According to Schaefer (1954), fish population dynamics are modelled:

$$B_{t+1}=B_{t+r}(1–B_t/k)B_t–C_t. \tag{2}$$

The exploited biomass in the year (t+1) is B_{t+1}, while the existing biomass and catch in year t is B_t and C_t, correspondingly; r is the intrinsic population growth rate and k is carrying capacity.

According to FishBase (2015, www.fishbase.org) and Froese et al. (2017), the prior standard r-ranges of *P. olivaceus* are 0.2–0.8 used in current study. The prior range for k can be determined using the following Eqs.3 & 4 (Froese et al., 2017).

$$k_{\text{low}}=\max(C)/r_{\text{high}};\ k_{\text{high}}=4\max(C)/r_{\text{low}}, \tag{3}$$

$$k_{\text{low}}=2\max(C)/r_{\text{high}};\ k_{\text{high}}=12\max(C)/r_{\text{low}}, \tag{4}$$

where k_{low} and k_{high} are lower and upper limits of the carrying capacity k. Equation 3 is for the stocks with low prior biomass, while Eq.4 is applied to the stocks with higher prior biomass at the end of the given time series dataset.

To minimize the effect of extreme catch values, the data were smoothed by employing a 3-year moving average (Froese and Pauly, 2015; Froese et al., 2017). Three different biomass ranges are low (0.01–0.4), medium (0.2–0.6), and high (0.5–0.9) (Table 1).

2.5 Bayesian Schaefer method (BSM)

Bayesian state-space surplus production models (BSM) incorporate the additional knowledge of the relative abundance CPUE (Meyer and Millar, 1999; Best and Punt, 2020). The catchability coefficient q can be used to express an abundance index using following Eq.5:

$$\text{CPUE}_t=qB_t, \tag{5}$$

CPUE_t, B_t, and q denoted the catch per unit of effort, biomass, and catchability coefficient, respectively. The basic Schaefer production model can be changed using the abundance index CPUE (Eq.6) (Froese et al., 2017).

$$\text{CPUE}_{t+1}=\text{CPUE}_{t+r}(1–(\text{CPUE}_t/qk))\text{CPUE}_t–qC_t. \tag{6}$$

The higher and lower prior of catchability q for past higher biomass could be expressed by Eqs.7 & 8:

$$q_{\text{low}}=0.25r_{\text{pgm}}(\text{CPUE}_{\text{mean}}/C_{\text{mean}}), \tag{7}$$

$$q_{\text{high}}=0.5r_{\text{high}}(\text{CPUE}_{\text{mean}}/C_{\text{mean}}), \tag{8}$$

where q_{high} and q_{low} are the upper and lower priors for the catchability coefficient q. Parameter r_{pgm} and r_{high} are the mean and high prior range for r, and $\text{CPUE}_{\text{mean}}$ and C_{mean} are the mean catch per unit of effort and mean catch for the past 15 years. When the stocks have low past prior biomass, multipliers are changed below (Eqs.9 & 10):

$$q_{\text{low}}=0.5r_{\text{pgm}}(\text{CPUE}_{\text{mean}}/C_{\text{mean}}), \tag{9}$$

$$q_{\text{high}}=1.0r_{\text{high}}(\text{CPUE}_{\text{mean}}/C_{\text{mean}}). \tag{10}$$

The mean catch per unit of effort ($\text{CPUE}_{\text{mean}}$) and mean catch are taken for the last 10 years.

Table 1 Suggested prior biomass ranges of *P. olivaceus* in Pakistan under assessment

Stock	B_{start}/k	B_{int}/k	B_{end}/k
P. olivaceus	0.2–0.6	0.2–0.6	0.5–0.9

B_{start}/k: initial biomass estimate of the fish stock; B_{int}/k: updated biomass after natural and fishing mortality; B_{end}/k: final biomass used to assess stock status and set future catch limits.

2.6 A stock production model incorporating covariates (ASPIC)

ASPIC version 5.0 (Prager, 2016) is tailored for non-equilibrium surplus production models, offering two types: Fox and Logistic (a variant of GENFIT). While ASPIC typically requires an initial proportion (IP) of starting biomass relative to carrying capacity (B_1/k ratio), it is not mandatory. The study used calculated IP values (0.4 and 0.6) for the Balochistan and Sindh, and also applied a range of IP values (0.1–0.9) to evaluate variations in stock biomass estimates. The key output parameters include MSY, q, k, and fishing mortality at maximum sustainable yield (F_{MSY}), crucial for determining maximum sustainable yield and optimum fishing effort. By employing ASPIC, two non-equilibrium stock production models can evaluate Biological Reference Points (BRPs), gaining valuable insights into fisheries dynamics across different scenarios. The logistic population growth model is represented by Eq.11, while the Gompertz growth (Eq.12) is associated with Fox's model (Schaefer, 1954).

$$\mathrm{d}B/\mathrm{d}t=rB(k–B), \tag{11}$$

$$\mathrm{d}B/\mathrm{d}t=rB(\ln k–\ln B). \tag{12}$$

3 RESULT

3.1 CMSY and BSM outcomes from Balochistan and Sindh

The CMSY and BSM models were employed to estimate key fisheries reference points (r, k, MSY, and B/biomass at maximum sustainable yield (B_{MSY}), F/F_{MSY}) to assess the stock status of *P. olivaceus* fishery along the Balochistan and Sindh coasts. For Balochistan, the CMSY model produced following estimates r=0.384 (0.244–0.602), k=28 900 (19 900–42 000), MSY=2 440 (1 890–3 050). The BSM models results were r=0.265 (0.142–0.495), k= 4 010 (2 410–6 650), MSY=2 430 (1 790–3 290). Similarly, for Sindh the CMSY estimated r=0.378 (0.239–0.596), k=29 200 (20 400–41 700), MSY= 2 670 (2 090–3 590), while the BSM model yielded r=0.282 (0.148–0.495), k=4 110 (2 430–6 660), MSY= 2 650 (1 720–4 090) (Table 2). Both models provided reliable estimations for evaluating fishing mortality and enhancing fishery management for *P. olivaceus*. The Analysis showed $B_{2022}/B_{\mathrm{MSY}}$ values below 1, confirming that *P. olivaceus* stocks are overexploited in both regions (Table 2). The schematic plots generated through BSM analysis illustrated the patterns in the catch, stock size, exploitation, and F/F_{MSY} along the Balochistan and Sindh coast in Pakistan (Fig.3). Catch exhibited an upward trend over time, while stock size showed a decline. The exploitation rate of *P. olivaceus* has been steadily increasing. CMSY estimated $F_{2022}/F_{\mathrm{MSY}}$ at 2.1 for Balochistan and 1.99 for Sindh, while BSM yielded 1.481 and 1.546 respectively,

Table 2 Determination of the estimated fisheries reference points (*r*, *k*, MSY, *B*/*B*$_{\mathrm{MSY}}$, *F*/*F*$_{\mathrm{MSY}}$) and the status of fish stock *P. olivaceus* in exploited fisheries along Pakistan's Coast using the CMSY and BSM approaches

P. olivaceus		Balochistan coast	Sindh coast
CMSY	r	0.384	0.378
		(0.244–0.602)	(0.239–0.596)
	k	28 900	29 200
		(19 900–42 000)	(20 400–41 700)
	MSY	2 440	2 670
		(1 890–3 050)	(2 090–3 590)
	$B_{2022}/B_{\mathrm{MSY}}$	0.238	0.084
		(0.149–0.392)	(0.163–0.392)
	$F_{2022}/F_{\mathrm{MSY}}$	2.1	1.99
	B_{MSY}	12 600	14 600
		(87 100–18 200)	(10 200–20 800)
	B_{2022}	6 880	2 440
		(3 780–9 940)	(1 290–5 140)
BSM	r	0.265	0.282
		(0.142–0.495)	(0.148–0.495)
	k	4 010	4 110
		(2 410–6 650)	(2 430–6 660)
	MSY	2 430	2 650
		(1 790–3 290)	(1 720–4 090)
	$B_{2022}/B_{\mathrm{MSY}}$	0.349	0.122
		(0.226–0.660)	(0.321–0.628)
	$F_{2022}/F_{\mathrm{MSY}}$	1.481	1.546
	B_{MSY}	14 500	20 000
		(1 010–2 070)	(1 210–3 330)
	B_{2022}	5 060	2 440
		(4 480–1 140)	(1 290–5 140)
Stock status		Strongly overfished	Strongly overfished

Units of r and F are per year, k, MSY, and B are mt. The stock status is based on Palomares et al. (2018) and Froese et al. (2018).

indicating overfishing in both regions (Table 2). The stock size of this fishery has been declining since 2000, while the fishing mortality rate has been on the rise since 2005. The current fishing mortality rate is 1.5 times higher than the target rate, and the stock size is 40% below the target. If the current fishing pressure continues, further decline is expected. The data points on the graphs demonstrate the negative impact of fishing activities on the population size of *P. olivaceus*, emphasizing the need for informed decisions to promote sustainable fishing practices. Stakeholders can use the trends shown in the graphs (Fig.3) to work towards maintaining healthy fish populations and preserving marine ecosystems for this species.

Figure 4 depict the Kobe plot results of *P. olivaceus* in Balochistan and Sindh, Pakistan. This plot visually represents the relationship between relative exploitation and relative biomass of the fishery, with color-coded zones indicating

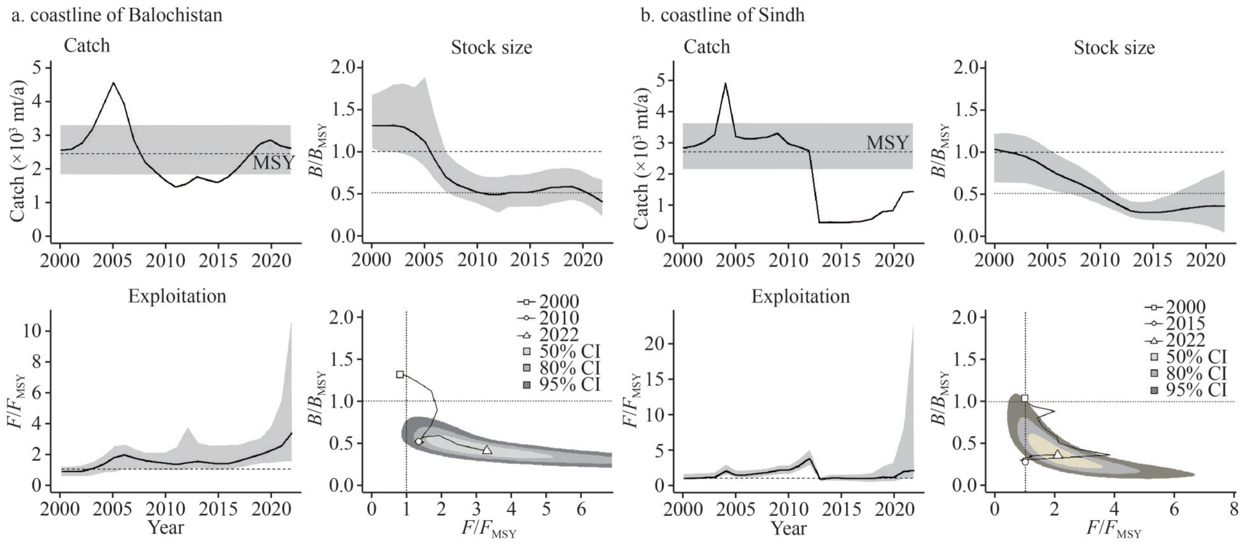

Fig.3 Schematic plots based on BSM analysis for the *P. olivaceus* fishery along the coast of Balochistan and Sindh, Pakistan, illustrating the relative biomass (B/B_{MSY}) and exploitation (F/F_{MSY})

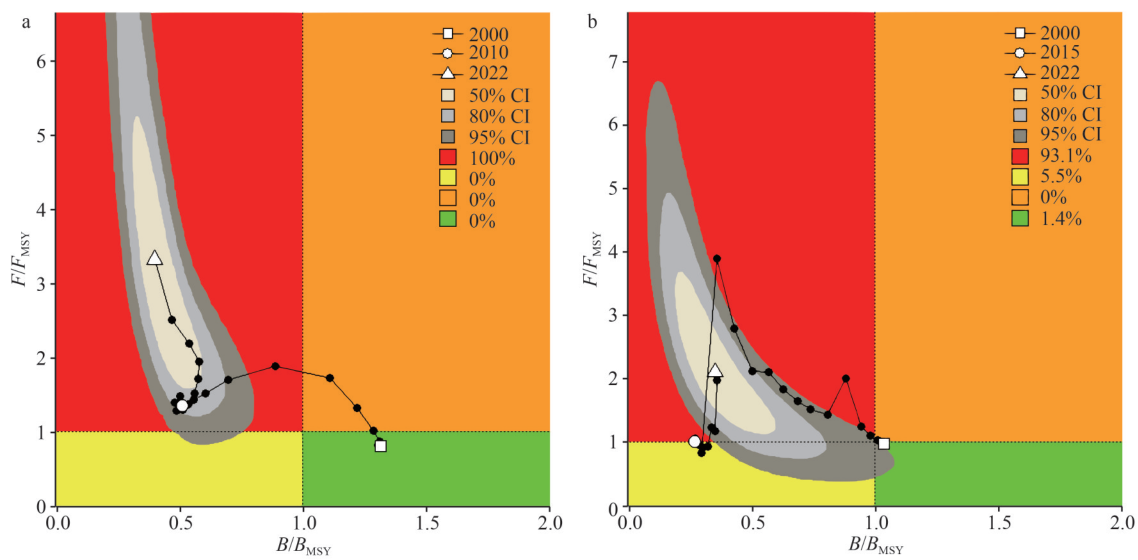

Fig.4 Kobe plot diagram of relative biomass and exploitation estimation of *P. olivaceus* fishery from Pakistan during 2000–2022 for Balochistan (a) and Sindh (b)

The dots represent the estimated biomass relative to B_{MSY} (B/B_{MSY}), while the triangles indicate the highest fishing mortality relative to F_{MSY} (F/F_{MSY}) during last years. The 95% confidence intervals, reflecting the uncertainty in the estimates. The squares: the initial biomasswhite circles: middle catch, triangles: last year catch, and black dotted lines: annual catches.

the health status of the stock. The green area represents the safe zone of the fishery, where sustainable fishing pressure and healthy biomass generate MSY. The orange zone indicates biomass nearing overfishing due to intense fishing pressure. The red region represents depleted stock biomass that is unable to produce MSY due to continuous over-exploitation. The yellow zone indicates the stock's recovery phase, characterized by reduced fishing pressure. The stock variation is shown as a black line, with the square and triangle indicating the initial (2000) and last year (2022) biomass. The estimated values for fishery management of B_{2022}/B_{MSY}=0.349 (0.226–0.660) and 0.122 (0.321–0.628) indicate that the *P. olivaceus* fishery is severely overfished in Pakistani waters (Table 2; Fig.4).

3.2 ASPIC outcome from Balochistan and Sindh

The results from the ASPIC software are presented in Tables 3 and 4, including key output parameters such as MSY (maximum sustainable yield), CV (coefficient of variation), R^2 (goodness of it), B_{MSY}, and F_{MSY}. A higher R^2 value of 0.5 indicates a better fit. The key parameters using initial proportion (IP) values of 0.4 and 0.6 in the ASPIC for Balochistan and Sindh were estimated (Table 3). The MSY values for FM (Fox model) and LM (Logistic model) were determined to be 1 585, 1 379, 3 260, and 3 024 mt, respectively. The R^2 values indicated a goodness of fit model for FM in Sindh (R^2>0.686) compared to LM in Balochistan (R^2=0.360). Table 4 displays the IP values ranging from 0.1 to 0.9 generated by different parameters in the ASPIC software. Notably, larger MSY values were obtained with smaller IP input values, highlighting the sensitivity of the model to different IP inputs. Furthermore, it was observed that FM exhibited greater sensitivity compared to LM, being consistent with the findings in Table 3.

4 DISCUSSION

The effectiveness of catch-only models in data-poor stock assessments and fisheries management demonstrates their capacity to infer and predict key aspects of stock status. These models estimate critical, often unobservable parameters, such as MSY, using available data, much like traditional statistical stock assessment models. Inference, in this context, refers to the ability of catch-only models to generate reliable estimates of these parameters. Their practical value to management depends on the accuracy and robustness of these estimates. The utility of these models is ultimately determined by the accuracy, robustness, and consistency of their input and outputs in guiding sustainable fisheries management (Ovando et al., 2022). The BSM model is based on Bayesian state-space modeling, and the CMSY approach are both widely used to estimate fisheries reference points. These methods can reliably estimate standard benchmarks such as MSY=$rk/4$, F_{MSY}=0.5r, and B_{MSY}=0.5k, provided that historical catch data have adequate quality and are appropriately selected (Froese et al., 2017). However, a key challenge in the Bayesian estimation of stock status lies in managing the uncertainty inherent in model outputs, particularly when informing policy and providing scientific advice on exploitable biomass trends over time. As emphasized by Brodziak et al. (2011), such uncertainties necessitate the adoption of precautionary management approaches to safeguard fishery resources and ensure long-term substantiality.

The catch and effort data of the demersal *P. olivaceus* were analyzed using two surplus production models: the Fox model (Fox, 1970) and the Logistic model (Schaefer, 1954). These models aim to determine the key management benchmarks such as optimum fishing effort and MSY. Required inputs include CPUE data and the total landed catch,

Table 3 The ASPIC estimates (non-bootstrapped) using calculated IP values (0.4 and 0.6) for *P. olivaceus* fishery from Balochistan and Sindh, Pakistan

Model	IP	R^2	k	q	MSY (mt)	B_{MSY}	F_{MSY}	CV
				Balochistan				
Fox	0.4	0.360	37 840	6.01E-05	1 585	13 920	0.114	0.01
Logistic	0.4	0.348	40 320	5.43E-05	1 379	20 160	0.068	0.139
				Sindh				
Fox	0.6	0.731	44 110	6.27E-04	3 260	16 230	0.201	0.046
Logistic	0.6	0.728	12 850	7.55E-04	3 024	6 424	0.471	0.095

Table 4 The ASPIC results using IP=0.1−0.9 for *P. olivaceus* fishery from the northern Arabian Sea coast of Balochistan and Sindh, Pakistan

Model	Parameter	Balochistan								
	IP	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Fox model	R^2	0.339	0.349	0.338	0.360	0.363	0.350	0.338	0.339	0.336
	k	59 330	47 500	59 330	37 840	37 840	47 480	59 330	59 330	59 330
	q	3.92E-05	3.76E-05	3.93E-05	6.01E-05	6.01E-05	3.76E-05	3.92E-05	3.92E-05	3.76E-05
	MSY	1 047	1 555	1 046	1 585	1 049	1 553	1 049	1 045	1 043
	B_{MSY}	21 830	17 470	21 830	13 920	13 920	17 470	21 830	21 830	21 830
	F_{MSY}	0.048	0.089	0.048	0.114	0.114	0.089	0.048	0.048	0.048
	CV	0.225	0.225	0.208	0.010	0.307	1.483	0.225	0.194	0.297
Logistic model	R^2	0.341	0.342	0.332	0.348	0.313	0.384	0.347	0.342	0.331
	K	49 100	49 030	59 330	40 320	98 960	13 250	40 040	49 080	59 330
	q	3.76E-05	3.76E-05	3.76E-05	5.43E-05	4.56E-05	3.79E-04	5.44E-05	3.76E-05	3.59E-05
	MSY	1 185	1 189	898	1 379	1 251	2 884	1 385	1 185	883
	B_{MSY}	24 550	24 510	29 660	20 160	49 480	6 626	20 020	24 540	29 660
	F_{MSY}	0.05	0.049	0.030	0.068	0.025	0.435	0.069	0.048	0.030
	CV	1.109	0.949	0.315	0.139	0.231	0.036	0.126	1.473	0.263
		Sindh								
Model Parameter										
	IP	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Fox model	R^2	0.763	0.740	0.761	0.760	0.741	0.731	0.721	0.757	0.725
	K	44 110	44 110	44 110	44 110	44 110	44 110	44 110	44 110	44 110
	q	7.07E-04	6.20E-04	6.89E-04	6.79E-04	6.37E-04	6.27E-04	6.15E-04	6.73E-04	6.22E-04
	MSY	3 597	3 297	3 551	3 523	3 333	3 260	3 189	3 494	3 221
	B_{MSY}	16 230	16 230	16 230	16 230	16 230	16 230	16 230	16 230	16 230
	F_{MSY}	0.222	0.203	0.219	0.2171	0.205	0.201	0.197	0.215	0.199
	CV	0.052	0.074	0.052	0.050	0.049	0.046	0.047	0.040	0.047
Logistic model	R^2	0.702	0.746	0.783	0.794	0.649	0.728	0.688	0.643	0.599
	K	53 640	25 880	16 130	1.33E+04	4 574	12 850	12 100	12 810	12 780
	q	6.59E-04	7.26E-04	8.30E-04	8.57E-04	2.40E-03	7.55E-04	7.61E-04	6.98E-04	6.78E-04
	MSY	8 402	4 781	3 706	3 312	3 548	3 024	2 991	2 906	2 871
	B_{MSY}	26 820	12 940	8 063	6 664	2 287	6 424	6 051	6 404	6 392
	F_{MSY}	0.313	0.370	0.460	0.497	1.551	0.471	0.494	0.454	0.449
	CV	0.005	0.003	0.001	0.041	0.005	0.095	0.102	0.120	0.128

while age structure data are not required for these models (Mehanna and El-Gammal, 2007; Haddon, 2011). Surplus production models operate on the principle of depletion, which refers to the reduction in stock abundance indicators caused by the fishing pressure. Accurate estimation of stock parameters using these models requires consistent and long-term records of catch and effort data (Maunder et al., 2006). Typically, when the surplus production of the stock exceeds the catch, it signifies growth in population size; when the catch matches the surplus production, the catch is sustainable and the population size remains stable. However, if the catch surpasses the surplus production, the population size will decrease, indicating overfishing (Hoggarth et al., 2006).

Pakistan marine resources are under immense pressure and require urgent, sustainable conservation measures to protect the fish stocks. The overfishing issue highlights a lack of effective management and regulation in the fisheries sector. According to the FAO's fisheries stock assessment report for Pakistan in 2015, marine resources are being overexploited due to the continuous increase in fishing efforts, leading to an ecological disaster (Fanning et al., 2015). Findings from present study support this observation, as it reveals that in 2005, a higher fishing effort of 1 319 boats resulted in a greater yield of 6 592 mt in Sindh, which is the highest in the dataset. In contrast, fishing efforts of 932 boats and 898 boats in 2000 in Balochistan and Sindh yielded 2 637 mt and 2 809 mt, respectively. The predicted yield in 2007 and 2000 was 2 886 mt and 3 227 mt, respectively. The fluctuations in Balochistan vessel numbers (2010–2015) likely reflect changes in registration policies, enforcement and socioeconomic disruptions. (Fig.2). These results indicate an inverse relationship between fishing effort and CPUE, highlighting reduced efficiency with increased effort decreases (Fig.2). Optimal fishery performance is typically observed when fewer vessels generate higher yields which aligns with sustainable exploitation practices (Hoggarth et al., 2006).

4.1 Juxtaposition in Balochistan and Sindh, Pakistan

The analysis of fisheries data from Balochistan and Sindh during 2000–2022 provides valuable insights into the trends and dynamics of the *P. olivaceus* fishery (Fig.2). Distinct differences in fishery management are evident between two regions. Although Balochistan consistently showed higher effort, its CPUE generally lower than that of Sindh, indicating reduced efficiency or yield per unit of effort. Interestingly, the predicted yields, estimates of future catches based on current data, also reflect a similar trend where Sindh occasionally forecasts higher yields despite lower efforts, suggesting a potentially more sustainable or efficient management of fishery resources in that region. This juxtaposition between the two areas highlights the complexities of marine resource management and underscores the importance of tailored strategies that consider regional ecological and operational dynamics. These findings offer important guidance for stakeholders and policy makers aiming to optimize yield while ensuring sustainability.

4.2 Stock status of *P. olivaceus* using CMSY and BSM

The CMSY method, utilizing catch statistics and supplementary data, has been employed to estimate the MSY and related biological population parameters which employed a surplus production-based Monte Carlo approach (Froese et al., 2017). The results indicate that *P. olivaceus* stock along both the Balochistan and Sindh coasts are under considerable pressure from overfishing. This evidence from elevated fishing mortality rates and biomass levels well below the B_{MSY} threshold. These findings are consistent with previous studies that applied similar methodologies to assess other fish stocks in Pakistani waters, which also reported signs of overexploitation (Raza et al., 2022, 2023; Baloch et al., 2025; Kalhoro et al., 2025). Collectively, this underscores the urgent need for targeted and regions specific management interventions to ensure the sustainability of this fishery from Pakistan.

4.3 Estimated ASPIC parameter of *P. olivaceus*

The deterministic production model suggests that annual changes in biomass are influenced by the previous year catch and stock levels, with recruitment, population growth, and natural mortality encapsulated within a single intrinsic growth rate parameter (r) (Prager, 2016). In this study, time-series data from 2000 to 2022 for the *P. olivaceus* were analyzed using the ASPIC model, which incorporates covariates and does not assume stock equilibrium. The analysis revealed significant differences in MSY estimates between the Balochistan and Sindh coasts. For Balochistan the Fox model estimated an MSY of 1 585 mt, while the Logistic model estimated slightly lower estimate of 1 379 mt. In contrast, the Sindh coast yielded higher MSY estimates, Fox model estimated 3 260 mt and the Logistic model estimated 3 024 mt. Graphical tools such as schematic outputs and Kobe plots, illustrated severe over-exploitation, particularly in Balochistan coast, where biomass levels consistently fell below B_{MSY}, placing the stock in a critical depletion zone. These findings underscore the urgent need for region-specific fisheries management interventions to halt overfishing and initiate stock recovery. The comparative analysis also indicated more stable stock trends on the Sindh coast, suggesting that either the local management practices are more effective or environmental variability is less intense compared to Balochistan. This regional contrast highlights the importance of tailored strategies in managing demersal fishery resources. Previous studies utilizing the ASPIC model have similarly identified signs of overexploitation in several demersal fish stocks in Pakistani waters. For instance, Kalhoro et al. (2013, 2015) demonstrated depleted biomass and unsustainable fishing mortality in different species using ASPIC models. Such consistency across studies validates the robustness of the ASPIC framework in assessing fisheries status under data-limited conditions. Overall, the divergent MSY outcomes from the Fox and Logistic models in both regions reflect the ecological and operational variability across Pakistan coasts and reinforce the necessity of regional adoptive management to ensure long-term sustainability of *P. olivaceus* and similar demersal stocks.

4.4 Notable outcome from previous study

Effective fisheries management relies on assessing stock status through BRPs and MSY estimates. Unfortunately, Pakistan lacks these crucial values due to insufficient data. However, data-limited methods like ASPIC and CMSY have emerged as valuable tools for evaluating fish stocks and improving resource management in such context. The catch-only models like CMSY and surplus production models such as BSM and ASPIC reply on limited input data and assumptions, which may introduce uncertainties in estimating parameters such as MSY and biomass. The absence of age, size, or recruitment data may affect model precision, making results sensitive to the quality of historical catch and effort records. Numerous studies have focused on the biomass evaluation of various fish species in Pakistani waters using different models (Baloch et al., 2025). The CMSY method was employed to estimate the stock of tuna, mackerel and other Scombridae species (Raza et al., 2022; Kalhoro et al., 2024a, b, 2025). However different species of the Haemulidae family have been exploited worldwide such as in Spain (Pajuelo et al., 2003), Egypt (Osman et al., 2019), Oman (AL-Nahdi, 2021), Türkiye (Avşar et al., 2021), Indonesia (Mous et al., 2020), and Pakistan (Baset et al., 2020). Moreover, our findings show that *P. olivaceus* is over-exploited and similar to the previous studies (Table 5). On the other hand, this study is the inaugural assessment of the stock status of *P. olivaceus* in Pakistan's marine waters.

5 CONCLUSION

We employed multiple stock assessment tools, including CMSY, BSM, and ASPIC models to strengthen the robustness of results and reduce uncertainty inherent in data-limited fisheries assessments. Our analysis clearly revealed that *P. olivaceus* (Olive grunt) stocks along both the Balochistan and Sindh coasts are severely over-exploited, emphasizing the urgent need for targeted and effective management strategies to restore these stocks to sustainable levels. The current fishing mortality with $F_{2022}/F_{MSY}>2$ (CMSY) indicates that fishing pressure in more than twice the sustainable level required to achieve the MSY. To align with this target, a 50% reduction in the active fleet size is recommended. Similarity, the BSM modeling

Table 5 Comparative investigation of the *Pomadasys* species (family: Haemulidae) in the present with previous stock conducted worldwide

Species	Region	Assessment method	Result	Reference
P. incisus	Spain	Pauly, Beverton, and Holt; Ault and Ehrhardt	Over exploited	Pajuelo et al., 2003
P. stridens	Egypt	FiSAT model	Over exploited	Osman et al., 2019
P. maculatus	Pakistan	FiSAT model	Not exploited	Baset et al., 2020
P. kaakan	Indonesia	Length based assessment	Over exploited	Mous et al., 2020
P. commersonnii	Oman	Beverton and Holt	Over exploited	AL-Nahdi, 2021
P. stridens	Türkiye	FiSAT model	Over exploited	Avşar et al., 2021
P. olivaceus	Pakistan	CMSY and ASPIC	Over exploited	Present study

showed F_{2022}/F_{MSY}=1.5, suggesting that a 33% reduction in fishing effort would be sufficient to reach sustainable exploitation levels. The findings address the importance of adopting sustainable fishing practices to ensure the long-term viability of survival of the *P. olivaceus* populations. Notably, the application of surplus production models proved useful in estimating key biological reference points, such as MSY, B_{MSY}, and F_{MSY}, and can enhance the reliability of management decisions in data-poor fisheries. The fisheries management is inherently complex, influenced by ecological variability, economic pressure, and governance capacity. The contrasting trends observed in Balochistan and Sindh reflect regional differences in fishing intensity, policy enforcement, and ecosystem dynamics. These differences underscore the necessity of region-specific management strategies, informed by localized data and adoptive modeling approaches. To address these challenges, science-based catch limits should be enforced through the catch limit quotas (i.e., TAC) and effort reduction 33%–50% to align with MSY estimates. Seasonal closures during spawning periods and the establishment of marine protected areas around key habitats are essential to support stock recovery. Strengthening data collection and standardized monitoring at landing sites will improve stock assessments and whole region-specific reporting will aid targeted policymaking. Engaging local communities in co-management can enhance compliance and stewardship. Continues stock monitoring and environmental changes are vital to ensure long-term sustainability. These integrated measures can help rebuild *P. olivaceus* stocks, protect marine biodiversity, and sustain coastal livelihood.

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