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Stock assessment of *Scomberomorus commerson* (Kingfish) fishery of Oman: Perspectives of sustainability

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ABSTRACT

Scomberomorus commerson (here after 'Kingfish') is the choicest table fish of the Gulf Cooperation Council (GCC) region and the most valuable finfish of Oman. Catch-effort data from 2000 to 2019 of Oman's Kingfish fishery was fit to Schaefer model (log-normal assumption) for estimating maximum sustainable yield (MSY) and biological reference points (BRPs). Carrying capacity (K), catchability coefficient (q), population growth rate (r) and MSY of Kingfish were 36,745 tonnes, 0.0000161, 0.382 and 3,507 tonnes, respectively. At present, fishing effort (E_{NOW}) (i.e. number of boats) is 18,982, which is beyond the sustainable limit i.e. $E_{MSY} = 11{,}846$ and if the number of boats reaches to 23,692 then Kingfish stock may collapse. All the BRPs are higher than their sustainable limits, which indicate Kingfish stock is overfished. Stock Reduction Analysis suggests that the stock was in the safe zone between 2005 and 2007, it was in the overfishing zone from 2008 to 2012 and 2013 onwards the stock is in the overfished zone. A complete ban on Kingfish fishing in Oman may allow the stock to rebuild to Biomass at Maximum Sustainable Yield in three years or limiting the annual catch at 1,500 tonnes/year till 2026 may yield the same result. A transboundary management of Kingfish fishery is suggested for the GCC region. Forming a joint scientific council for monitoring and facilitating data availability, similar ban periods, mesh size regulations and a 'payment for ecosystem services' scheme may lead Kingfish fishery of the GCC region towards sustainability.

1. Introduction

One of the aims of fisheries science is to let the managers know about the state of fish stocks that are commercially exploited (Barnett et al., 2019; Hilborn et al., 2020). Stock assessment plays an important role in decision-making process of sustainable management of fisheries (Lockerbie et al., 2016; Benson and Stephenson, 2018). It is a process of collecting and analyzing demographic information of a fish stock (Begg et al., 1999; Punt, 2019). The process involves mathematical and statistical models to examine the retrospective development of one or multiple stock(s), for quantitative predictions of its possible behavior in future for a better management of fisheries resources, maintain profitableness and stability of the industry, reduce by-catch, and over-fishing risks (Ricard et al., 2012; Rosenberg et al., 2014; Punt, 2019; Privitera-Johnson and Punt, 2020).

The Gulf Cooperation Council (GCC) region has become an area of economic contrast in the past three decades because it includes some of the world's richest countries with rapidly evolving oil and gas-dependent economies and some of the world's poor nations confronted by political instability (Jabado and Spaet, 2017). Fishing continues to play an important role in maintaining subsistence, commerce, and cultural heritages of the GCC region (Jayabalan et al., 2011; Alshubiri et al., 2020). The GCC region is rich in coastal–marine resources, which provide food and livelihood for millions of people (Kristofersson and Anderson, 2006). Uncontrolled fishing has left most of the key fishery resources of the GCC region in overexploited state (Jayabalan et al., 2011; Alshubiri et al., 2020).

One of such exploited fishery resources of the GCC region is Kingfish (family: Scombridae) (Roa-Ureta et al., 2019). Kingfish are well distributed in Indian Ocean and West Pacific Ocean (Collette, 2001; Randall, 1995; Roa-Ureta et al., 2019). Among different species of Kingfish, in Arabian Gulf, Gulf of Oman and Arabian Sea, Narrow-barred Spanish mackerel (*Scomberomorus commerson*, Lacépède, 1800) is common (Carpenter et al., 1997; Roa-Ureta, 2015). *Scomberomorus commerson* (hereafter written as 'Kingfish') fishery of the GCC region is an open access fishery (Govender et al., 2006; Jayabalan et al., 2011). Locally known as "Kanaad/Khabat", Kingfish is the most valuable finfish of Oman, it

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fetches up to 2.88 OMR (1 OMR = 2.6 US$) per kg and it is also exported to other countries of the GCC region and elsewhere in the world (Khan et al., 2003; MAFWR, 2019). Kingfish is a carnivorous species that feeds primarily on sardines and anchovies (Devaraj, 1998). During spring Kingfish does long-shore migration from Arabian Sea to Arabian Gulf to spawn and by the end of summer it migrates back to Arabian Sea (Siddeek, 1995). A genetic analysis of Kingfish stock in the ROPME (Regional Organization for the Protection of the Marine Environment) sea area (i.e. Arabian Sea, Gulf of Oman and Arabian Gulf) shows, a single homogeneous genetic stock exists throughout the region (Hoolihan et al., 2006). So, a transboundary effort may do better management of Kingfish fishery of Oman and the GCC region.

Kingfish is often caught by artisanal fishermen of Oman by using a variety of fishing gears, including hand lines, trolling lines, drift and set gillnets and beach seines (Govender et al., 2006; Roa-Ureta et al., 2019). So, this species is important to traditional fishery of Oman and provides financial security to a large number of fishermen (De Rodellec et al., 2001). To meet increasing demand of Kingfish, number of fishing boats in Oman has increased about 1.84 times in 2019 compared to the number of boats which used to fish Kingfish in early 21 century; therefore, fishing pressure has increased (Govender et al., 2006; MAFWR, 2019). Kingfish catch of Oman was only 2,088 tonnes in 2002 after that the catch steadily increased and in 2016 the highest catch 7,011 tonnes was recorded, thereafter, the catch has declined, and in 2019 the catch is 3.34 times less than the catch of 2016 (MAFWR, 2019). Previous studies of Kingfish stock assessment of Oman are mostly based on length and or age-based models (Claereboudt et al., 2004; McIlwain et al., 2005; Claereboudt et al., 2005; Govender et al., 2006; Jayabalan et al., 2011; Roa-Ureta et al., 2019); catch-effort data for the stock assessment has not been attempted earlier. By fitting catch-effort data to Schaefer model this study aims to assess (i) stock status of Kingfish and if the stock is within the sustainable limit and (ii) Maximum Sustainable Yield (MSY) and Biological Reference Points (BRPs) of Kingfish fishery of Oman. Existing management practices of Kingfish fishery of Oman and the GCC region are reviewed. Predictions are made on the Kingfish stock status of Oman for the current decade (2020 to 2030) based on plausible scenarios of exploitation.

2. Method

2.1. Catch area, techniques, and collection-analysis of catch-effort data

Oman has a long coastline of 3,165 km and an exclusive economic zone (EEZ) of 5,33,180 km^2 that extends from the borders of Yemen in the south to the Hormuz strait in the north. Oman is surrounded by Arabian Sea, Gulf of Oman and Arabian Gulf (Fig. 1), which are rich in fishery resources. Fig. 1 shows Kingfish fishing areas and landing centers along the coasts of Gulf of Oman, Arabian Gulf (Western part of Musandam region) and Arabian Sea. From 2000 to 2019, annual catch (tonnes) and effort (number of boats) data of Kingfish fishery was obtained from the annual 'Fisheries Statistics Book' published by the Ministry of Agriculture Fisheries and Water Resources (MAFWR) of Oman (see Table 1). As per the annual reports of the MAFWR, 78% of total fishing effort of Oman is directed to catch Kingfish (MAFWR, 2019). Various types of fishing gears are used for catching Kingfish, among them hand and trolling lines (HL+TL) and gillnet are the most prominent ones (MAFWR, 2019). Gear wise effort data was not available from 2000 to 2010; therefore, identifying any one specific gear as the major gear was not possible. Under such circumstances, an aggregate of all the efforts of catching Kingfish was used in the analysis. The catch per unit effort (CPUE) (Shapiro normality test: W = 0.97, p = 0.83) data were normally distributed so a generalized linear model of Gaussian family was used to assess its temporal variability. For the temporal variability of the catch and effort data generalized linear models of Poisson family were used. All the analyses were performed in R.4.0.3 (R. Core Team, 2020) considering 5% ($p < 0.05$) significance level.

Table 1
Kingfish (*Scomberomorus commerson*) catch (tonnes), effort (number of boats) and catch per unit effort (CPUE) (tonnes/boat) of Oman from 2000 to 2019.

Year	Catch	Effort	CPUE
2000	2,559	10,333	0.248
2001	2,785	10,502	0.265
2002	2,088	10,649	0.196
2003	2,764	10,788	0.256
2004	3,198	10,876	0.294
2005	3,372	10,577	0.319
2006	2,932	10,691	0.274
2007	3,158	10,812	0.292
2008	3,760	11,541	0.326
2009	3,766	11,655	0.323
2010	4,060	14,632	0.277
2011	3,372	14,610	0.231
2012	5,620	15,556	0.361
2013	4,176	16,647	0.251
2014	4,979	17,399	0.286
2015	3,992	17,878	0.223
2016	7,011	18,258	0.384
2017	3,341	18,652	0.179
2018	2,601	19,043	0.137
2019	2,098	18,982	0.111

2.2. Analyzing catch-effort data by using CEDA software

Surplus Production Model (SPM) is conventionally used for the assessment of commercially any exploited fish stock if catch-effort time series is available (Karim et al., 2020). The SPMs are not as realistic as age-structured models but are useful in estimating the optimum yield specially for open access fisheries where data deficiency is a major problem. These models provide better estimates of BRPs than the age-structured models (Froese et al., 2017; Karim et al., 2020; Winker et al., 2020a,b). The SPMs are used to determine MSY that corresponds to certain BRPs such as biomass at MSY (B_{MSY}), fishing effort at MSY (E_{MSY}) and fishing mortality at MSY (F_{MSY}), current stock biomass (B_{NOW}), current fishing effort (E_{NOW}) and current fishing mortality (F_{NOW}), maximum biomass near collapse (B_{COLL}), the maximum fishing effort near collapse (E_{COLL}) and the maximum fishing mortality near collapse (F_{COLL}). Estimates of BRPs often indicate the performance of a fishery and provide fishery managers the vital information required for the sustainable management of fishery resources (Sissenwine and Shepherd, 1987). Schaefer model is a SPM that is often used for stock assessment of one or multiple fish species (Kilduff et al., 2009). Schaefer model requires catch-effort data as input for estimating the key parameters such as carrying capacity (K), catchability coefficient (q), intrinsic population growth rate (r), MSY, replacement yield (R_{Yield}) and final biomass (B_{Final}) of a fish stock (Karim et al., 2020). In addition to BRPs, historical stock size and fishing mortality could be derived from Schaefer model (Ji et al., 2019).

The Catch and Effort Data Analysis (CEDA version 3.0.1) software was developed by Marine Resources Assessment Group (MRAG) for its Fishery Management Science Program (Kirkwood et al., 2001). This software is a useful stock assessment tool of estimating the key parameters (e.g. K, q, r, MSY, R_{Yield} and B_{Final}) and BRPs of a certain fish stock (Kirkwood et al., 2001). Schaefer model was built for the stock assessment of Kingfish

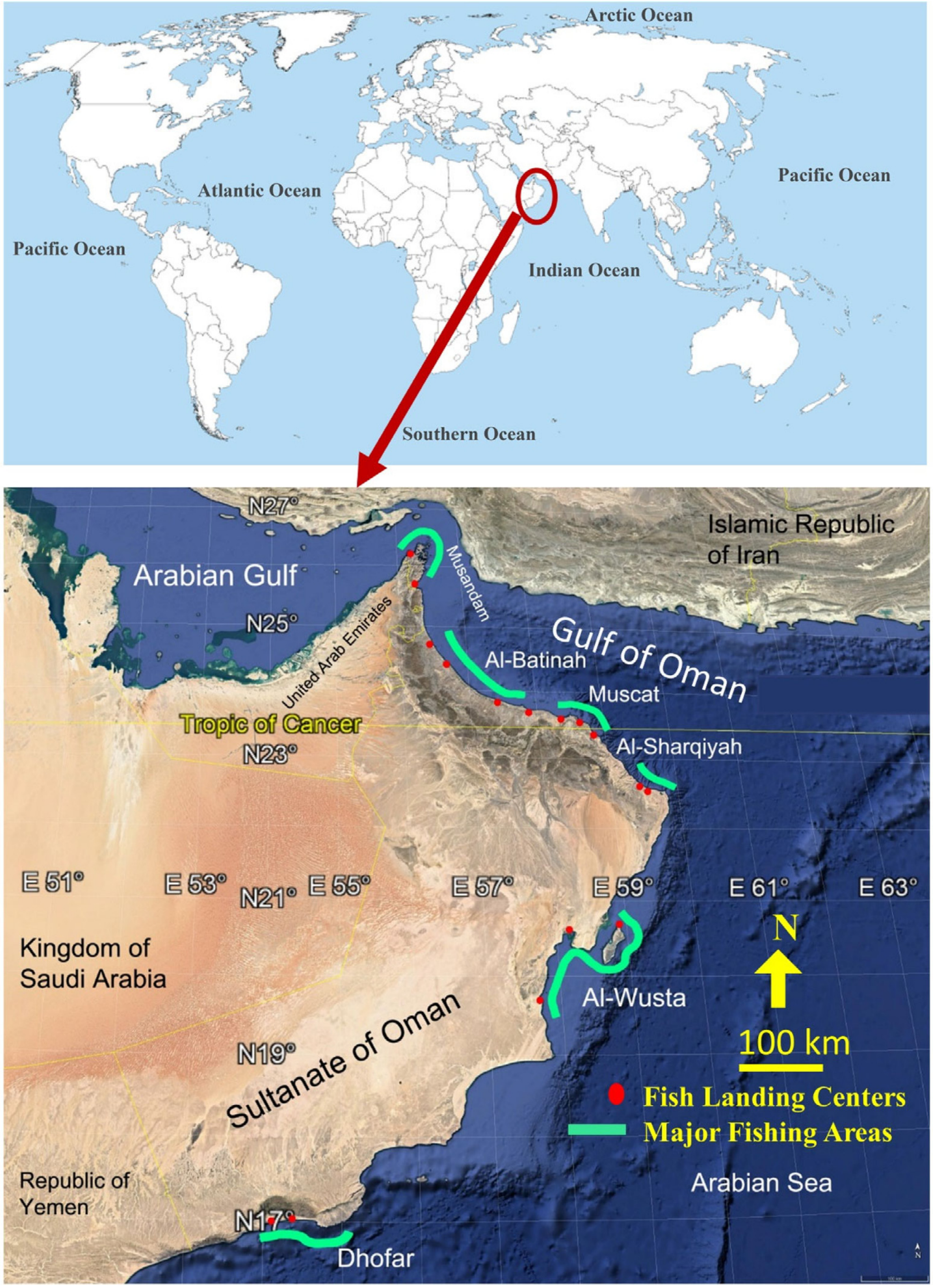

Fig. 1. Major Kingfish (*Scomberomorus commerson*) fishing areas and landing centers in Oman.

fishery of Oman by using CEDA software. In fishery science, initial proportion (IP) is considered as the ratio of initial to maximum catch. An IP value of 1 indicates that the fishery started from a heavily exploited stock whereas an IP value of 0 indicates that the fishery started from a virgin stock (Khatun et al., 2019). The CEDA software requires an input parameter IP for estimation of the K, q, r, MSY, R_{Yield} and B_{Final} values. In the present study, IP was considered at 0.4 because the initial catch (i.e. the catch of 2000) of Kingfish was about 40% of the maximum catch from 2000 to 2019 tenure. Schaefer model (log-normal error assumption) was computed using the logistic population growth equation i.e. dB/dt = rB(1-(B/K)) (Schaefer, 1954). Where, B = Biomass (tonnes) of stock, t = time (years), r = intrinsic population growth rate of the stock, and K = carrying capacity of the stock. The CEDA software can estimate biomass, expected catch and expected CPUE over the years. In the CEDA software the initial biomass (IB) was estimated considering IB = K(IP). The main output parameters from CEDA software are K, q, r, MSY, R_{Yield} and B_{Final}. The coefficient of determination (i.e. R^2) and coefficient of variation (i.e. CV) were obtained from the CEDA software; however, for obtaining the CV bootstrapping confidence limit method had been used.

In order to assesses the stock status of Kingfish, BRPs such as B_{MSY}, E_{MSY} and F_{MSY} were derived from the key parameters (K, q, r, MSY, R_{Yield} and B_{Final}) and compared with the B_{NOW}, E_{NOW} and F_{NOW}. The B_{COLL}, E_{COLL} and F_{COLL} were also estimated. The BRPs were estimated by considering MSY = rK/4, B_{MSY} = K/2, E_{MSY} = r/2q, F_{MSY} = r/2, B_{COLL} = K, E_{COLL} = r/q and F_{COLL} = r. The current biomass of the stock was derived from the CEDA software and the current fishing mortality was calculated by using the equation: $F_{NOW} = C_{NOW}/B_{NOW}$, where C_{NOW} is the last year catch. B_{NOW}/B_{MSY} and F_{NOW}/F_{MSY} ratios from 2000 to 2019 were calculated to assess the stock status of Kingfish using the Kobe plot. The CEDA software predicts the future stock size by using different management scenarios of a fishery. Kingfish stock status of Oman is predicted for the current decade (i.e. 2020 to 2030) under different management scenarios such as (i) uncontrolled effort (i.e. if the existing (2000 to 2019) fishing effort continues), (ii) E_{MSY} (i.e. in this case a steady fishing effort was considered based on the effort at MSY level), (iii) fishing ban (i.e. a ban period until the stock rebuilds to B_{MSY}), (iv) Total Allowable Catch (TAC) of R_{Yield}, (i.e. in case total allowable catch is fixed at R_{Yield}), (v) TAC of MSY (i.e. if total allowable catch is fixed at MSY), and (vi) if TAC of 1,500 tonnes until $B_{NOW} = B_{MSY}$.

2.3. Stock status analysis of Kingfish fishery

Stock Reduction Analysis (SRA) is a stock assessment system approach on stock using the exponential form of weight-recorded capture equations and annual capture (Kimura et al., 1984). The Kobe Plot I+II software (Version 3, 2014) consists of Kobe I (stock status trajectory plot) and Kobe II (risk assessment diagram). Kobe Plot I was used to derive the historical stock status trajectory plots for Biomass (B)/B_{MSY} and Fishing mortality (F)/F_{MSY} using the results of the stock assessments. Kobe II was used to draw the color diagrams for the results of the risk assessments for the B/B_{MSY} and the F/F_{MSY} (i.e., probabilities of violating their MSY levels in the future by different catch level scenarios). Kingfish stock status of Oman (from 2000 to 2019) was analyzed by using the SRA of Kobe Plot software.

3. Results and discussion

3.1. Catch, effort and CPUE

From 2000 to 2019, total catch of Kingfish was 71,632 tonnes, the average catch was 3,582 tonnes, the lowest catch 2,088 tonnes recorded in 2002, and the highest catch 7,011 tonnes recorded in 2016 (Table 1). Overall, during the study period Kingfish catch of Oman has increased ($Z = 34.11$, $p < 0.001$, df = 18); however, from 2016 onwards, Kingfish catch has significantly declined ($Z = -54.99$, $p < 0.001$, df = 2) and reached 2,098 tonnes in 2019 (Table 1). Kingfish fishing effort continued its increasing trend during the period of this study ($Z = 121$, $p < 0.001$, df = 18). The highest CPUE was 0.38 tonnes/boat recorded in 2016 and the lowest 0.11 tonnes/boat recorded in 2019 (Table 1). From 2000 to 2019 the average CPUE was 0.26 tonnes/boat. During the study period the CPUE did not vary significantly ($t = -1.31$, $p = 0.206$, df = 18).

3.2. Key parameters (K, q, r, MSY)

Results indicate that the carrying capacity (K), the catchability coefficient (q), the biological growth rate (r) and the MSY of Kingfish stock in Oman were 36,745 tonnes, 0.0000161, 0.382 and 3,507 tonnes, respectively (Table 2). The K, q and r of *Scomberomorus* spp. were 208,359.20 tonnes, 0.00000821 and 0.088, respectively in Pakistan (Baset et al., 2017). From 2004 to 2006, the average Kingfish catch, biomass and MSY of the GCC region were 15,389 tonnes, 28,185 tonnes and 14,825 tonnes, respectively (Jayabalan et al., 2011). Oman contributes 20.58% of the total Kingfish catch of the GCC region (Jayabalan et al., 2011). In the early 21 Century, the annual average yield of Kingfish was 15,455 tonnes for the GCC region, which was higher than the estimated MSY of 14,711 tonnes (Claereboudt et al., 2004). Kingfish stock

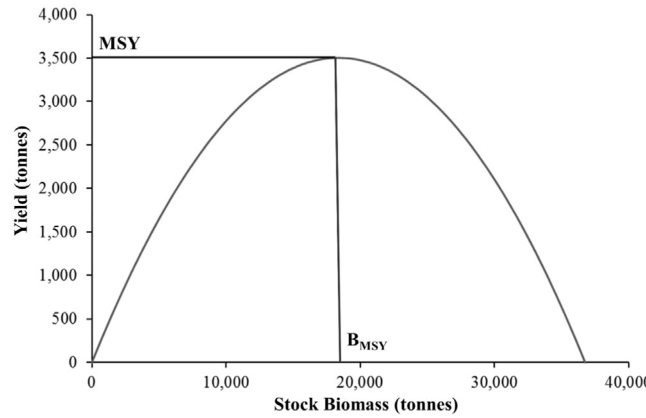

Fig. 2. Schaefer model representing the yield versus stock biomass of Kingfish (*Scomberomorus commerson*) fishery of Oman.

showed a long-term decline trend in the Gulf of Carpentaria of Queensland, Australia and the rate of decline exacerbated between 2007 and 2018 (Bessell-Browne et al., 2020). By using CEDA software the estimated MSY of *Scomberomorus* spp. was found between 3,600 and 4,000 tonnes in Pakistan; however, the annual catch of *Scomberomorus* spp. was much higher than the MSY, which suggest an overfished condition of the fishery (Baset et al., 2017). Any variation of IP value provides a different estimation of MSY. In this study, an IP value (initial year (2000) catch/maximum year (2016) catch) of 0.4 (i.e. 2559/7011) was considered. For that IP value, Schaefer model (log-normal error assumption) estimated MSY to be 3,507 tonnes (Table 2).

3.3. Biological reference points

Fig. 2 shows Kingfish yield vs. stock biomass in Oman. The B_{MSY} of Kingfish in Oman was 18,373 tonnes and MSY was 3,507 tonnes (Fig. 2). A detail accounts of the estimated BRPs are presented in Table 3. As of Schaefer model, B_{NOW} value was 9,363 tonnes. The fishing mortality at present (F_{NOW}) was estimated at 0.22 per year. If the fishing mortality reaches to 0.38 per year then Kingfish stock of Oman may collapse. The sustainable limit of fishing mortality is 0.19. Govender et al. (2006) estimated the fishing mortality (F_{Curr}) for male and female Kingfish of Oman, and the values were 0.402 per year for males and 0.534 per year for females, which indicates that females are fished at a higher rate than the males. The current fishing mortality of Kingfish is higher than the optimum fishing mortality, which suggests Kingfish stock is overfished and it requires rebuilding. At present, E_{NOW} is 18,982 but the sustainable limit is (i.e. E_{MSY}) is 11,846. In case the fishing effort reach to 23,692 then Kingfish stock of Oman may collapse. Results also suggest that all the BRPs of Kingfish fishery of Oman at present are higher than their sustainable limits; therefore, intervention is required for sustainable management of the stock biomass.

3.4. Stock predictions for the current decade

The current study assumes that a fish stock can never be totally driven to extinction (Musick and Bonfil, 2005); however, fish stock size could be affected by different additive (e.g. growth or recruitment and immigration) and destructive (e.g. mortality and emigration) forces which often act together (Hilborn and Walters, 2013). By using different fishing efforts and TACs, predictions were drawn on Kingfish stock of Oman for the current decade (2020–2030) (Fig. 3). Results suggested that an uncontrolled effort would lead to a decline in the stock of Kingfish from its

Table 2
Schaefer model estimates of the key parameters of Kingfish (*Scomberomorus commerson*) fishery of Oman.

Carrying capacity (K) (tonnes)	Catchability coefficient (q)	Population growth rate (r)	MSY (tonnes)	R_{Yield} (tonnes)	B_{Final} (tonnes)	R^2	Coefficient of variation (CV)
36,745	0.0000161	0.382	3,507	2,766	9,929	0.46	0.033

Table 3
Schaefer model estimates of the biological reference points of Kingfish (*Scomberomorus commerson*) fishery of Oman.

B_{MSY} (tonnes)	E_{MSY} (tonnes)	F_{MSY}	B_{NOW} (tonnes)	E_{NOW} (tonnes)	F_{NOW}	B_{COLL} (tonnes)	E_{COLL} (tonnes)	F_{COLL}
18,373	11,846	0.19	9,363	18,982	0.22	36,745	23,692	0.38

Biomass at MSY (B_{MSY}), fishing effort at MSY (E_{MSY}) and fishing mortality at MSY (F_{MSY}), current stock biomass (B_{NOW}), current fishing effort (E_{NOW}) and current fishing mortality (F_{NOW}), maximum biomass near collapse (B_{COLL}), the maximum fishing effort near collapse (E_{COLL}) and the maximum fishing mortality near collapse (F_{COLL}).

current level and if the fishing effort remains uncontrolled then Kingfish fishery of Oman would be seriously affected by 2030. In case fishing is continued at E_{MSY} level then the stock biomass would increase considerable from the current level, which would be a healthy sign for the fishery. A complete ban on Kingfish fishery of Oman may allow the stock to rebuild to B_{MSY} within three years (2020–2023) (Fig. 3). If TAC equals R_{yield} then the predicted stock biomass of this decade (2020–2030) would continue at the current level (Fig. 3). If TAC equals MSY then stock may collapse (Fig. 3) since such an initial stock cannot support the production at MSY level (Hoggarrth et al., 2006). There is a persistent need to rebuild the stock to B_{MSY} level. For that, if the TAC is limited to 1,500 tonnes per year then that may allow the stock to rebuild to B_{MSY} by 2026. If the stock equals or exceeds $B_{MSY,}$ then any catch at MSY level is sustainable.

3.5. Existing stock status

The estimated biomass (in tonnes) of Kingfish stock of Oman is presented in Fig. 4. The results suggest that Kingfish stock biomass is decreasing ($R^2 = 0.41$, $P < 0.01$) in Oman (Fig. 4). During this study, the maximum biomass (i.e. 19,604 tonnes) was estimated in 2008 and the minimum biomass (i.e. 9,310 tonnes) was estimated in 2018, whereas the final biomass (i.e. the biomass of 2020) was estimated 9,929 tonnes. The SRA suggests stock status between 2000 to 2019 of Oman and the corresponding Kobe plot is presented in Fig. 5. Results demonstrate that Kingfish stock was in the 'safe zone' in between 2005 and 2007, after that the stock was in 'overfishing zone' between 2008 and 2012 and it is in the 'overfished' zone from 2013 to 2019 but from 2017 to 2019 the stock is approaching towards recovering zone (Fig. 5). In open access fisheries, fish stocks are often biologically overfished (Bjørndal and Conrad, 1987; Pauly et al., 2002; Worm et al., 2009). Results suggests that Kingfish stock is shrinking and the current stock biomass is lower than the B_{MSY}. Globally, Kingfish is overfished (FAO, 2011). In the early 21 Century, Kingfish stock of Oman was experiencing intense fishing pressure particularly along the coast of Arabian Sea (Claereboudt et al., 2005). Over-exploitation of Kingfish in Gulf of Oman could be due to lack of regulation on mesh sizes of gillnets (McIlwain et al., 2005; Jayabalan et al., 2011). Estimates of the Catch-MSY model (Martell and Froese, 2012) suggested that currently the stock of Spanish mackerel of Indian Ocean is overfished (Dan, 2020). Kingfish stock assessed by Bayesian Schaefer Model suggested "collapsed" status of Kingfish stock in Taiwan (Ju et al., 2020).

3.6. Existing management policies

Small-scale coastal–marine fisheries such as Kingfish fishery are important for Oman because 98% of Oman's total catch is artisanal (Khalfallah et al., 2016). 56% of Oman's large pelagic fish species and 68% of important demersal fish species are fully overexploited (World Bank, 2015). Thousands of artisanal boats target Kingfish in Arabian Gulf, Gulf of Oman and Arabian Sea; therefore, it is one of the most important fishery resources of the GCC region (Roa-Ureta, 2015). In the past, Regional Commission for Fisheries (RECOFI) and Indian Ocean Tuna Commission (IOTC) jointly addressed problems and expressed their concerns related to the protection and management of Kingfish stock, and emphasized the need of negotiating for the technical assistance from the regional organizations (Bose and Al-Balushi, 2010). The GCC through governmental offices of respective countries has recently implemented a seasonal fishing ban on Kingfish fishing between 15 August to 15 October of each year, which has targeted the spawning time, fishing is allowed for the rest of the year and it is not impossible that illegal fishing or illegal landing takes place even during the fishing ban period (Roa-Ureta et al., 2019). The GCC countries have brought rules on mesh size, and minimum landing sizes for various types of artisanal vessels since 1990s (Siddeek et al., 1999; Roa-Ureta et al., 2019). Recently the GCC countries restricted the time spent at sea from 15 August to 15 October of each year (Roa-Ureta et al., 2019). These rules and restrictions were aimed to achieve sustainability in Kingfish fishery of Oman and other countries of the GCC region. Even after that, exploitation of Kingfish is continuing in unhealthy ways that include overfishing (recruitment overfishing and growth overfishing) and lack of compliance to rules and regulations is still a issue (Jayabalan et al., 2011; Alshubiri et al., 2020). For such reasons, coastal–marine food web, fish supply and fishing communities of Oman and the GCC countries are facing challenges (Alshubiri et al., 2020).

3.7. Recommendations for sustainability

The entire ROPME Sea area has a single stock of Kingfish, so it could be managed better with a transboundary initiative of the GCC region. More scientific studies on biology and population dynamics of Kingfish are required in the GCC region to evaluate the vulnerabilities of Kingfish stock. It is vital to form a Joint Scientific Council like that of Regional Commission for Fisheries (RECOFI) for Kingfish. That Council may host a group of fishery scientists and management experts for conceptualizing a transboundary management plan of Kingfish fishery of the GCC region including scientific monitoring, control and surveillance of fisheries regulations, implementation of common ban period, and successful implementation of the transboundary initiatives. In order to ensure the long-term sustainability of Kingfish fishery, Oman shall continue to play its proactive role in developing effective co-operatives with other GCC countries (Al-Balushi et al., 2016). Transboundary management recommendations are essentially long-term measures which would take time to yield the

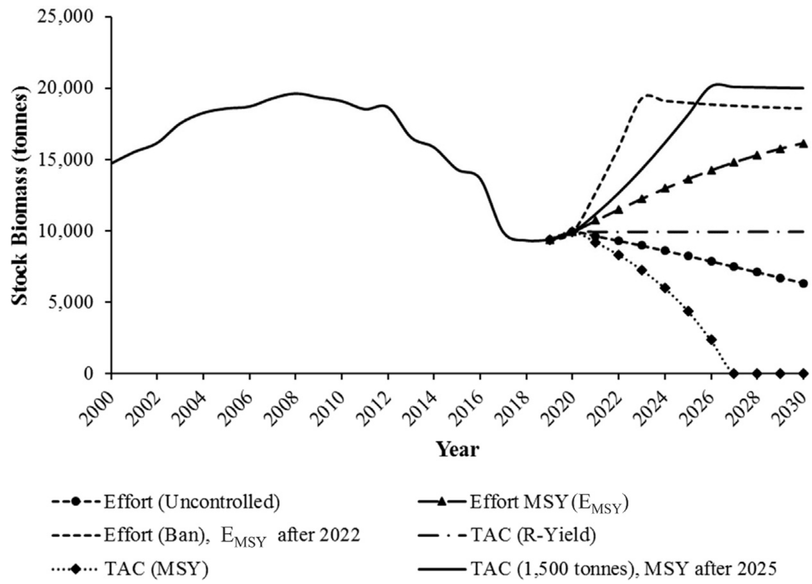

Fig. 3. Kingfish (*Scomberomorus commerson*) stock biomass prediction of the current decade (2020–2030) for Oman considering different scenarios of catch and effort.

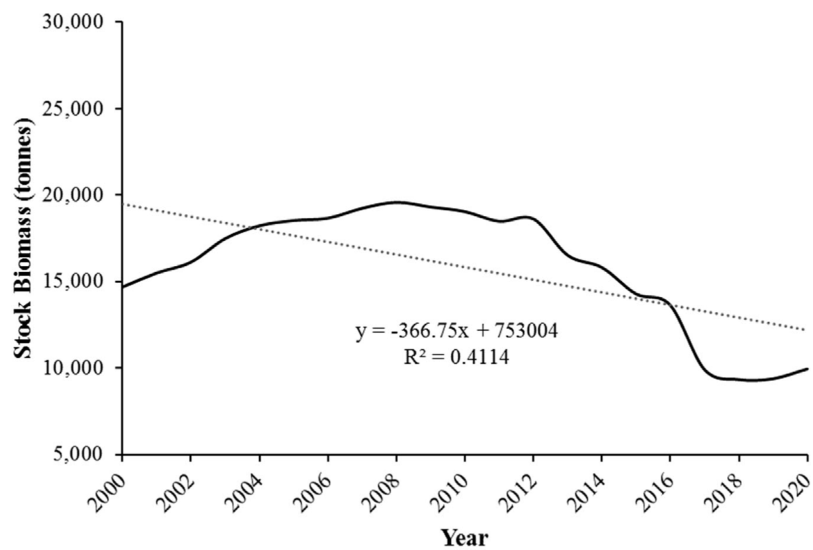

Fig. 4. Schaefer model estimates of stock biomass (tonnes) of Kingfish (*Scomberomorus commerson*) fishery of Oman from 2000 to 2020.

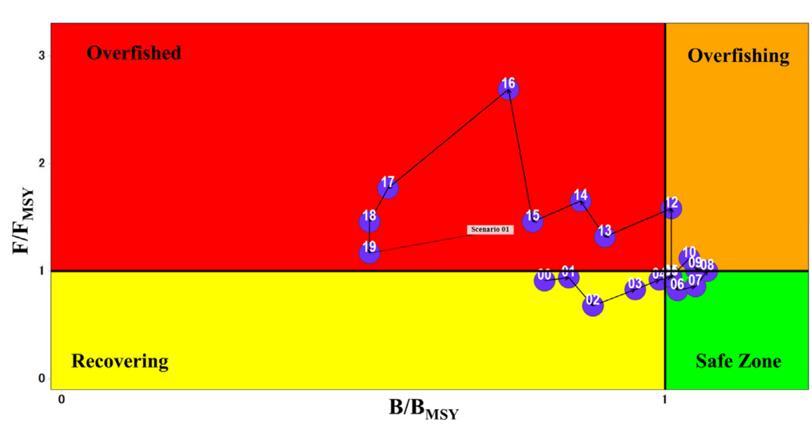

Fig. 5. Kingfish (*Scomberomorus commerson*) stock status from 2000 to 2019 in Oman using Kobe plot.

desired results; therefore, for the time being some intermediate actions plans are required to improve the current health of Kingfish fishery of the GCC region. At present, the management strategies adopted for the sustainability of Kingfish fishery of

Oman seems to be less effective; therefore, the catch is declining. So, Kingfish fishing effort (i.e. number of boats) needs to be reduced to 11,846 from the existing effort of 18,982. Excessive fishing effort shall be restricted from the top down to counter too many fishermen chasing too few fish (Finkbeiner et al., 2017). If resource conservation and stock rebuilding goals are to be met for Kingfish fishery, increased mesh size (130–170 mm) regulations (Dudley et al., 1992; Hosseini et al., 2021) for gillnets would be required along with a significant reduction in fishing effort (Grandcourt et al., 2005). Use of demersal trawl nets are prohibited in Oman since 1992 (Siddeek et al., 1999), which possibly benefits Kingfish fishery. A year-round trawl ban was implemented in 1990 in the Gulf of Castellammare (NW Sicily, Mediterranean Sea), which resulted in 8-fold increase in biomass, and four years after the ban all the considered species underwent an increase; therefore, a management strategy based on year-round trawling ban may prove effective, especially in areas where multispecies and multigear artisanal fisheries make up a large part of the fishing industry (Pipitone et al., 2000). A transboundary initiative of banning trawl nets is needed in the GCC region at least for a few years to reduce the bycatch and rebuild Kingfish stock from its overfished status. Based on the results, imposing a complete ban on Kingfish fishing for three years is recommended for Oman. That may allow Kingfish stock of Oman to rebuild to B_{MSY} in the short-term. One other option could be limiting the annual catch to 1,500 tonnes until 2026, which may rebuild the current stock to B_{MSY}. These measures may draw some unintended short-term consequences such as lack of fishing-related employment options during the ban period and concerns of food security for the local community as observed in case of a seasonal ban (45 days) on fishing effort in Tamil Nadu and Puducherry of India (Colwell et al., 2019). Such concerns could be mitigated to a large extent by introducing a 'payment for ecosystem services (PES)' scheme to conserve and sustainably manage Kingfish stock. The PES is already in place for the conservation of Hilsa stock of Bangladesh (Dutta et al., 2021), which yielded promising results and the stock has recovered considerably in the last decade. The PES may work for Oman and other countries of the GCC region because a large number of artisanal fishermen are concentrating on fishing Kingfish. That is similar to the Hilsa fisheries of Bangladesh and India (Dutta et al., 2021). The recommendations of a few years of fishing ban or substantial reduction of the current fishing efforts may seem draconic for the socio-economic conditions of the fisher communities of Oman and the GCC region. Implemented along with a PES scheme, such draconic measures, may meet the intermediate goals of the long-term sustainability of Kingfish fishery of the GCC region.

CRediT authorship contribution statement

Ahmed M. Al-Shehhi: Conceptualization, Methodology, Software, Formal analysis, Writing – original draft. **Sachinandan Dutta:** Conceptualization, Funding acquisition, Methodology, Software, Formal analysis, Validation, Investigation, Writing – review & editing. **Sourav Paul:** Conceptualization, Validation, Investigation, Methodology, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.rsma.2021.101970.

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