Assessment of Indian Ocean Indo-Pacific king mackerel (*Scomberomorus guttatus*) using data poor catch-based methods

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IOTC Secretariat

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Introduction

Assessing the status of the stocks of neritic tuna species in the Indian Ocean is fairly challenging due to the lack of available data. This includes limited information on stock structure, a lack of standardised CPUE series and biological information. A number of assessment methods for the data-poor context of neritic tuna species have been used by IOTC in recent years, including a first stock assessment attempt for Indo-pacific king mackerel (*Scomberomorus guttatus*) in 2015 (IOTC-2015-WPNT05-24).

In this paper, two data-poor methods are again applied to assess the status of Indian Ocean Indo-pacific king mackerel: (i) a Catch-MSY method, based on stock reduction analysis (Kimura and Tagart 1982; Walters et. al. 2006; Martell and Froese 2012) and a recently developed posterior-focussed Optimised Catch Only Method, OCOM (Zhou et al., 2013). Other neritic species investigated using the same methods in 2016 included: Indian Ocean Longtail tuna (*Thunnus tonggol*) (IOTC-2016-WPNT06-17) and Narrow-barred Spanish mackerel (*Scomberomorus commerson*) (IOTC-2016-WPNT06-18).

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.

Fisheries and Catch Trends

Nominal catches of *S. guttatus* are lower than many of the other neritic species, with a total catch of only 49 060 t reported in 2014 (Table 1). Catches increased to a reported maximum of 53 448 t in 2009 and have remained lower in subsequent years. The countries reporting the highest catches of *S. guttatus* are India, Indonesia, I.R. Iran and Myanmar (Figure 1). Catches by gear continues to be dominated by gillnet (Figure 1; Figure 2). There have been some changes to the nominal catch estimates since the assessment in 2015, but these were limited to the years between 2009 and 2013 and were relatively minor (Figure 3).

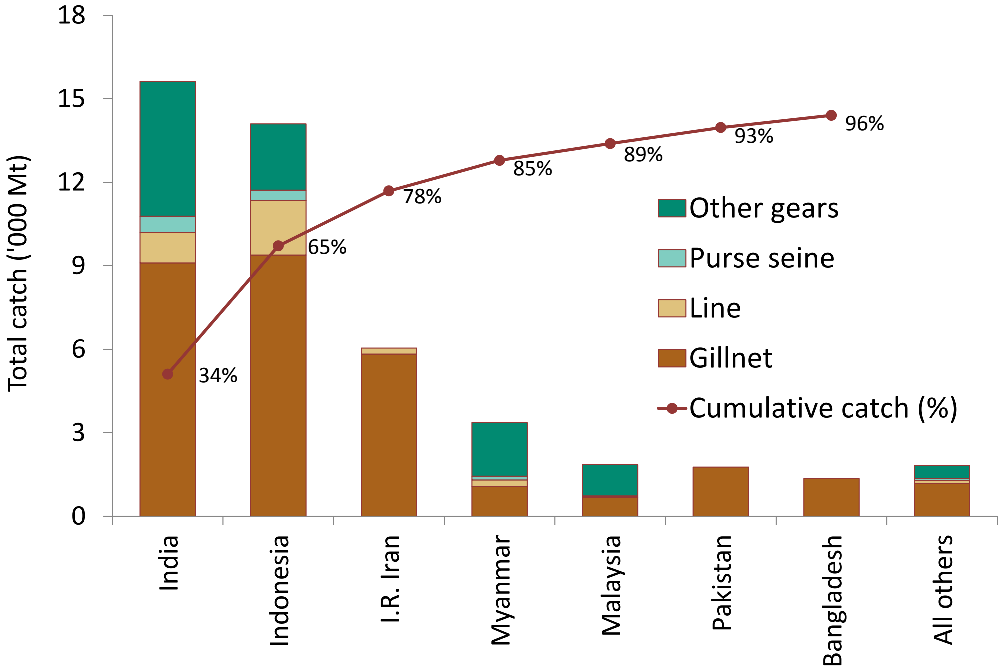

Figure 1. Average catches in the Indian Ocean over the period 2012-2014, by country. Countries are ordered from left to right, according to the level of catches of *S. guttatus* reported. The red line indicates the (cumulative) proportion of catches of *S. guttatus* for the countries concerned, over the total combined catches of this species reported from all countries and fisheries

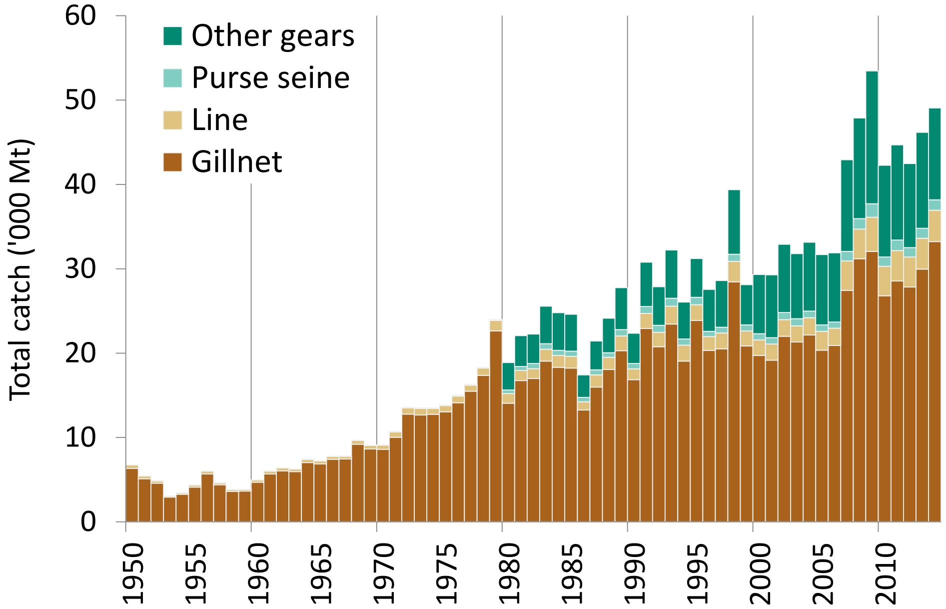

Figure 2. Annual catches of *S. guttatus* by gear as recorded in the IOTC Nominal Catch database (1950–2014)

Table 1. Catch data for *S. guttatus* in the Indian Ocean, 1950-2014 (source IOTC Nominal Catch Database)

Year	Catch (t)	Year	Catch (t)	Year	Catch (t)	Year	Catch (t)
1950	6,744	1967	7,803	1984	24,798	2001	29,280
1951	5,431	1968	9,678	1985	24,603	2002	32,898
1952	4,871	1969	9,081	1986	17,420	2003	31,803
1953	3,083	1970	9,132	1987	21,431	2004	33,144
1954	3,461	1971	10,740	1988	24,140	2005	31,689
1955	4,368	1972	13,587	1989	27,759	2006	31,889
1956	6,035	1973	13,484	1990	22,363	2007	42,923
1957	4,636	1974	13,497	1991	30,783	2008	47,880
1958	3,824	1975	13,847	1992	27,877	2009	53,448
1959	3,844	1976	15,040	1993	32,219	2010	42,260
1960	4,971	1977	16,307	1994	26,046	2011	44,684
1961	6,026	1978	18,331	1995	31,213	2012	42,476
1962	6,414	1979	24,015	1996	27,559	2013	46,170
1963	6,282	1980	18,878	1997	28,601	2014	49,060
1964	7,415	1981	22,074	1998	39,385		
1965	7,230	1982	22,265	1999	28,113		
1966	7,780	1983	25,563	2000	29,326		

As reported in IOTC-2015-WPNT05-24, the Secretariat uses catch estimation procedures for many neritic species given that they are often caught together and can be difficult to separate by species, which typically results in reports of aggregate, mixed species catches. These issues extend to the seerfishes, *S. commerson* and *S. guttatus*. Nominal catches of each species often have to be estimated from the best available data, which may include the proportional representation of species caught by the fleet in previous years, or be based on proportional catches by similar fleets that are used as proxies. Notable catches that require estimation procedures include those for Bangladesh, Indonesia, Iran, Malaysia, Myanmar, Pakistan, Thailand, and Yemen, with prominent issues described more fully in IOTC-2015-WPNT05-24.

The use of estimation procedures results in the nominal catches of the neritic species being closely correlated (Figure 4). As expected, the catches of *S. guttatus* are particularly correlated with *S. commerson.* This should be taken into consideration when considering the reliability of the assessment results, given that these methods are almost wholly reliant on the catch series trends. This highlights the interdependency of the data, and therefore the assessments, which depend on accurate reporting by species.

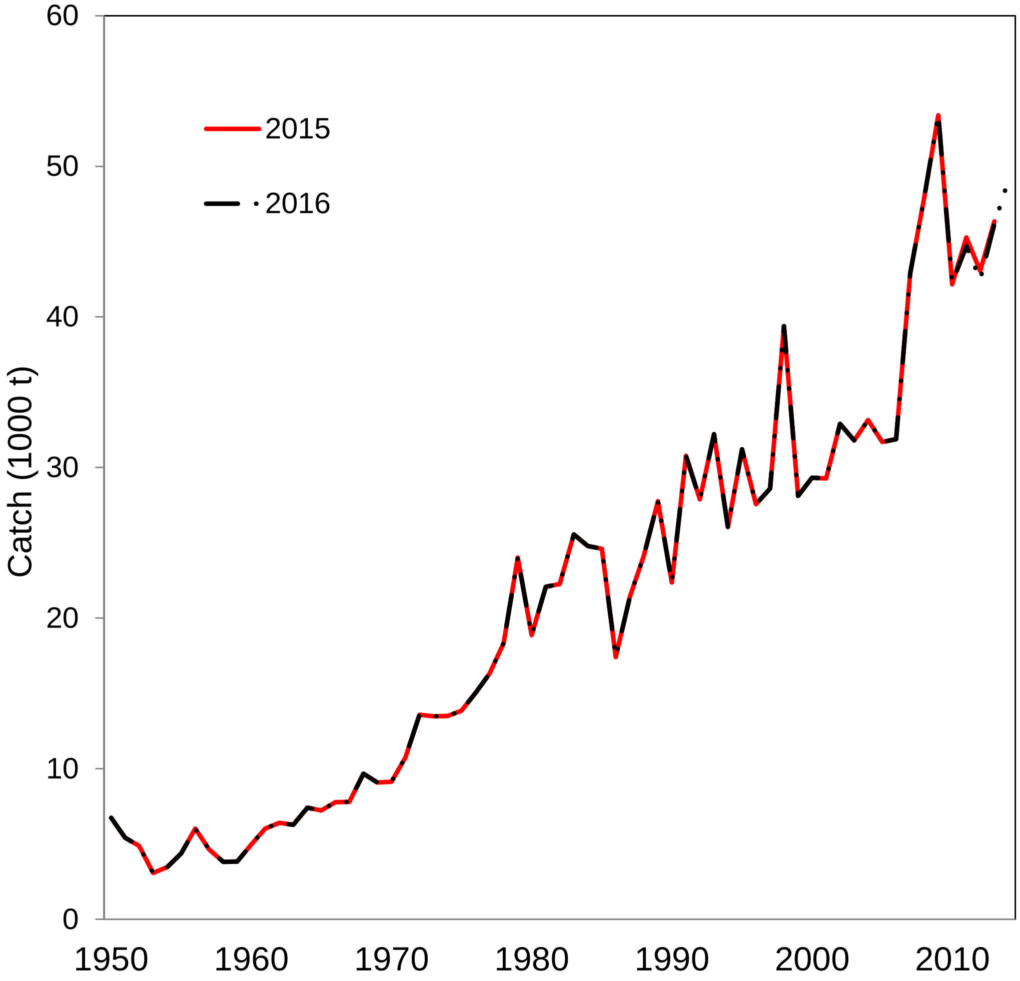

Figure 3. Revisions to IOTC nominal catch data for Indo-Pacific king mackerel

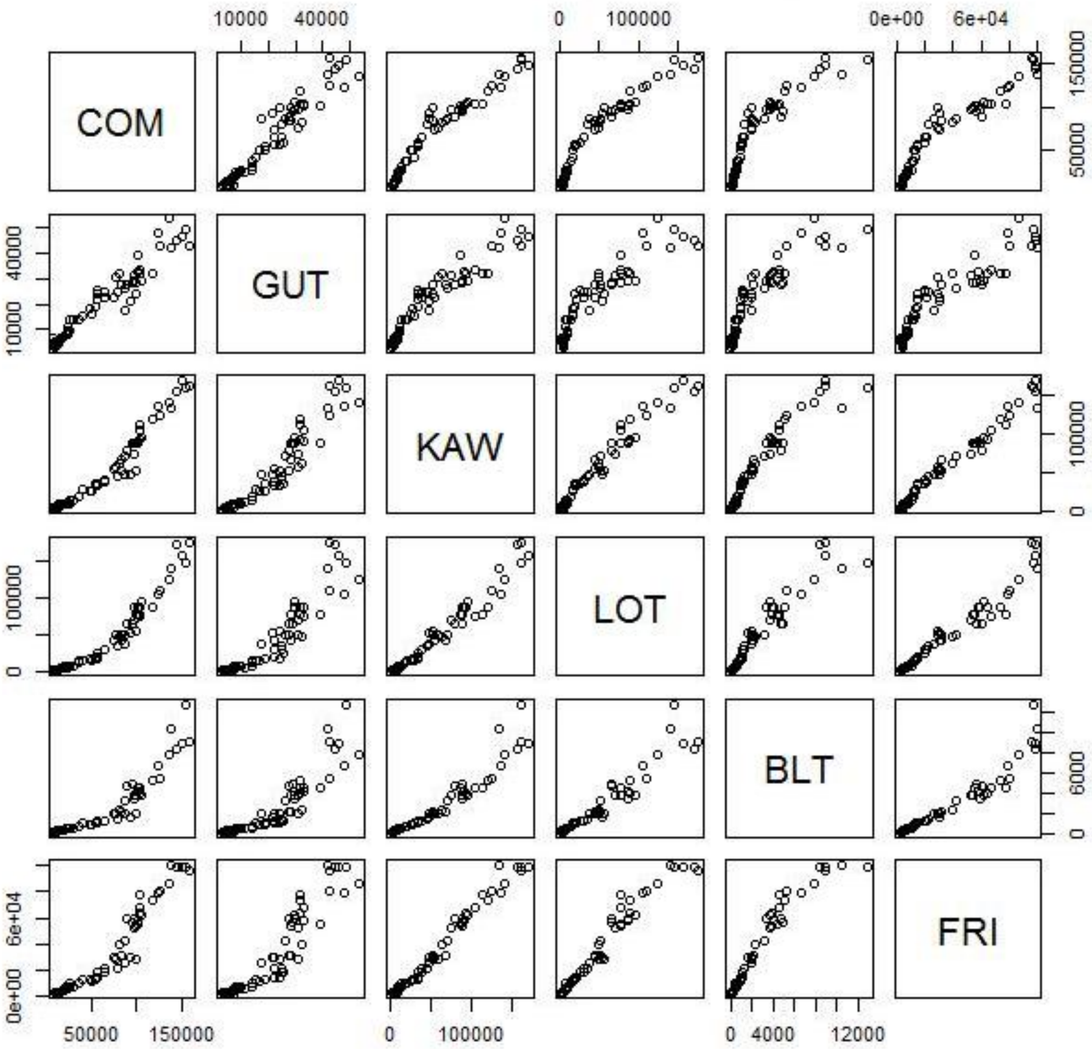

Figure 4. Scatterplot matrix showing the correlations between catches of the six neritic tuna species. COM *(Scomberomorus commerson)*, GUT *(Scomberomorus guttatus*), KAW *(Euthynnus affinis)*, LOT *(Thunnus tonggol)*, BLT (*Auxis rochei*) and FRI (*Auxis thazard*).

Methods

1) Catch-MSY method

This method, developed by Martell and Froese (2012) relies on only a catch time series dataset, which was available from 1950 – 2014, 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 then used (Equation 1), 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.

$$B_{t+1} = B_t + rB_t\left(1-\frac{B_t}{B_0}\right) - C_t$$

Equation 1.

There are no known prior distributions of the parameters *r* and *K*, so a uniform distribution was used from which values were randomly drawn. A reasonably wide prior range was set for *r* based on the known level of resilience of the stock as proposed by Martell and Froese (2012) where stocks with a very low resiliency are allocated an r value from 0.015 - 0.1, low resiliency 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 high level of resilience and so a range of 0.6 - 1.5 was used.

A reasonably wide prior range was also used for *K*, which ranged from the minimum catch in the times series to the maximum multiplied by 50, i.e., *K* is between max(C) and 50*max(C). The ranges for starting and final depletion levels were based on the ratio of starting and final catch to the maximum as in Table 2. This essentially gives a lower initial biomass if the initial catch was large, relative to the maximum, and gives a higher initial biomass if the initial catch was relatively lower. Conversely, in terms of the final biomass, a higher biomass is expected with a higher final catch (relative to the maximum) and a lower biomass if the final catch is lower relative to the maximum (Martell and Froese (2012).

Table 2. Rules to determine starting and final biomass levels were B is biomass and k is carrying capacity

	Catch/max catch	*B/k*
First year	<0.5	0.5 – 0.9
	≥0.5	0.3 – 0.6
Final year	>0.5	0.3 – 0.7
	≤0.5	0.01 – 0.4

This resulted in the prior ranges used as specified in Table 3. The model worked sequentially through the range of initial biomass depletion level with intervals of 0.05 and random pairs of r and K were drawn based on the uniform distribution for the specified ranges. A Bernoulli distribution was then used as the likelihood function for accepting each r-k pair, for a given starting biomass level, which has never collapsed the stock or exceeded carrying capacity and that results in a final biomass estimate which falls within the assumed depletion range. All *r-k* combinations for each starting biomass which were considered feasible were retained with the corresponding biomass trajectories.

Table 3. Prior ranges used for each species (Catch – MSY method)

Species	**Initial *B/k***	**Final *B/k***	***r***	***K (1000 t)***
Indo-Pacific king mackerel	0.5 - 0.9	0.3 – 0.7	0.6 - 1.5	53 - 2672
			0.6 - 1.8	91 - 218

Management quantities were calculated based on geometric means of the standard Schaefer model equations, i.e.:

$$MSY = \frac{rk}{4}\,,\ B_{MSY} = \frac{k}{2} \text{ and } F_{MSY} = -ln\left[1 - \left[\frac{MSY}{(Bmsy+MSY)}\right]\right]$$

2) Optimised Catch Only Method (OCOM)

The Optimised Catch-Only Method was developed by Zhou *et al*. (2013) and also relies on only a catch time series dataset without necessary knowledge of prior distributions. The idea behind this approach is to use unconstrained priors on both *r* and *K*, that is $0 < K < \infty$ and $0 < r < \infty$. Because the two parameters are negatively correlated, the maximum *K* is constrained by *r* = 0 and maximum *r* is constrained by the minimum viable *K*. The aim of this approach is to identify the likely range of both r and *K* and the most likely *r* ~ *K* combination on the curve which retain a viable population over time (i.e. where $Bt > Ct$, $Bt \leq K$ *and* $Bt > 0$ always hold true). This approach produces results from a number of trials from which the improbable values are then excluded, so the method has been referred to as a posterior-focused catch-based method for estimating biological reference points (Zhou *et al.*, 2013).

The approach uses an optimisation model to estimate the feasible *r* value corresponding to a fixed final depletion level and a sampled *K* value by minimising the difference between the final biomass and the given depletion level (i.e. minimising the objective function $|B_{2014} - DK|$ where B_{2014} is the biomass in the final year of data, K is the carrying capacity and D is the depletion level). All feasible combinations of *r* and *K* are retained and the biomass dynamics model is re-run without any further constraints for a large number of simulations (500). The biomass trajectories are stored and those which are considered unfeasible according to the biomass constraints described above are removed.

Maximum *K* was set at 50 * max(*C*) and minimum *K* was set at max(*C*). The starting *K* population was set as a logarithmic sequence between these two values. Starting depletion levels comprised the range 0.05 to 0.8 in steps of 0.05. A wide prior range of *r* values was used, from 0.1 to 2. A biomass dynamics model was then run with the associated constraints: $Bt \leq K$, $Bt > 0$, $B > C$. The biomass in 1950 was assumed equal to the carrying capacity ($Bt_{1950} = K$). The optimisation routine was then used to retain the *r* values which result in a biomass closest to the fixed final biomass by minimising the difference between B_{2014} and *DK*. Where the difference between the final biomass and the specified depletion level was >10% of *K*, the values were considered unfeasible and were not retained. This resulted in a matrix of r values for each combination of K and final depletion level.

As a second step in the method, estimates of the von Bertalanffy parameters L_∞ and *K* were obtained from the literature (IOTC-2016-WPNT06-DATA12). Five different methods were then used to derive possible range for the intrinsic population growth rate r as used in Zhou and Sharma (2014).

$r = 2\,\omega M$, where $\ln(M) = 1.44 - 0.982 \ln(t_m)$ (Hoenig 1983).

$r = 2\,\omega M$, where $\log(M) = -0{\cdot}0066 - 0{\cdot}279 \log(L_\infty) + 0{\cdot}6543 \log K + 0{\cdot}4634 \log(T)$ (Pauly, 1980);

$r = 2\,\omega M$, where $M = 1.65/t_{mat}$ (Jensen 1996).

$r = 2\,\omega$ M, where $\ln(M) = 0.55 - 1.61 \ln(L) + 1.44 \ln(L_\infty) + \ln(\kappa)$ (Gislason et al. 2010).

$r = 2\,\omega$ M, where $M = (L/L_\infty)^{-1.5}\,\kappa$ (Charnov et al. 2012).

Using the mean and standard deviation, this resulted in a set of estimated *r* values ranging from 0.98 to 2 ($0.56 \leq M \leq 1.15$).

Based on the recent study by Then et al. (2014) which evaluated the predictive performance of empirical estimators for natural mortality, and a lack of information in the literature on t_{max}, the Pauly (1980) equation was updated based on the recommendation by Then et al. (2014):

$$M = 4.118 K^{0.73} L_\infty^{-0.33}$$

This was used to derive an alternate range for M, resulting in a set of estimated *r* values ranging from 0.82 to 2. This new range was used to perform a second set of model runs and the results are compared below.

While depletion levels were originally set ranging up to 0.8, it is fairly unlikely that any tuna stock is only 20% depleted so a range of alternative maximum depletion levels were also explored (Table 4).

Table 4. Prior ranges used for *S. guttatus* (OCOM method)

Initial B/k	Final B/k	K (1000 t)	r	Run
1	0.05 – 0.8 0.05 – 0.7 0.05 – 0.6 0.05 – 0.5	53 448 – 2 672 411	0.98 - 2 0.82 - 2	(5 equation average) (Then et al., 2014)

As before, median *MSY* was calculated from *r* and *K* $MSY = \frac{rK}{4}$,

While median B_{MSY} and F_{MSY} were calculated from the equations $B_{MSY} = \frac{K}{2}$ and

$$F_{MSY} = -ln\left[1 - \left[\frac{MSY}{(Bmsy+MSY)}\right]\right]$$

The range of *r* and *K* values were further reduced by selecting only those combinations corresponding to the 25th - 75th percentile values of *MSY* and the biomass dynamics simulation model was run again for each retained combination of *r* and *K* values with no constraints on the final depletion level this time. While the three base parameters, r, K and MSY were obtained at the first step, the final biomass and depletion are largely controlled by the limiting conditions (i.e., the assumed depletions levels) imposed at this step so these were instead derived subsequently by re-running the model without a pre-defined depletion level. Uncertainty was introduced in terms of the variability in values of K and r used in each run as well as each year within model runs. For base runs, the maximum upper depletion level was set at *D = 0.7*.

Results

Catch-MSY method

The feasible *K* values did not reach the maximum available limit (2 672 411 t) on the first model run, only reaching nearly 350 000 t while possible *r* values spanned through the full range possible under the assumptions (0.6 – 1.5) (Figure 5). Given that r and *K* are confounded, a higher *K* generally gives a lower *r* value. At the extreme ends of the tail a very small change in *r* necessitates a large change in *K* to maintain a viable population and so these values are unlikely (Zhou et al. 2013). Therefore, the upper *K* boundary was reduced to the smallest *K* (218 046 t) corresponding to the lowest r values to remove the less probable tail of the distribution (Figure 5) (Zhou et al., 2013) and the range for *r* was expanded to 1.2 multiplied by the maximum *r* (0.6 - 1.8). The model results from this second run gave a more normal distribution of r with little change in MSY, which remained at around 45,000 t (Figure 6). This was taken as the base model run and the results for this simulation are presented.

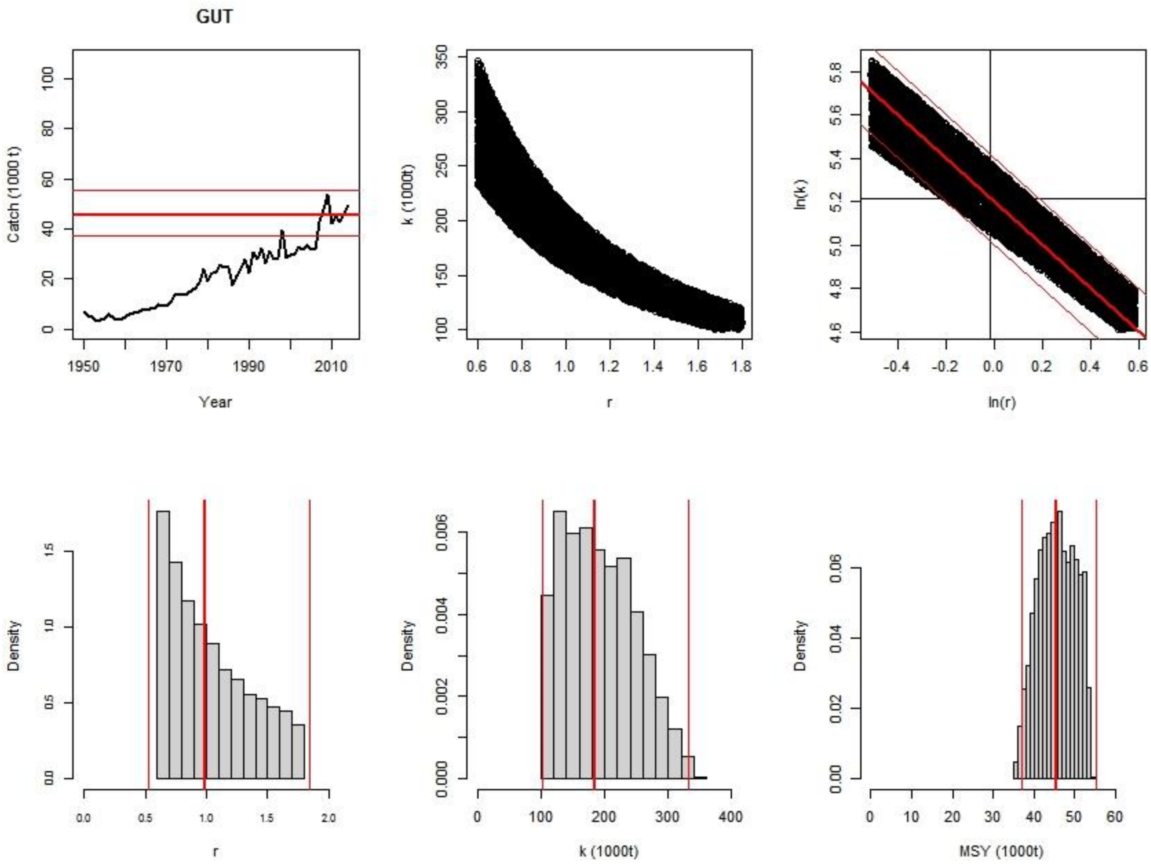

Figure 5. All feasible *r* and *K* combinations resulting from model simulations based on the original parameter constraints

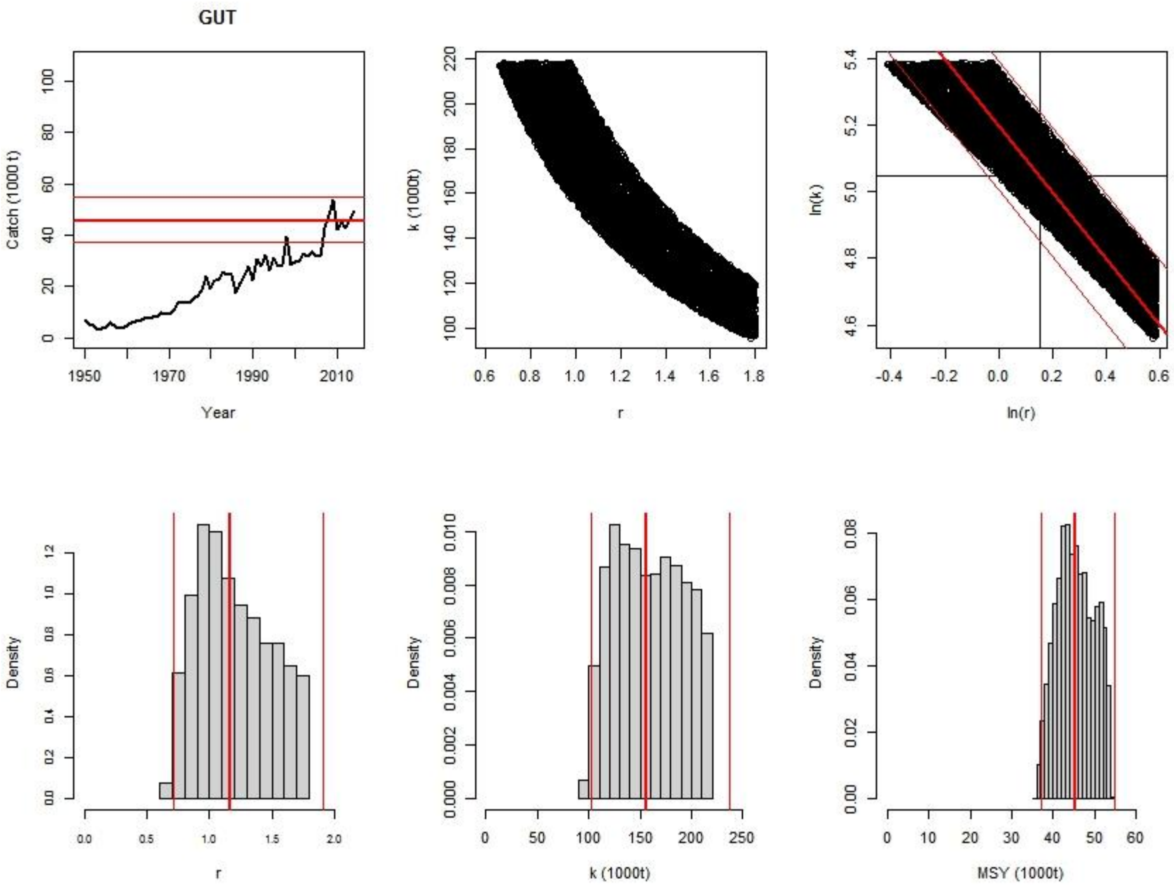

Figure 6. All feasible *r* and *K* combinations with further parameter constraints on max*(K)*

Figure 7 shows the simulated biomass trajectories for all plausible *r*, *K* and starting biomass combinations. This suggests there was a steady decline in biomass until 2007, followed by a more rapid decrease in biomass up to 2009 at which time the catches decreased and the stock trajectory stabilised. This corresponds to the gradual rise in nominal catches until 2007, the larger increase in catches starting in 2007 and peaking in 2009, and followed by a catch reduction in relation to the peak since 2010. However, catches again began to increase again in 2013 and 2014, with catches in the latter year (49 060 t) now the second highest in the series after 2009 (Table 1).

Table 6 provides a summary of the distributions of the key biological parameters across all feasible runs at all starting depletion levels. Further examination of the results (not shown) indicates that key reference points, such as MSY, are relatively insensitive to assumptions regarding the initial biomass level. Management quantities based on geometric means and plausible ranges are provided in Table 7.

The IOTC target and limit reference points for *S. guttatus* tuna have not yet been defined, so the values applicable for all other IOTC species are used as in (). The KOBE matrix plot suggests that based on the Catch-MSY model results, *S. guttatus* is not overfished ($B_{2014}/Bmsy$ = 1.06) but is subject to overfishing ($F_{2014}/Fmsy$ = 1.02) (Figure 8).

Table 5. IOTC reference points for *S. guttatus*

Stock	Target Reference Point	Limit Reference Point
Other IOTC species	B_{MSY}; F_{MSY}	50% of B_{MSY}; 20% above F_{MSY}

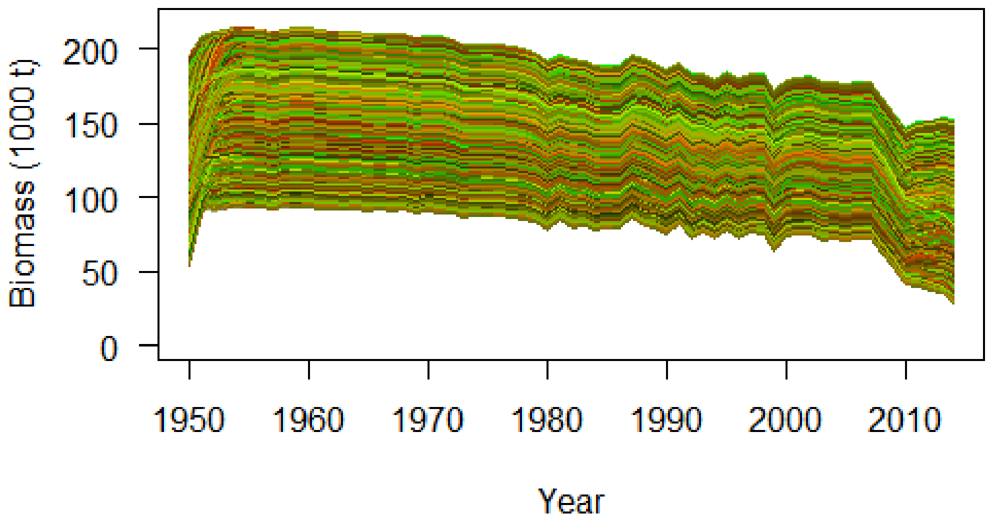

Figure 7. Simulated biomass trajectories based on the Catch-MSY method (Martell and Froese, 2012)

Table 6. Key biological parameters from the Catch-MSY assessment for all starting depletion levels (0.5-0.9)

Quantile	K	r	B_{MSY}	MSY	Bend	Final D
0%	95 735	0.66	47 867	35 873	28 894	0.30
25%	136 498	0.95	68 249	41 860	68 538	0.50
50%	**162 512**	**1.13**	**81 256**	**44 922**	**87 197**	**0.54**
75%	188 868	1.36	94 434	48 757	107 494	0.57
100%	218 023	1.80	109 011	54 034	152 192	0.70

Table 7. Key management quantities from the Catch MSY assessments for aggregate Indian Ocean *S. guttatus*, in 2015 and 2016. Geometric means and plausible ranges across all feasible model runs. n.a. = not available.

Management Quantity	2015	2016
Most recent catch estimate (year)	46 340 t (2013)	49 060 t (2014)
Mean catch – most recent 5-yrs[2]	49 886 t (2009 – 2013)	44 930 (2010 – 2014)
MSY (plausible range)	44 167 (34 939 - 52 842)	45 022 (35 873 - 54 034)
Data period used in assessment	1950 - 2013	1950 – 2014
F_{MSY} (plausible range)	0.45 (0.29 - 0.64)	0.45 (0.28 – 0.64)
B_{MSY} (plausible range)	77 925 (47 520 – 106 187)	79 695 (47 867 – 109 011)
$F_{current}/F_{MSY}$ (plausible range)	1.00 (0.67 – 1.91)	1.02 (0.70 – 1.94)
$B_{current}/B_{MSY}$ (plausible range)	1.04 (0.60 – 1.40)	1.06 (0.60 – 1.40)
$SB_{current}/SB_{MSY}$ (80% CI)	n.a	n.a
$B_{current}/B_0$ (plausible range)	0.55 (0.30 - 0.70)	0.53 (0.30 – 0.70)
$SB_{current}/SB_0$ (80% CI)	n.a	n.a
$B_{current}/B_{0, F=0}$ (80% CI)	n.a	n.a
$SB_{current}/SB_{0, F=0}$ (80% CI)	n.a	n.a

[2] Data at time of assessment

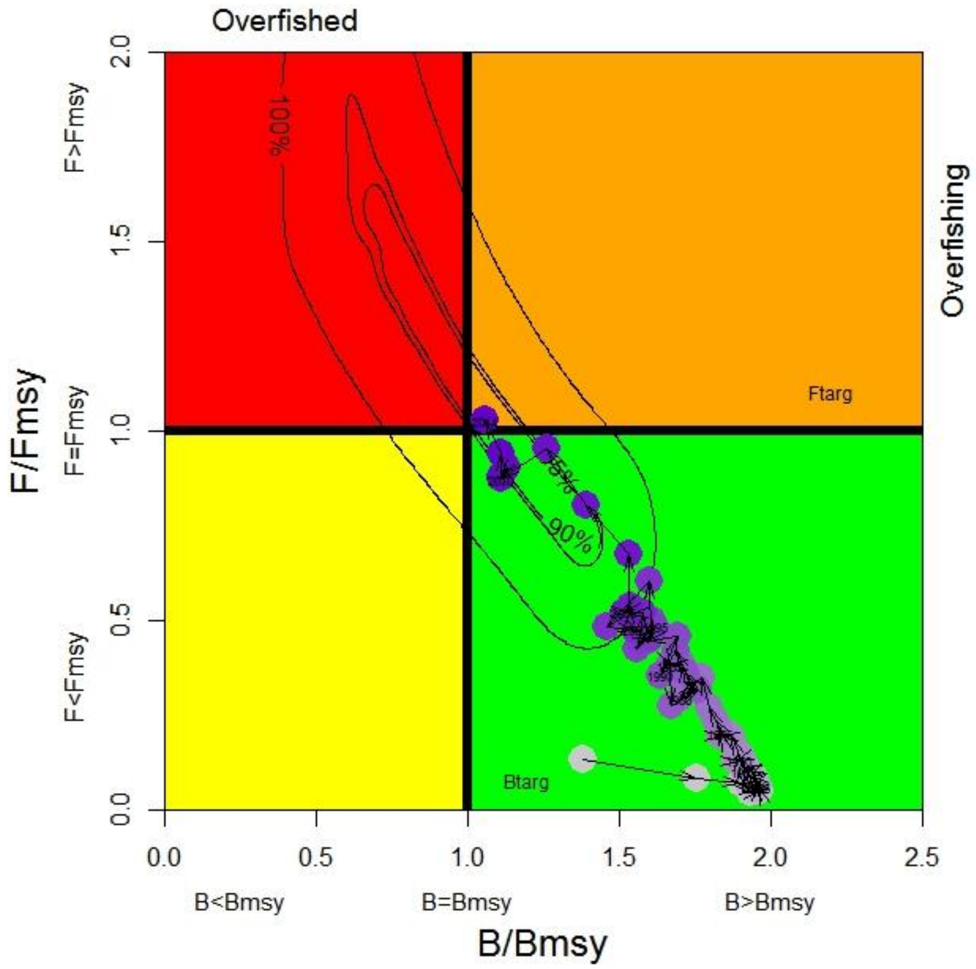

Figure 8. Catch-MSY assessment for Indian Ocean *S. guttatus*. Kobe plot (All plausible model runs shown around 2014 estimate). Blue circles indicate the trajectory of the point estimates for the SB ratio and F ratio for each year 1950–2014. Target (Ftarg and Btarg) reference points are shown as B_{MSY} and F_{MSY}.

OCOM method

Figure 9 shows the initial plausible range of *r* and *K* parameter values retained by the biomass dynamics model. This range was further narrowed with the introduction of informative priors based on the literature Figure 10 which resulted an *r* range of 0.98 - 2.

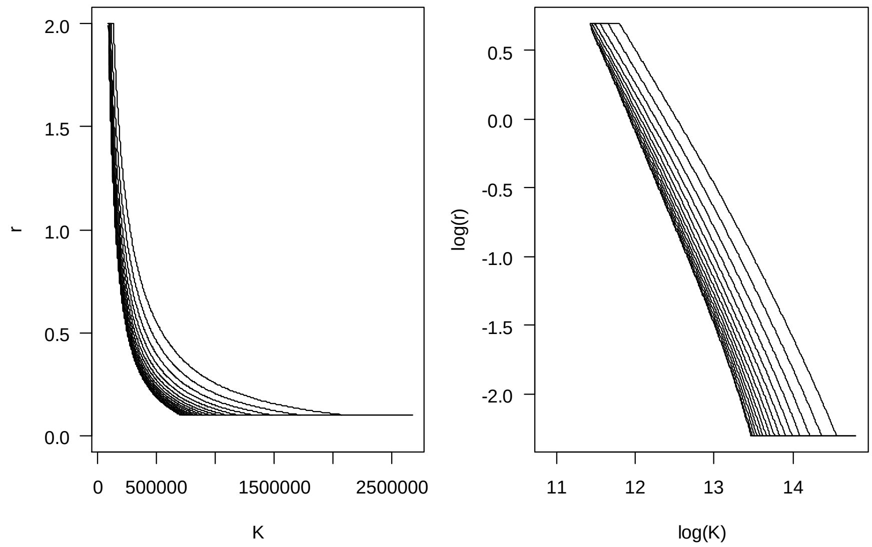

Figure 9. Initial plausible range of r and K values (non-informative priors)

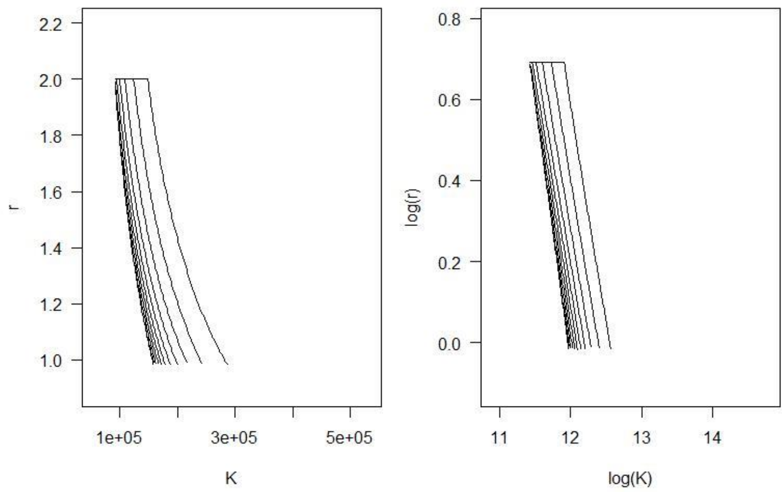

Figure 10. Plausible range of r and K with informative priors on r (0.98 - 2)

The range of values was dependent on the level of stock depletion assumed for the final year, with *r*, *K* and *MSY* all positively correlated with the depletion level (Figure 11). There were no feasible solutions found when the depletion level was assumed to be lower than 0.25.

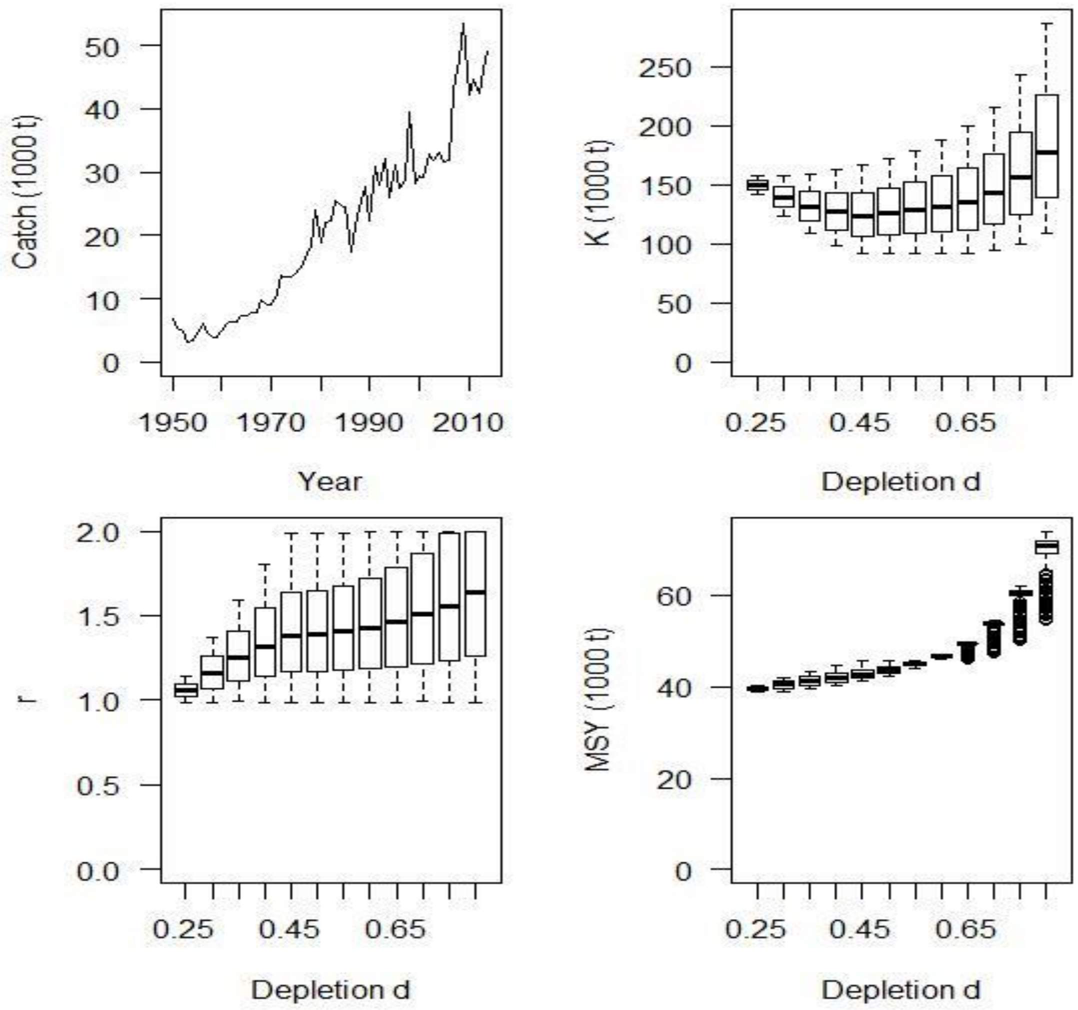

Figure 11. *S. guttatus* catch history, feasible carrying capacity, population growth rate and MSY at each assumed depletion level. There is no feasible solution when the depletion is assumed to be below 0.25.

Base case model results (for a maximum depletion level of 0.7) indicate that the biomass was approximately 130 000 t in 1950 and declined to approximately 73 000 t by 2014 (Figure 12). The estimated MSY associated with this projection is 45 000 t and ranges from approximately 42 000 t to 47 000 t based on the assumed upper depletion level (Table 8).

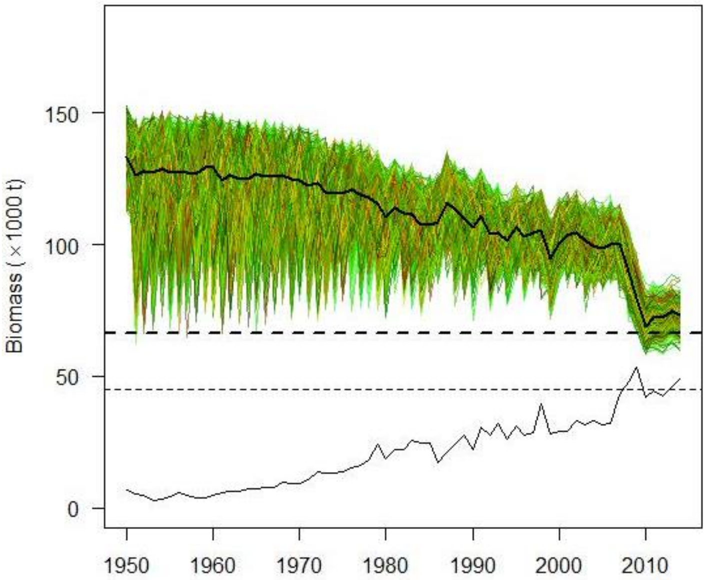

Figure 12. *S. guttatus* biomass trajectories from 500 simulations with upper depletion = 0.7.

Table 8. OCOM key biological parameters for *S. guttatus* under four assumed upper depletion levels[3]

Upper d	Quantile	K	r	MSY	B_{2014}	D
0.8	0%	91,804	0.98	38,856	69,982	0.49
0.8	25%	116,146	1.17	43,432	80,727	0.58
0.8	50%	138,009	1.41	46,921	84,503	0.61
0.8	75%	161,437	1.73	54,181	88,861	0.64
0.8	100%	286,121	2.00	74,047	101,352	0.73
0.7	0%	91,804	0.98	38,856	59,690	0.44
0.7	25%	112,560	1.15	42,642	70,226	0.53
0.7	**50%**	**132,704**	**1.36**	**44,953**	**73,088**	**0.55**
0.7	75%	152,816	1.65	49,259	75,933	0.57
0.7	100%	215,764	2.00	54,395	87,700	0.66
0.6	0%	91,804	0.98	38,856	42,938	0.33
0.6	25%	111,901	1.13	41,804	57,350	0.44
0.6	50%	130,640	1.33	43,674	61,124	0.47
0.6	75%	148,973	1.58	45,239	63,997	0.49
0.6	100%	187,367	2.00	47,096	72,708	0.56
0.5	0%	91,804	0.99	38,856	30,170	0.23
0.5	25%	113,446	1.12	41,105	48,973	0.38
0.5	50%	130,640	1.29	42,441	53,058	0.41
0.5	75%	146,942	1.52	43,512	56,766	0.44
0.5	100%	171,886	1.99	45,613	66,141	0.50

[3] NB While K, R and MSY are derived from the optimisation model, B_{2014} and D are highly dependent on the fixed assumptions and so the values presented here are from a further, unconstrained model run.

Future projections were run up to 2020 based on two different catch scenarios. The first scenario assumes the future catch remains constant. This was simulated as a constant catch tonnage, equal to the catch in 2014, and resulted in a rapid decline of the stock (Figure 13). It is unlikely that such high catch levels could be maintained into the future given that the catch rate would decline with the projected decreasing biomass. Therefore, as an alternative, this was also simulated as a constant catch relative to the target biomass level, i.e. C_{2014}/B_{MSY}. This projection predicts that the catch decreases from the 2014 level but remains at a relatively high level, resulting in a stock biomass which stabilises somewhat below B_{MSY} (Figure 14).

The second set of projections was based on the assumption that a constant catch of MSY was achieved annually. This was also simulated as a fixed future catch level (Figure 15) as well as a fixed future catch rate equal to the optimum rate for achieving the target biomass, i.e. MSY/ B_{MSY} (Figure 16). While both of these projections result in a biomass which rapidly stabilises around the corresponding B_{MSY} level there is more uncertainty associated with the fixed catch level compared with the fixed catch rate due to the high uncertainty in the biomass level. Nevertheless, a fixed catch level is more indicative of a potential management scenario, whereas achieving a fixed catch rate would be extremely difficult to achieve in practice and so provides a less realistic scenario.

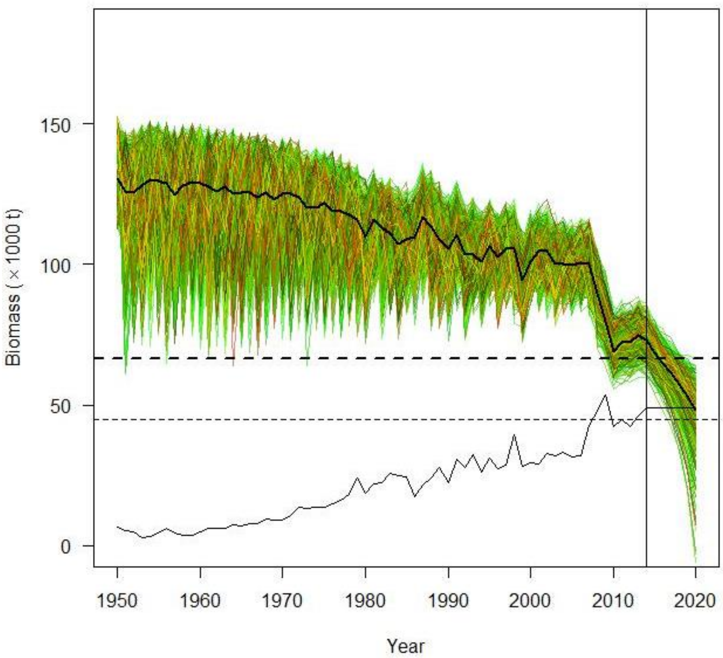

Figure 13. Projected *S. guttatus* biomass trajectories under hypothetical annual catches equivalent to those of the final year (C_{2014}) until 2020. The vertical line is the last year for which catch data are available.

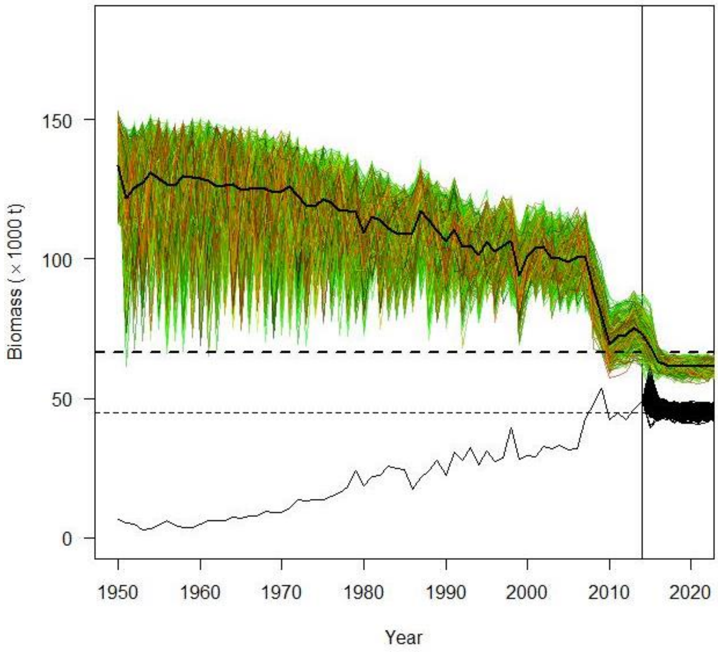

Figure 14. Projected *S. guttatus* biomass trajectories under hypothetical annual catch rate (C_{2014}/B_{MSY}) at 2014 level until 2020. The vertical line is the last year for which catch data are available.

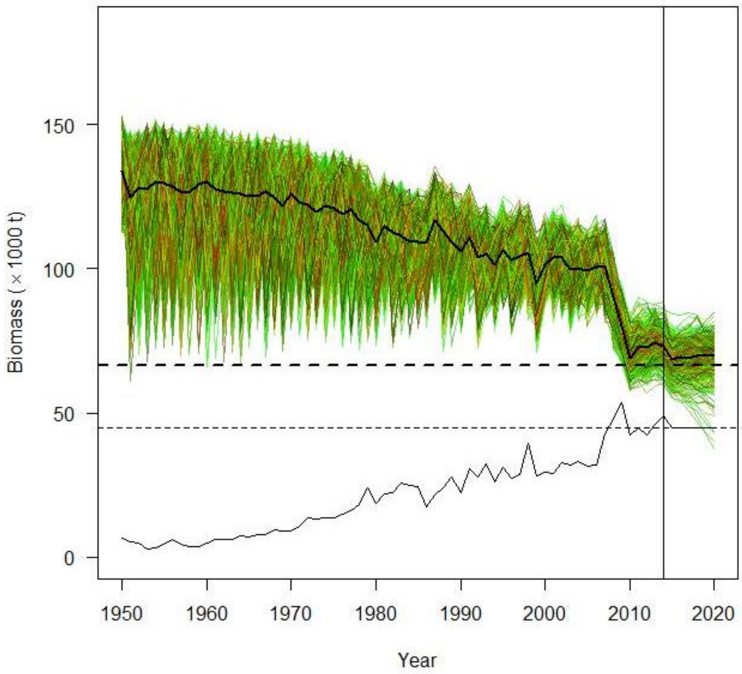

Figure 15. Projected *S. guttatus* biomass trajectories under hypothetical future annual catch equivalent to MSY until 2020. The vertical line is the last year for which catch data are available.

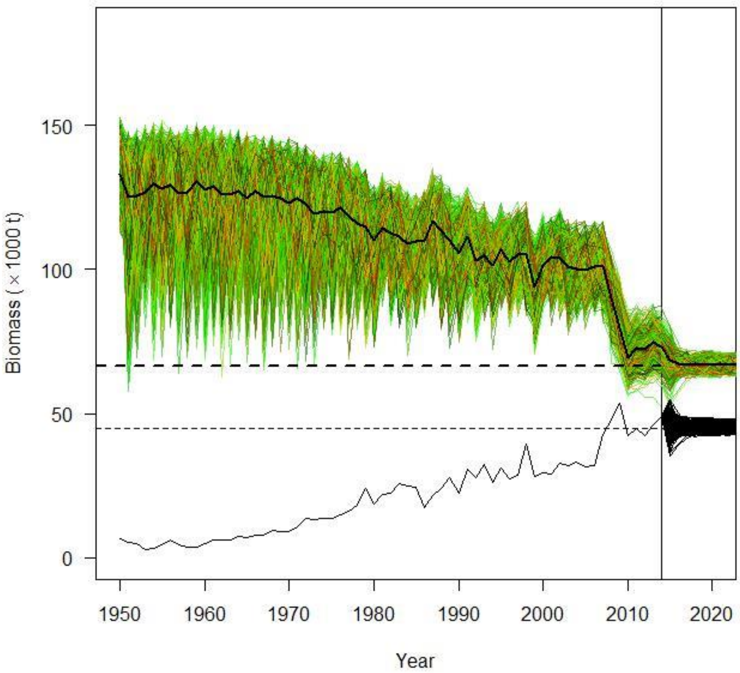

Figure 16. Projected *S. guttatus* biomass trajectories under hypothetical annual catch rate at MSY level (C_{MSY}/B_{MSY}) until 2020. The vertical line is the last year for which catch data are available.

Management quantities based on geometric means and plausible ranges based on the OCOM model results are provided in Table 9, estimating the geometric mean MSY at 45 632 t. The KOBE matrix plot indicates that based on these model results (using the average growth estimated across a range of empirical models), *S. guttatus* is not currently overfished (B_{2014}/B_{MSY} = 1.10) and not subject to overfishing (F_{2014}/F_{MSY} = 0.98) (Figure 17). However, based on the alternative run using the growth estimation method recommended by Then et al. (2014), *S. guttatus* is assessed as not currently overfished (B_{2014}/B_{MSY} = 1.05) but is subject to overfishing (F_{2014}/F_{MSY} = 1.03).

Table 9. Key management quantities from the OCOM assessment for Indian Ocean *S. guttatus*, using a base case with maximum depletion of 70%. Geometric means and plausible ranges in brackets. n.a. = not available.

Management Quantity	2015	2016	2016 (alternative run)
Most recent catch estimate	46 354 t (2013)	49 060 t (2014)	49 060 t (2014)
Mean catch (last 5 years)	49 870 t (2009 – 2013)	44 930 (2010 – 2014)	44 930 (2010 – 2014)
MSY (plausible range)	42 978 t (35 752–52 857)	45 632 t (38 856 – 54 395)	44 931 t (37 189- 54 395)
Data period used in assessment	1950 – 2013	1950 - 2014	1950 – 2014
F_{MSY} (plausible range)	0.42 (0.34 – 0.52)	0.52 (0.40 – 0.69)	0.48 (0.35 – 0.69)
B_{MSY} (plausible range)	82 846 (60 324– 131 088)	65 951 (45 901 – 107 881)	71 626 (45 902 – 128 190)
$F_{current}/F_{MSY}$ (plausible range)	1.05 (0.91 – 1.27)	0.98 (0.85 – 1.14)	1.03 (0.88 – 1.28)
$B_{current}/B_{MSY}$ (plausible range)	1.01 (0.80 - 1.20)	1.10 (0.84 – 1.29)	1.05 (0.80 – 1.29)
$SB_{current}/SB_{MSY}$ (80% CI)	n.a	n.a.	n.a.
$B_{current}/B_0$ (plausible range)	0.52 (0.34 - 0.74)	0.55 (0.42 – 0.64)	0.53 (0.33 – 0.93)
$SB_{current}/SB_0$ (80% CI)	n.a	n.a.	n.a.
$B_{current}/B_{0,\ F=0}$ (80% CI)	n.a	n.a.	n.a.
$SB_{current}/SB_{0,\ F=0}$ (80% CI)	n.a	n.a.	n.a.

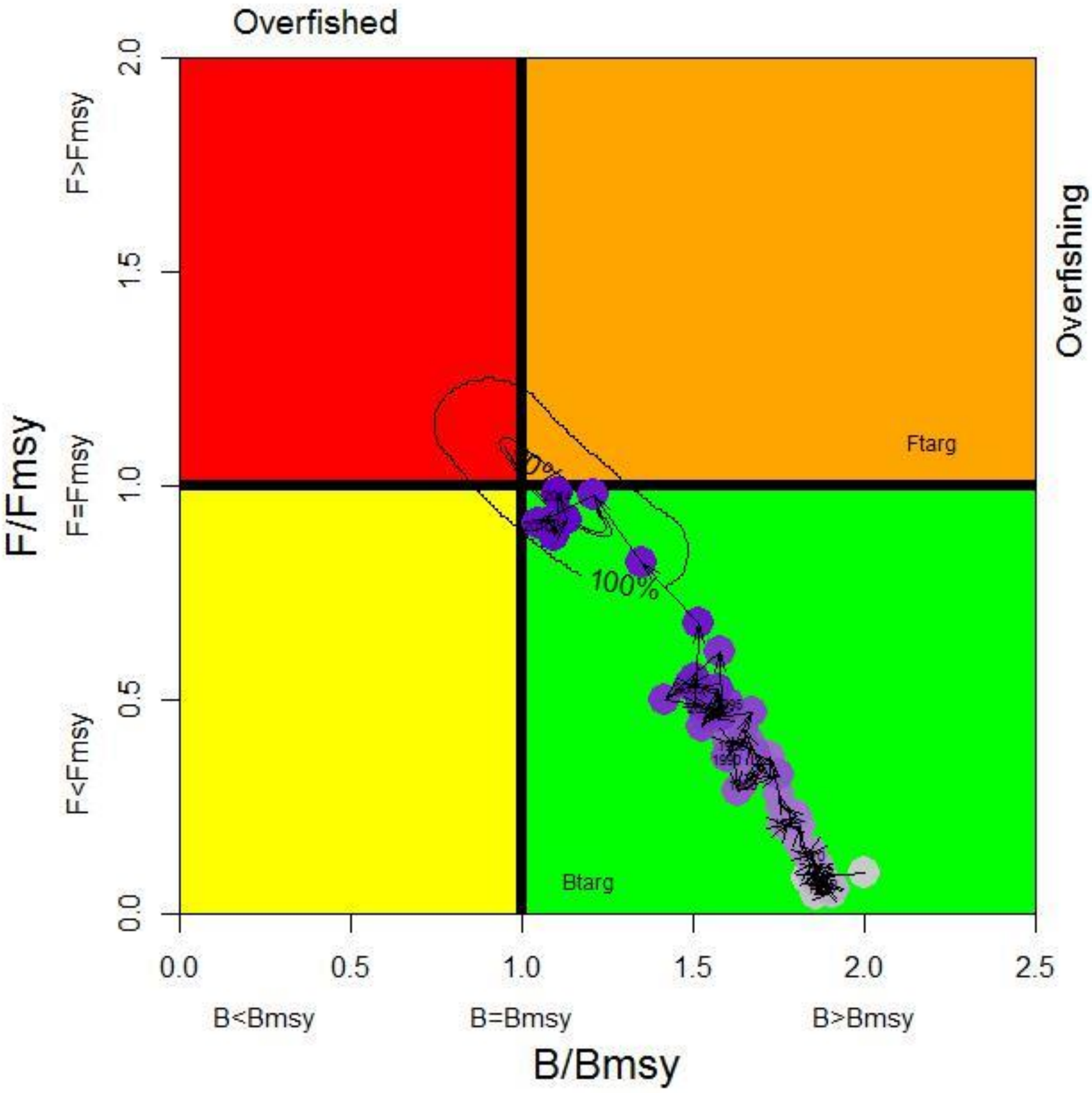

Figure 17. *S. guttatus* OCOM Indian Ocean assessment Kobe plot (Plausible range shown around 2014 estimate). Blue circles indicate the trajectory of the point estimates for the SB ratio and F ratio for each year 1950–2014. Target reference points are shown (B_{MSY} and F_{MSY}).

Discussion

Model results were very similar with a mean MSY of around 45 000 t estimated by both Catch-MSY and OCOM models (Table 10), which is slightly higher than MSY estimates from assessments in 2015 (Table 7; Table 9; IOTC-2015-WPNT05-24). The average catch over the last 5 years has been close to 2016 estimates of MSY, but catches over the last 2 years have exceeded this key reference point (Table 1).

Table 10. Key management quantities from the Catch-MSY and OCOM[4] assessments for Indo-Pacific king mackerel. Geometric means are provided (with plausible ranges across all feasible model runs). n.a. = not available.

Management Quantity	Catch-MSY	OCOM (run 1)
Most recent catch estimate (2014)	49 060 t	49 060 t
Mean catch 2010–2014	44 930	44 930
MSY (plausible range)	45 022 (35 873 - 54 034)	45 632 t (38 856 – 54 395)
Data period used in assessment	1950 – 2014	1950 - 2014
F_{MSY} (plausible range)	0.45 (0.28 – 0.64)	0.52 (0.40 – 0.69)
B_{MSY} (plausible range)	79 695 (47 867 – 109 011)	65 951 (45 901 – 107 881)
F_{2014}/F_{MSY} (plausible range)	1.02 (0.70 – 1.94)	0.98 (0.85 – 1.14)
B_{2014}/B_{MSY} (plausible range)	1.06 (0.60 – 1.40)	1.10 (0.84 – 1.29)
SB_{2014}/SB_{MSY} (80% CI)	n.a	n.a.
B_{2014}/B_0 (plausible range)	0.53 (0.30 – 0.70)	0.55 (0.42 – 0.64)
SB_{2014}/SB_0 (80% CI)	n.a	n.a.
$B_{2014}/B_{0,\,F=0}$ (80% CI)	n.a	n.a.
$SB_{2014}/SB_{0,\,F=0}$ (80% CI)	n.a	n.a.

Both models indicated that *S. guttatus* is not currently overfished with B_{2014}/B_{MSY} estimated at 1.06 and 1.10 for the Catch-MSY and OCOM models, respectively. Results of the alternative OCOM run also indicate that the stock is not overfished (B_{2014}/B_{MSY} = 1.05). However, there is discrepancy between the models in terms of the mortality-based indicator. As was the case in 2015, the Catch-MSY model indicated the Indo-Pacific king mackerel is subject to overfishing with an F_{2014}/F_{MSY} ratio of 1.02. Though run 1 of the OCOM model suggested that overfishing is not occurring (F_{2014}/F_{MSY} = 0.98), results from the alternative run corresponded to those of Catch-MSY (F_{2014}/F_{MSY} = 1.03). Therefore, based on the weight-of-evidence currently available, it is likely that the stock is not currently '*overfished*' but is '*subject to overfishing'*.

There are substantial uncertainties that are described throughout this paper and these ratios are borderline, being very close to 1. This suggests that the stock is very close to being fished at MSY levels and that higher catches could not be sustained. A precautionary approach to management is recommended.

Given that the assessments conducted are data-poor methods with considerable uncertainty and that both are based primarily on the catch data and an underlying Schaefer model, alternative assessment methods using different data and alternative assumptions should be used to explore the status of the stock further.

[4] using a base case run with maximum depletion level of 70% of B_0.

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