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. Stock assessments was conducted for Indo-Pacific king mackerel (*Scomberomorus guttatus*) in 2015, using data-limited methods (Martin & Sharma 2015). This paper provides an update to the C-MSY assessment (Froese et al. 2016) based on the most recent catch information. In addition, a length-based method for estimation of spawning potential ratio (Hordyk et al. 2014) was also applied to the available length composition data of the Indo-Pacific king mackerel from the gillnet fishery.

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 1950–2019, given that records for 2020 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 43 468 t reported in 2019 (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).

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.

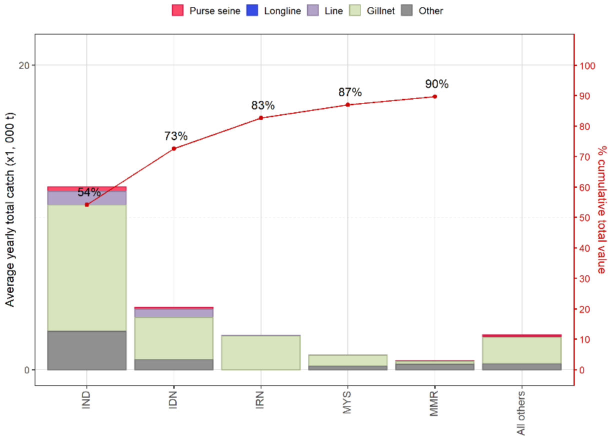

Figure 1: Average catches in the Indian Ocean over the period 2015-2019, by country. The red line indicates the (cumulative) proportion of catches of *S. guttatus* by country.

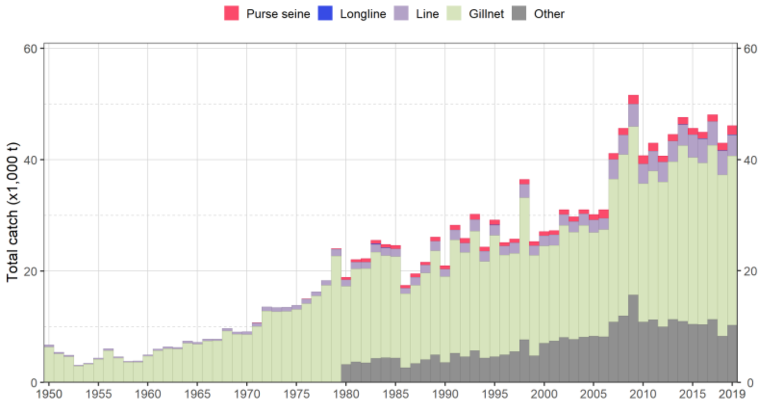

Figure 2: Annual catches of *S. guttatus* by gear, 1950 – 2019 (IOTC database).

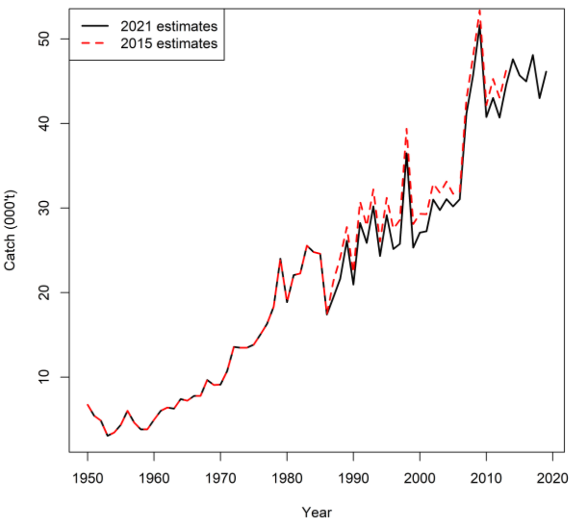

Figure 3: Revisions to IOTC nominal catch data for *S. guttatus* (datasets used for the 2015 and 2020 assessments).

Table 1. Catch data for *S. guttatus* in the Indian Ocean, 1950-2019 (source IOTC Database)

Year	Catch (t)	Year	Catch (t)
1950	6 744	1985	24 603
1951	5 431	1986	17 420
1952	4 871	1987	19 503
1953	3 083	1988	21 637
1954	3 461	1989	26 140
1955	4 368	1990	20 954
1956	6 035	1991	28 237
1957	4 636	1992	25 884
1958	3 824	1993	30 213
1959	3 844	1994	24 338
1960	4 971	1995	29 166
1961	6 026	1996	25 158
1962	6 426	1997	25 765
1963	6 282	1998	36 471
1964	7 415	1999	25 317
1965	7 230	2000	27 102
1966	7 780	2001	27 263
1967	7 803	2002	31 013
1968	9 678	2003	29 768
1969	9 081	2004	31 062
1970	9 132	2005	30 328
1971	10 740	2006	31 546
1972	13 587	2007	41 148
1973	13 484	2008	45 684
1974	13 497	2009	51 631
1975	13 847	2010	41 027
1976	15 040	2011	43 100
1977	16 307	2012	40 662
1978	18 331	2013	44 566
1979	24 015	2014	47 570
1980	18 878	2015	45 647
1981	22 074	2016	44 932
1982	22 265	2017	48 096
1983	25 563	2018	43 468
1984	24 798	2019	46 131

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.

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

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

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

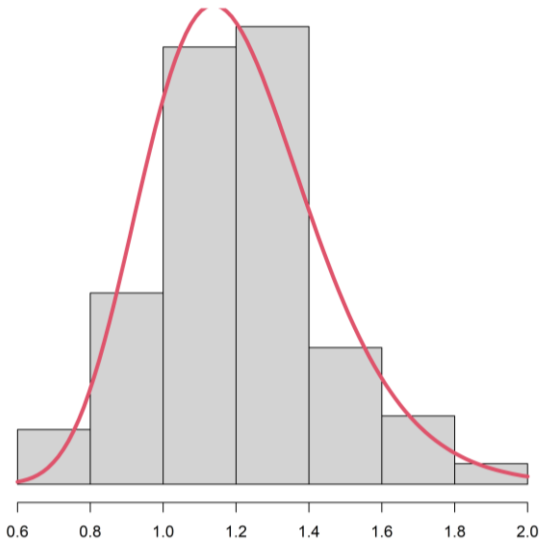

Figure 4: Estimated distribution of the population growth rate r for *S. guttatus*, using the LHM module of Edwards (2016).

4.2. Length-based Spawner Potential Ratio (LB-SPR)

The LB-BTR method (Hordyk et al. 2014a) estimates the Spawning Potential Ratio (SPR) of a stock directly from the size composition of the catch. The SPR of a stock is defined as the proportion of the unfished reproductive potential left at any given level of fishing pressure (Hordyk et al. 2014b) and is commonly used to set target and limit reference points for fisheries. The $F_{40\%}$, i.e. the fishing mortality rate that results in SPR at 40%, is considered risk adverse for many species. The LP-BTR establish that how length compositions and spawning ratios are determined by fishing mortality and life history ratio, which are known to be less variance across species. The LP-BTR uses maximum likelihood methods to estimate relative fishing mortality (F/M) and selectivity-at-length that minimize the difference between the observed and the expected length composition of the catch and calculates the SPR (Hordyk et al. 2014a). The LB-SPR model requires the following parameters: an estimate of the ratio M/k (i.e. the individual values of the M and k parameters may be unknown), L^{∞} (and associated variance), and maturity-at-size. These parameters for S. *guttatus* are obtained from Robinson (2015).

The length data used are those provided to the WPNT11 (IOTC-2020-WPNT10-DATA09-SFdata), which contains length samples by gear, fleet, year, month, and spatial area. For Indo-Pacific king mackerel, the sampling was poor, and only a few samples were available from the Sri Lanka gillnet fishery in the 1980s, and from the small purse seiners in the early 2000s. Therefore, it is not possible to assess the status of king mackerel using LB-BTR, instead we applied the method to gillnet data in the 1980s to demonstrate the application of the method. (The length samples from small purse seiners contain mostly younger fish whereas the LB-SPR model should be applied to data from the fleet that target the adult portion of the stock.)

1. Results

1.1. 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 85 000 – 188 000 (mean of 126 000). 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 46 900 t. The KOBE plot indicates that based on the C-MSY model results, Indo-Pacific king mackerel is currently not overfished (B2019/BMSY=1.03) and is not subject to overfishing (F2019/FMSY = 0.90). The average catch over the last five years is lower than the estimated MSY.

The CMSY produced more pessimistic results under the alternative r range of 0.2 – 0.6, with B2019 estimated to be 95% of BMSY, and F2019 estimated 13% higher than FMSY. This is not surprising as the stock is assumed to be less resilient (Table 3).

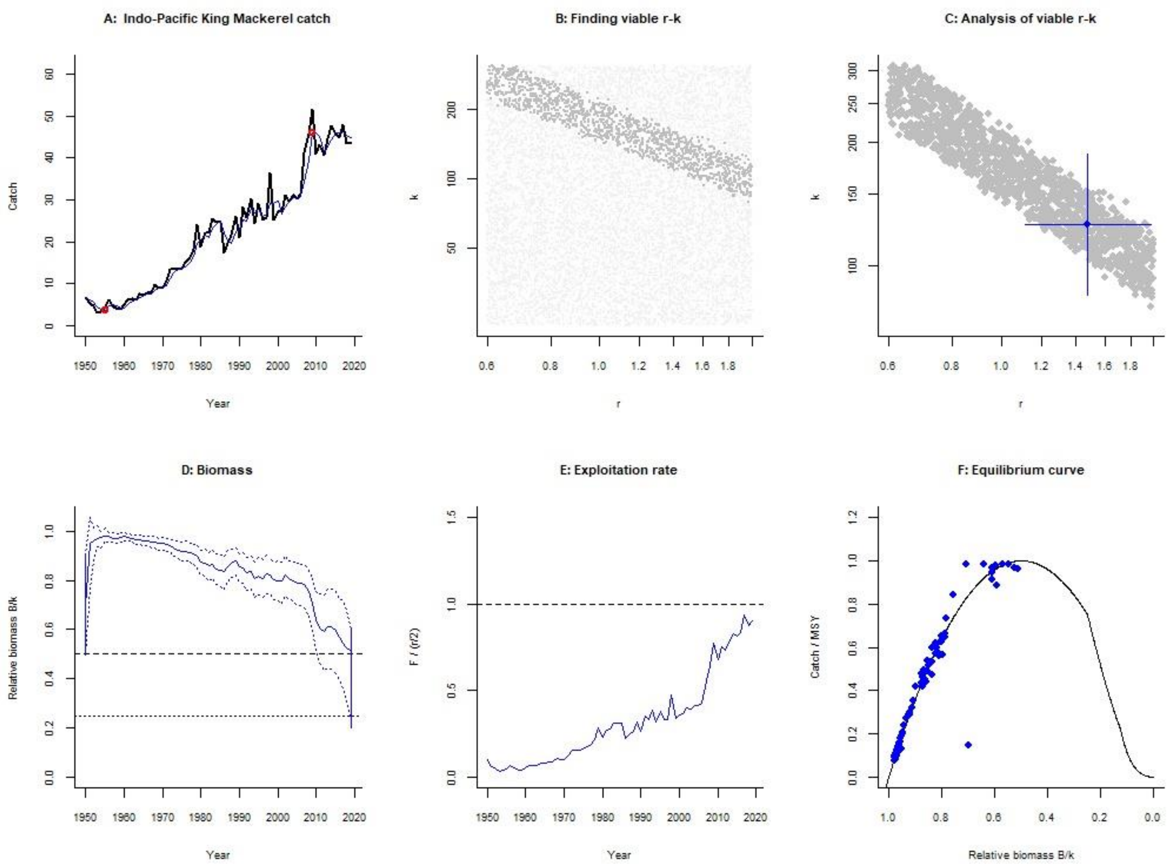

Figure 5. Results of CMSY reference model for Indo-Pacific King Mackerel.

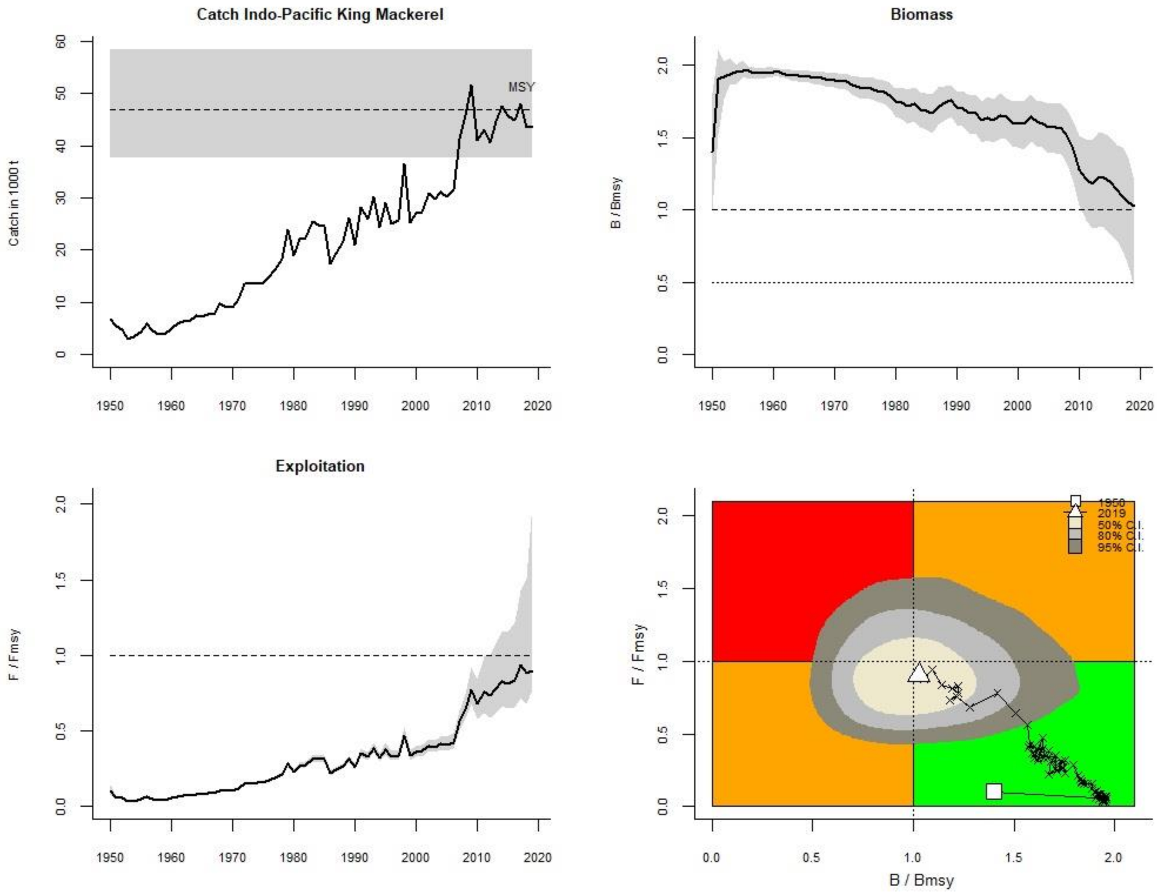

Figure 6. Graphical output of the CMSY reference model of Indo-Pacific King Mackerel for management purposes.

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	**Reference model （r 0.6–2.0）**	**Sensitivity (r 0.2–0.8)**
Most recent catch estimate	43 131 t (2019)	43 131 t (2019)
Mean catch –recent 5 years	45 112 t (2015 – 2019)	45 112 t (2015 – 2019)
MSY (95% CI)	46 900 (37 700 –58 400)	40 700 (31 900 –51 900)
Data period used in assessment	1950 – 2019	1950 – 2019
F_{MSY} (95% CI)	0.74 (0.56- 0.99)	0.28 (0.20- 0.39)
B_{MSY} (95% CI)	632 000 (42 000 – 940 000)	144 000 (91 700 – 226 000)
$F_{current}/F_{MSY}$ (95% CI)	0.90 (0.78 – 2.01)	1.13 (0.89 – 2.48)
$B_{current}/B_{MSY}$ (95% CI)	1.03 (0.46 – 1.19)	0.95 (0.43 – 1.19)
$B_{current}/B_0$ (95% CI)	0.51(0.23 - 0.60)	0.47(0.22 - 0.60)

1.2. LB-SPR method

The LB-SPR provides a reasonable fit to the length distribution in 1988 (Figure 7-left). The model estimated 50% and 95% selection to be around 36 and 41 cm respectively (Figure 7-right). The ratio of F/M was estimated to be around 0.4 (The ratio of F/M has often been used as a biological reference point, with FMSY= 0.87M considered a reasonable approximation for teleost (Zhou et al., 2012)). The Spawning potential ratio was estimated to be around 0.58 (the SPR of 0.4 is often considered a risk-averse target, see Hordyk et al. 2014a), indicating a relatively health status in the late 1980s when the samples were collected (Figure 7-right).

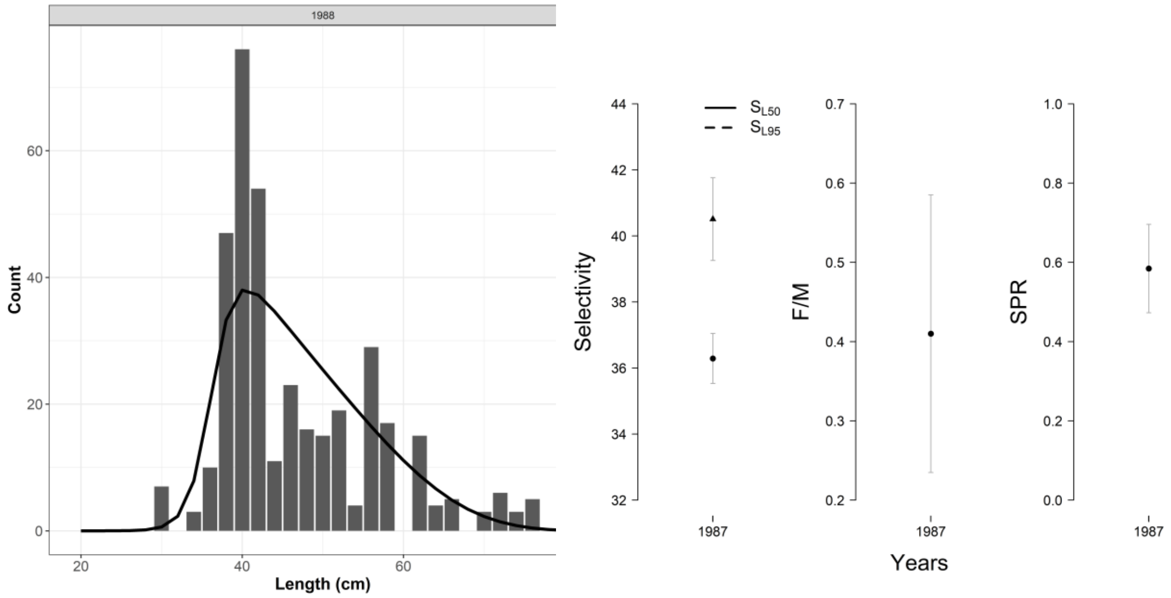

Figure 7: Results of LB-SPR method applied to the length samples from the gillnet fishery for Indo-Pacific king mackerel: Fits to the length frequency in 1988 (black dots) a; right – estimates (with 95% CI) of logistic selectivity parameter (a50 and a95), F/M, and Spawning Potential Ratio.

2. 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 (B2019 > BMSY) and is not subject to overfishing (F2019 < FMSY), although the estimates would be more pessimistic if the stock productivity is assumed to be less resilient. The C-MSY estimated a mean MSY of approx. 46 900 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 2019 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.

For Indo-Pacific king mackerel, we are not able to use LB-SPR to assess current stock status due to the lack the length samples in recent years, yet the analysis has demonstrated an application of the method for estimating Spawning Potential Ratio, a well-established biological reference point, by utilizing life history parameters and historical length samples. The LB-SPR has potential to provide a cost-effective tool for the assessment of IOTC neritic tuna stocks considering length data are one of the easiest and most affordable data to collect for many small-scale, data-poor fisheries (Hordyk et al. 2014a). In contract to the C-MSY method (and other catch only methods), which requires accurate and complete catch statistics, the LB-SPR only requires the length frequency data to be representative, which is more likely to achieve for many IOTC neritic tuna species.

One concern is that the LB-SPR model assumes asymptotic selectivity and the results are shown to be sensitive to the assumption (as the model interprets the absence of the large individuals from the size structure as evidence for a high level of exploitation, see Hordyk et al. (2014a)). In the analysis, the LB-SPR was applied to the length samples from the gillnet fishery. Although gillnet is typically featured a dome-shape selectivity, the doming is unlikely to be severe for Indo-Pacific king mackerel, given the relatively small size of this species ($L^{\infty} \approx 70cm$). Further, Hordyk et al. (2014a) showed that the species with high M/K ratio (such as king mackerel) are less sensitive to the doming, as fewer individuals live long enough to reach asymptotic size such that a smaller fraction of the population is affected by the dome-shaped selectivity.

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