Assessment of Indian Ocean Indo-Pacific King Mackerel

(*Scomberomorus guttatus*) using data-limited methods

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1. Introduction

Assessing the status of the stocks of neritic tuna species in the Indian Ocean is challenging due to the paucity of data. There is lack of reliable information on stock structure, abundance, and biological parameters. There has been no formal stock assessment conducted for Indo-Pacific king mackerel (*Scomberomorus guttatus*). Fu (2021) provides a preliminary assessment of *S. guttatus* using data-limited methods. This paper provides an update of that assessment using the C-MSY method (Froese et al. 2016), based on the most recent catch information. Additionally, a further development of this method, C-MSY++ (Froese et al. 2021), was also explored in the assessment.

2. Basic Biology

Indo-Pacific king mackerel, *Scomberomorus guttatus* (Bloch and Schneider, 1801), is a pelagic migratory fish inhabiting coastal waters at depths between 15 and 200m, sometimes entering turbid estuarine waters. Its distribution covers the Indo-West Pacific region from the Persian Gulf, India and Sri Lanka to southeast Asia (Collette, 2001). It is usually found in small schools and is a carnivorous species, feeding mainly on small fishes such as sardines and anchovies as well as squids and crustacean (Collette and Nauen, 1983). It reaches a maximum length of 76 cm, maturing at approximately 40 cm.

3. Catch, CPUE and Fishery trends

Nominal catch data were extracted from the IOTC Secretariat database for the period 1950–2022, given that records for 2023 were still incomplete at the time of writing. Nominal catches of *S. guttatus* are lower than many of the other neritic species, with a total catch of only 45 588 t reported in 2022 (Table 1). Catches increased to a reported maximum of 51 631t in 2009 and have remained somewhat lower in subsequent years. India, Indonesia, Iran, Myanmar, Pakistan and Malaysia all have important fisheries for *S. guttatus* and the catches are largely dominated by gillnets (Figure 1 and Figure 2).

In 2019, IOTC endorsed the revisions of Pakistani gillnet catches that introduce some changes in the catches of tropical tuna, billfish, as well as some neritic tuna species since 1987 (IOTC–WPDCS15 2019). However, the revision appears to have very minor effects on the Indo-Pacific king mackerel nominal catch series since the last assessment (Figure 3). Alternative estimates of nominal catches are also available (up to 2019) from the catch reconstruction work of the "Sea around us" project (Heidrich et al. 2023).

There is a relatively high uncertainty associated with the catch data for neritic tunas due to the difficulties in differentiating amongst the different species resulting in highly aggregated reported data, often as 'seerfishes' or other groupings. Therefore, the IOTC Secretariat uses various methods of estimating the disaggregated catches by species for assessment purposes. Fu & Martin (2017) showed there are close correlations between the catches over time of each of the six neritic tunas. The high level of correlation amongst these species is likely to be because they are often caught together, due to difficulty with species identification and also because of the estimation procedures used to assign proportions of catch amongst the various species. Species-specific reporting has improved over time, leading to a lower level of correlation in more recent years.

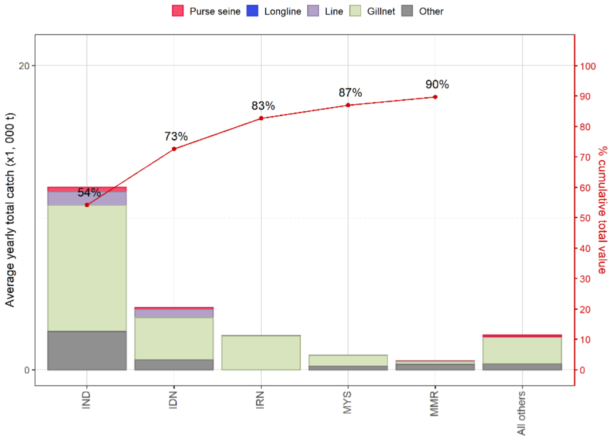

Figure 1: Average catches in the Indian Ocean over the period 2015-2022, by country. The red line indicates the (cumulative) proportion of catches of *S. guttatus* by country.

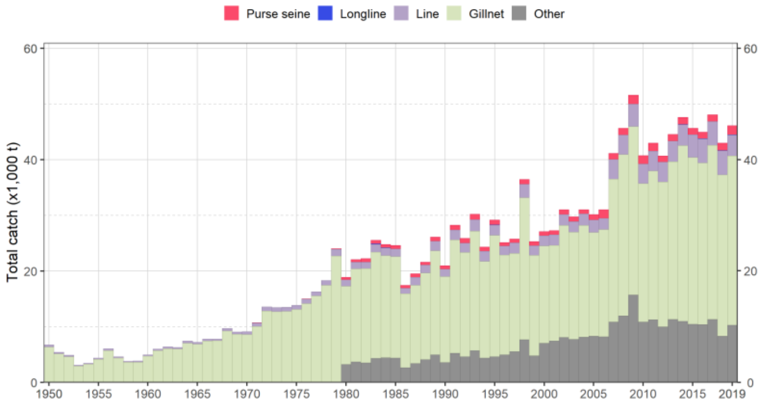

Figure 2: Annual catches of *S. guttatus* by gear, 1950 – 2019 (IOTC database).

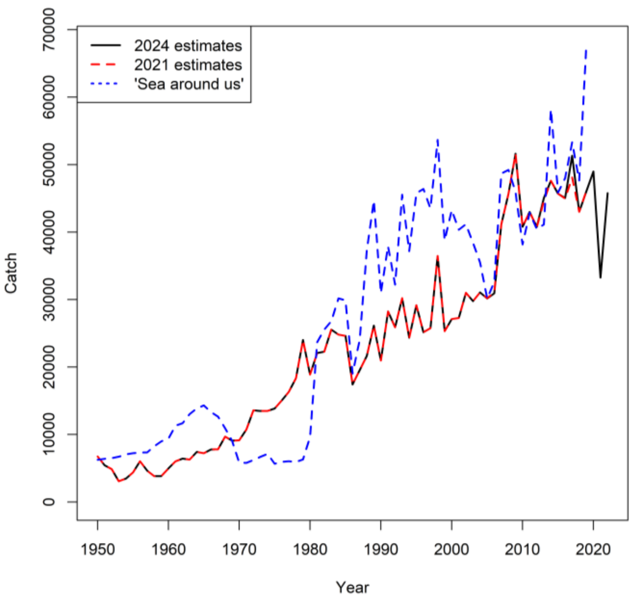

Figure 3: Revisions to IOTC nominal catch data for *S. guttatus* (datasets used for the 2021 and 2024 assessments).

Table 1. Catch data for *S. guttatus* in the Indian Ocean, 1950-2022 (source IOTC Database)

Year	Catch (t)	Year	Catch (t)
1950	6 744	1987	19 503
1951	5 431	1988	21 637
1952	4 871	1989	26 135
1953	3 083	1990	20 951
1954	3 461	1991	28 237
1955	4 368	1992	25 881
1956	6 035	1993	30 210
1957	4 636	1994	24 338
1958	3 824	1995	29 162
1959	3 844	1996	25 154
1960	4 971	1997	25 763
1961	6 026	1998	36 471
1962	6 420	1999	25 316
1963	6 282	2000	27 101
1964	7 415	2001	27 263
1965	7 230	2002	31 012
1966	7 780	2003	29 768
1967	7 803	2004	31 061
1968	9 678	2005	30 159
1969	9 081	2006	30 915
1970	9 132	2007	41 148
1971	10 740	2008	45 684
1972	13 587	2009	51 631
1973	13 484	2010	40 787
1974	13 497	2011	42 997
1975	13 847	2012	40 779
1976	15 040	2013	45 021
1977	16 307	2014	47 617
1978	18 331	2015	45 682
1979	24 015	2016	45 043
1980	18 878	2017	51 313
1981	22 074	2018	43 007
1982	22 265	2019	46 053
1983	25 553	2020	48 986
1984	24 798	2021	33 266
1985	24 603	2022	45 769
1986	17 420		

4. Methods

4.1. C-MSY method

The C-MSY method of Froese et al. (2016) was applied to estimate reference points from catch, resilience, and qualitative stock status information for the Indo-Pacific king mackerel. The C-MSY method represents a further development of the Catch-MSY method of Martell and Froese (2012), with a number of improvements to reduce potential bias. Like the Catch-MSY method, The C-MSY relies on only a catch time series dataset, which was available from 1950 – 2018, prior ranges of *r* and *K*, and possible ranges of stock sizes in the first and final years of the time series.

The Graham-Shaefer surplus production model (Shaefer 1954) is used (equation 1), but it is combined with a simple recruitment model to account for the reduced recruitment at severely depleted stock sizes (equation 2), where B_t is the biomass in time step *t*, *r* is the population growth rate, B_0 is the virgin biomass equal to carrying capacity, *K*, and C_t is the known catch at time *t*. Annual biomass quantities can then be calculated for every year based on a given set of *r* and *K* parameters.

$$B_{t+1} = \left[B + r\left(1 - \frac{B_t}{K}\right)B_t - C_t \right] \qquad \text{if } \frac{B_t}{K} > 0.25 \qquad (1)$$

$$B_{t+1} = \left[B + 4\frac{B_t}{K} r\left(1 - \frac{B_t}{K}\right)B_t - C_t \right] \qquad \text{if } \frac{B_t}{K} \leq 0.25 \qquad (2)$$

The prior range for *r* was estimated using the life history module (LHM) developed by Edwards (2016). The model implements Monte Carlo sampling of life history parameter distributions, with iterated solving of the Euler-Lotka equation (McAllister et al. 2001). The population parameters of *S. guttatus (*including growth, natural morality, maturity, and length-weight relationship) are based on values as collated by Robinson (2015). The estimated distribution of r suggested a credible range of 0.6 – 2.0 for *S. guttatus* (Figure 4). Martell and Froese (2012) proposed a classification of the stock resilience levels where stocks with a very low resiliency are allocated an r value from 0.05 – 0.5, medium resiliency 0.2 – 1 and high resiliency 0.6 – 1.5. Based on the FishBase classification, *S. guttatus* has a medium level of resilience and a range of 0.2 – 0.8 (Froese and Pauly 2015). For the analysis, the LHM estimates of 0.6 – 2.0 was used a reference case as they are based on existing parameter values where as FishBase resilience estimates of 0.2–0.8 was used as a sensitivity. The prior range of K was determined as

$$k_{low} = \frac{\max(C_t)}{r_{high}}, k_{high} = \frac{4\max(C_t)}{r_{low}} \qquad (3)$$

Where k_{low} and k_{high} are the lower and upper lower bound of the range of *k*, max(C) is the maximum catch in the time series, and r_{low} and r_{high} are lower and upper bound of the range of r values.

The ranges for starting and final depletion levels were assumed to be based on one of possible three biomass ranges: 0.01–0.4 (low), 0.2–0.6 (medium), and high (0.4–0.8), using a set of rules based on the trend of the catch series (see Froese et al. (2016) for details). The prior range for the depletion level can also be assumed optionally for an intermediate year, but this option was not explored in this report. With this approach, the prior range for the depletion level in 2019 was determined to be medium. The prior ranges used for key parameters are specified in Table 2.

C-MSY estimates biomass, exploitation rate, MSY and related fisheries reference points from catch data and resilience of the species. Probable ranges for r and k are filtered with a Monte Carlo approach to detect 'viable' r-k pairs. The model worked sequentially through the range of initial biomass depletion level and random pairs of *r* and *K* were drawn based on the uniform distribution for the specified ranges. Equation 1 or 2 is used to calculate the predicted biomass in subsequent years, each *r-k* pair at each given starting biomass level is considered variable if the stock has never collapsed or exceeded carrying capacity and that the final biomass estimate which falls within the assumed depletion range. All *r-k* combinations for each starting biomass which were considered feasible were retained for further analysis. The search for viable r-k pairs is terminated once more than 1000 pairs are found.

The most probable r-k pair were determined using the method described by Ferose et.al (2016). All viable r-values are assigned to 25–100 bins of equal width in log space. The 75th percentile of the mid-values of occupied bins is taken as the most probable estimate of r. Approximate 95% confidence limits of the most probable *r* are obtained as 51.25th and 98.75th percentiles of the mid-values of occupied bins, respectively. The most probable value of k is determined from a linear regression fitted to *log(k)* as a function of log(r), for r-k pairs where r is larger than median of mid-values of occupied bins. MSY are obtained as geometric mean of the MSY values calculated for each of the r-k pairs where r is larger than the median. Viable biomass trajectories were restricted to those associated with an r-k pair that fell within the confidence limits of the C-MSY estimates of r and k.

Table 2: Prior ranges used for *S. guttatus* in the C-MSY analysis reference model

Species	**Initial B/K**	**Final B/K**	***r***	***K (1000 t)***
Reference model	0.5–0.9	0.2–0.6	0.6–2.0	23 – 308

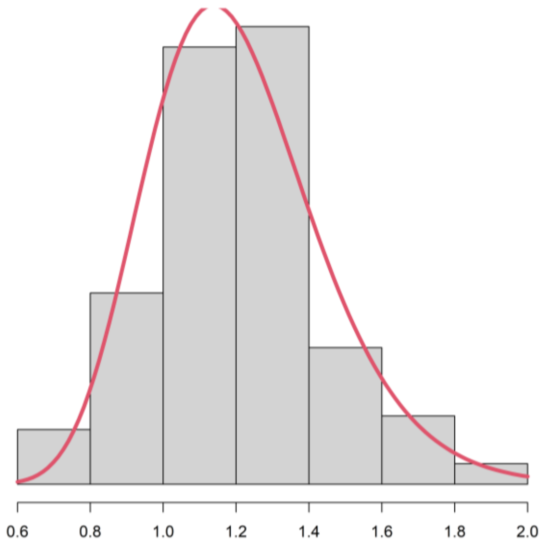

Figure 4: Estimated distribution of the population growth rate r for *S. guttatus*, using the LHM module of Edwards (2016).

4.2. CMSY++ method

The CMSY++ model is a further development of the CMSY method (Froese et al. 2021). The major difference is the use of a full Bayesian approach with MCMC (Markov chain Monte Carlo) modelling for the catch-only analysis, as opposed to the deterministic, stock reduction analytic approach. Another improvement to the CMSY is the introduction of multivariate normal priors for *r* and *k* in log space, replacing the previous uniform prior distributions. This allowed also for a simplified determination of the 'best' *r-k* pair in CMSY (Froese et al. 2021). The CMSY++ model is run using the same r, k, and biomass prior as in Table 2.

5. Results

5.1. C-MSY method

Figure 5 shows the results of the reference model from the CMSY analysis. Panel A shows the time series of catches in black and the three-years moving average in blue with indication of highest and lowest catch. The use of a moving average is to reduce the influence of extreme catches.

Panel B shows the explored r-k values in log space and the r-k pairs found to be compatible with the catches and the prior information. Panel C shows the most probable r-k pair and its approximate 95% confidence limits. The probable r values did not span through the full prior range, instead ranging from 1.12–1.97 (mean of 1.48) while probable K values ranged from 87 000 – 188 000 (mean of 127 000). Given that r and K are confounded, a higher K generally gives a lower r value. CMSY searches for the most probable r in the upper region of the triangle, which serves to reduce the bias caused by the triangular shape of the cloud of viable r-k pairs (Ferose et al. 2016).

Panel D shows the estimated biomass trajectory with 95% confidence intervals (Vertical lines indicate the prior ranges of initial and final biomass). The method is highly robust to the initial level of biomass assumed (mainly due to the very low catches for the early part of series), while the final depletion range has a determinative effect on the final stock status. The biomass trajectory closely mirrors the catch curve with a rapid decline since the late 2000s.

Panel E shows in the corresponding harvest rate from CMSY. Panel F shows the Schaefer equilibrium curve of catch/MSY relative to B/k. However, we caution that the fishery was unlikely to be in an equilibrium state in any given year.

Figure 6 shows the estimated management quantities. The upper left panel shows catches relative to the estimate of MSY (with indication of 95% confidence limits). The upper right panel shows the total biomass relative to Bmsy, and the lower left graph shows exploitation rate F relative to Fmsy. The lower-right panel shows the development of relative stock size (B/Bmsy) over relative exploitation (F/Fmsy).

The IOTC target and limit reference points for neritic tuna species have not yet been defined, so the values applicable for other IOTC species are used. Management quantities (estimated means and 95% confidence ranges) are provided in Table 3, which shows an average MSY of about 47 000 t. The KOBE plot indicates that based on the C-MSY model results, Indo-Pacific king mackerel is currently not overfished (B2022/BMSY=1.02) and is not subject to overfishing (F2022/FMSY = 0.95). The average catch over the last five years is just below the estimated MSY (Table 3).

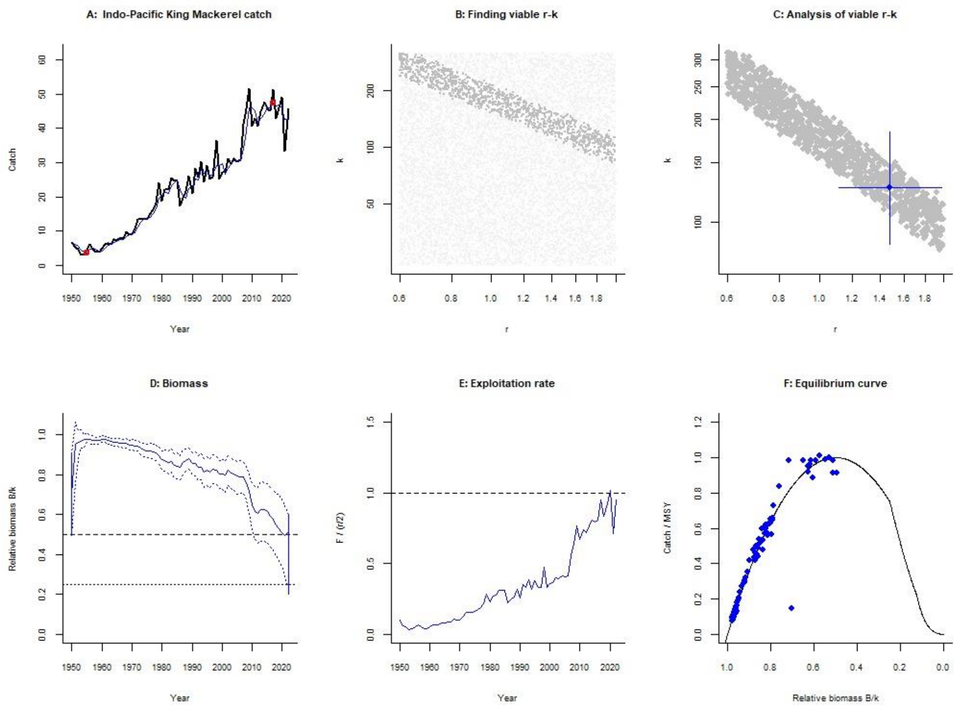

Figure 5. Results of CMSY reference model for Indo-Pacific King Mackerel.

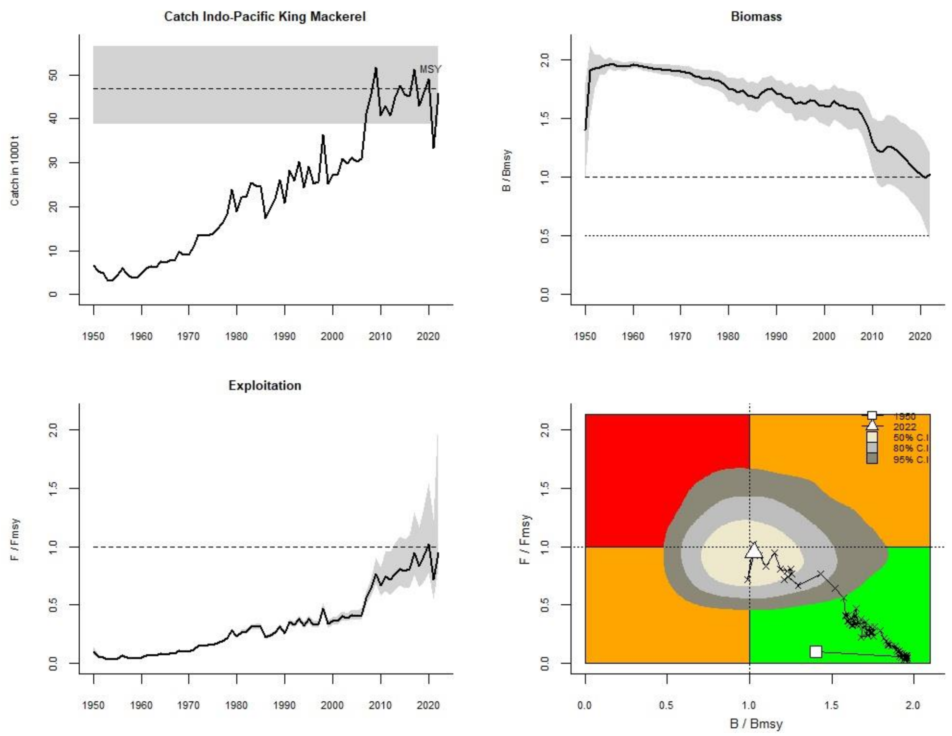

Figure 6. Graphical output of the CMSY reference model of Indo-Pacific King Mackerel for management purposes.

Table 3. Key management quantities from the Catch MSY assessment for Indo-Pacific king mackerel. Geometric means (and plausible ranges across all feasible model runs). n.a. = not available. Previous assessment results are provided for comparison.

Management Quantity	2021 Reference model	2024 Reference model	2024 CMSY++ model
Most recent catch estimate	43 131 t (2019)	45 769t (2022)	45 769 t (2022)
Mean catch –recent 5 years	45 112 t (2015 – 2019)	43 416 t (2018 – 2022)	43 416 t (2018 – 2022)
MSY (95% CI)	46 900 (37 700 –58 400)	47 000 (39 000 –56 000)	45 600 (38 400–51 900)
Data period used in assessment	1950 – 2019	1950 – 2022	1950 – 2022
F_{MSY} (95% CI)	0.74 (0.56- 0.99)	0.74 (0.56- 0.99)	0.49 (0.30–0.63)
B_{MSY} (95% CI)	632 000 (42 000 – 940 000)	631 000 (43 100 – 92 400)	93 100 (73 100–138 000)
$F_{current}/F_{MSY}$ (95% CI)	0.90 (0.78 – 2.01)	0.95 (0.82 – 2.13)	1.08 (0.61–2.08)
$B_{current}/B_{MSY}$ (95% CI)	1.03 (0.46 – 1.19)	1.02 (0.46 – 1.19)	0.89 (0.53–1.28)
$B_{current}/B_0$ (95% CI)	0.51(0.23 - 0.60)	0.51 (0.23 - 0.60)	0.45 (0.27–0.64)

5.2. CMSY++ method

The posterior estimates of key quantities from the CMSY++ model is shown in
Figure 7. The model resulted in more pessimistic estimate of stock status, indicating that Indo-Pacific king mackerel is currently overfished (B2022/BMSY=0.89) and is subject to overfishing (F2022/FMSY = 1.08). (Figure 8, Table 3).

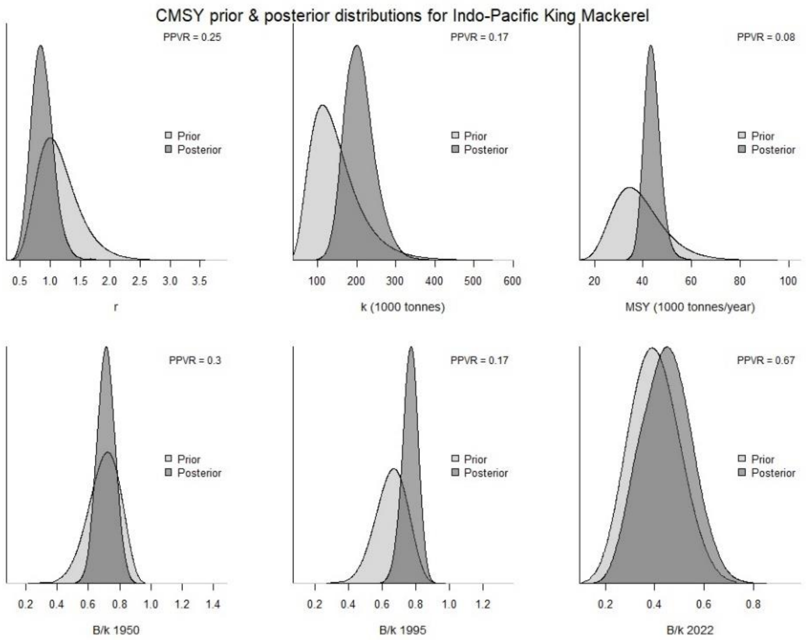

Figure 7. Prior and posterior distributions of CMSY++ model for Indo-Pacific King Mackerel.

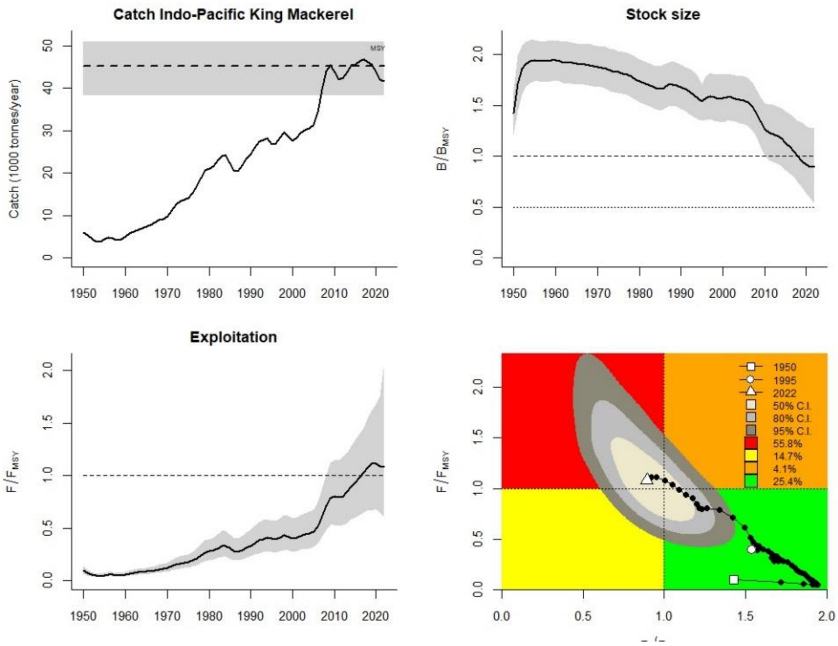

Figure 8. Graphical output of the CMSY++ reference model of Indo-Pacific King Mackerel for management purposes.

6. Discussion

In this report we have explored two data-limited methods in assessing the status of Indo-Pacific king mackerel: C-MSY and LB-SPR. The C-MSY is based on an aggregated biomass dynamic model and requires only the catch series as model input and uses simulations to locate feasible historical biomass that support the catch history. Estimates from the C-MSY model suggested that currently the stock of Indo-Pacific king mackerel in the Indian Ocean is not overfished (B2022 > BMSY) and is not subject to overfishing (F2022 < FMSY), although the estimates would be more pessimistic under the C-MSY++ framework. The C-MSY estimated a mean MSY of approx. 47 000 t with a relatively wider range. Reported catches of Indo-Pacific king mackerel in the Indian Ocean has increased considerably since the late 2000s, with recent catches ranging between 40600 and 51600. The catch in 2022 was below the estimated MSY. Despite the substantial uncertainties described throughout this paper, this suggests that the stock is very close to being fished at MSY levels and that higher catches may not be sustained. A precautionary approach to management is recommended.

The C-MSY assessment is based primarily on the catch data and an underlying Schaefer model. Production models often provide robust or stable estimates regardless of uncertainties in basic biological characteristics. In general, simple model cannot represent important dynamics and thus is more likely to yield biased results. The consistent estimates amongst C-MSY simulations are largely attributed to the strong assumptions imposed on the population dynamics and stock productivity, including the intrinsic growth rate and carrying capacity parameters. The assumption made on the terminal depletion level is subjective but is highly influential on estimates of stock status.

References

Collette, B.B., 2001. Scombridae. Tunas (also, albacore, bonitos, mackerels, seerfishes, and wahoo). p. 3721-3756. In K.E. Carpenter and V. Niem (eds.) FAO species identification guide for fishery purposes. The living marine resources of the Western Central Pacific. Vol. 6. Bony fishes part 4 (Labridae to Latimeriidae), estuarine crocodiles. FAO, Rome.

Collette, B.B. and C.E. Nauen, 1983. FAO Species Catalogue. Vol. 2. Scombrids of the world. An annotated and illustrated catalogue of tunas, mackerels, bonitos and related species known to date. Rome: FAO. FAO Fish. Synop. 125(2):137 p.

Charnov, E.R., Gislason, H., & Pope, J.P. 2013. Evolutionary assembly rules for fish life histories. Fish and Fisheries. 14: 213-224.

Edwards, C.T.T. 2016. BDM: Bayesian Biomass Dynamic Model, URL https://github.com/cttedwards/bdm.git

Froese, R. & Pauly, D., 2015. Fish Base.

Froese, R., Demirel, N., Caro, G., Kleisner, K.M. and Winker, H., 2016. Estimating fisheries reference points from catch and resilience. Fish and Fisheries, 18 (3). pp. 506-526. DOI 10.1111/faf.12190.

Froese, R., Demirel, N., Coro, G. and Winker, H. 2021. User Guide for CMSY++. GEOMAR, Germany, 17 pp.

Fu, D., Martin, S. 2017. Assessment of Indian Ocean longtail tuna (Thunnus tonggol) using data-limited methods. IOTC–2017–WPNT07–15.

Fu, D. 2021. Assessment of Indian Ocean Indo-Pacific King Mackerel (*Scomberomorus guttatus*) using data-limited methods. IOTC–2021–WPNT11–13.

Heidrich, K., Meeuwig J., Zeller, D. 2023. Reconstructing past fisheries catches for large pelagic species in the Indian Ocean. Frontiers in Marine Science 10:

Hordyk, A., Ono, K., Valencia, S., Loneragan, N., Prince, J. 2014a. A novel length-based empirical estimation method of spawning potential ratio (SPR), and tests of its performance, for small-scale, data-poor fisheries. ICES Journal of Marine Science (2015), 72(1), 217–231.

Hordyk, A., Ono, K., Valencia, S., Sainsbury, K., Prince, J. 2014b. Some explorations of the life history ratios to describe length composition, spawning-per-recruit, and the spawning potential ratio. ICES Journal of Marine Science (2015), 72(1), 204–216.

Martell, S. and Froese, R. 2012. A simple method for estimating MSY from catch and resilience. Fish and Fisheries. 14: 504–514.

Martin, S. and Sharma, R. 2015. Assessment of Indian Ocean Indo-Pacific king mackerel (*Scomberomorus guttatus*) using data poor catch-based methods. IOTC-2015-WPNT05-24.

McAllister, M. K., Pikitch E. K., and Babcock E. A. 2001. Using demographic methods to construct Bayesian priors for the intrinsic rate of increase in the Schaefer model and implications for stock rebuilding. Canadian Journal of Fisheries and Aquatic Sciences, 58, 1871-1890.

Pauly, D. 1980. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. J. Cons. Int. Explor. Mer: 175-192.

Robinson, J. 2015. Population Parameters: Indo-Pacific King Mackerel (*Scomberomorus guttatus*). IOTC–2016–WPNT06–DATA12.

Schaefer, M.B. 1954. Some aspects of the dynamics of populations important to the management of commercial marine fisheries. Bulletin, Inter-American Tropical Tuna Commission 1:27-56.

Zhou, S., Yin, S., Thorson, J. 2012. Linking fishing mortality reference points to life history traits: an empirical study. Canadian Journal of Fisheries and Aquatic Sciences, 69: 1292–1301.