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

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IOTC Secretariat[1]

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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. While a number of methods have been used to assess the stocks of some other neritic tuna species, this paper constitutes the first attempt at assessing the status of the Indo-pacific king mackerel (*Scomberomorus guttatus*) in the Indian Ocean.

In this paper, two data-poor methods were used 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 included: Indian Ocean Longtail tuna (*Thunnus tonggol*) (IOTC-2015-WPNT05-22), Narrow-barred Spanish mackerel (*Scomberomorus commerson*) (IOTC-2015-WPNT05-23) and Kawakawa *(Euthynnus affinis)* (IOTC-2015-WPNT05-21). Catch data for Bullet tuna (*Auxis rochei*) and frigate tuna (*Auxis thazard*) were considered too incomplete for the use of catch-based assessment methods in 2015.

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.

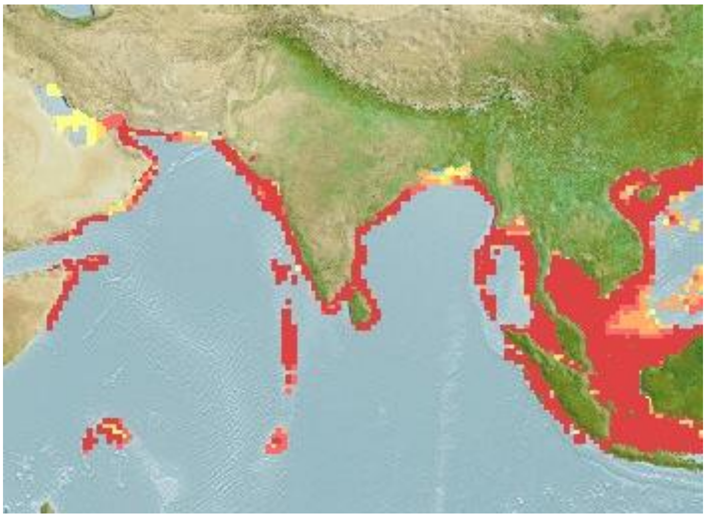

Figure 1. Distribution of *S. guttatus in* the Indian Ocean[2]

[2] Computer generated distribution maps for *Scomberomorus guttatus* (Indo-Pacific king mackerel), with modelled year 2100 native range map based on IPCC A2 emissions scenario. www.aquamaps.org, version of Aug. 2013. Web. Accessed 9 May. 2015.

Fisheries and Catch Trends

Nominal catches of *S. guttatus* are lower than many of the other neritic species, with a total catch of only 46 354 t reported in 2013 (Table 1). Catches increased to a reported maximum of 53 386 t 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 2 and Figure 3).

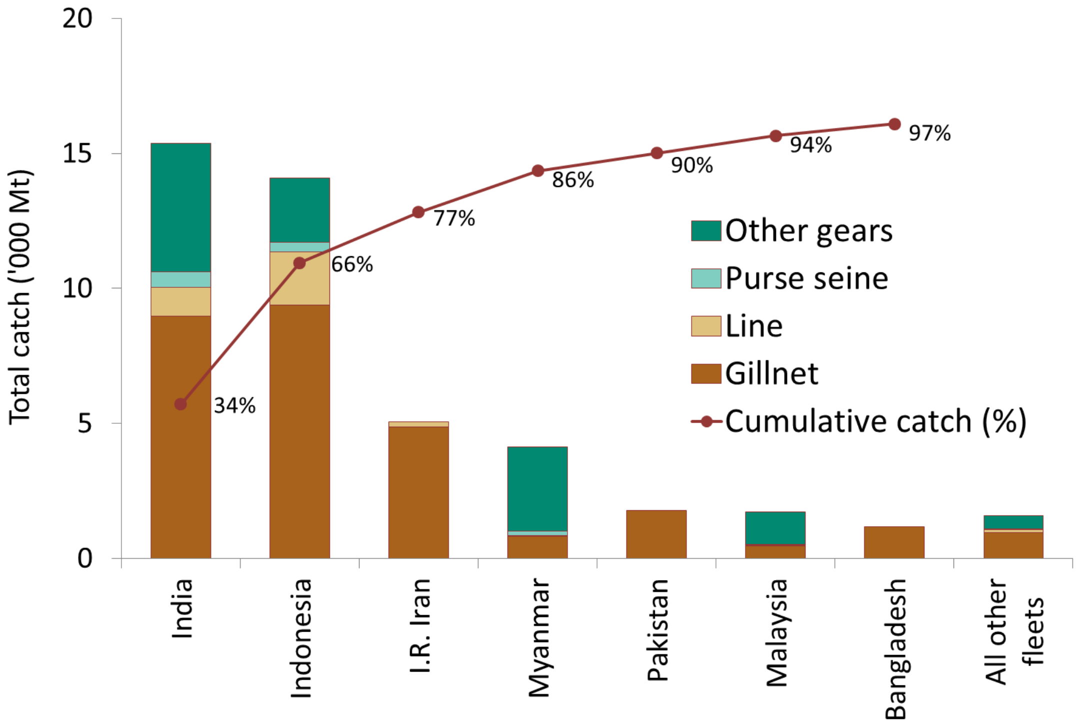

Figure 2. *Average catches in the Indian Ocean over the period 2010-2013, by country. Countries are ordered from left to right, according to the level of catches of S. guttatus reported. The red line indicates the (cumulative) proportion of catches of S. guttatus for the countries concerned, over the total combined catches of this species reported from all countries and fisheries.*

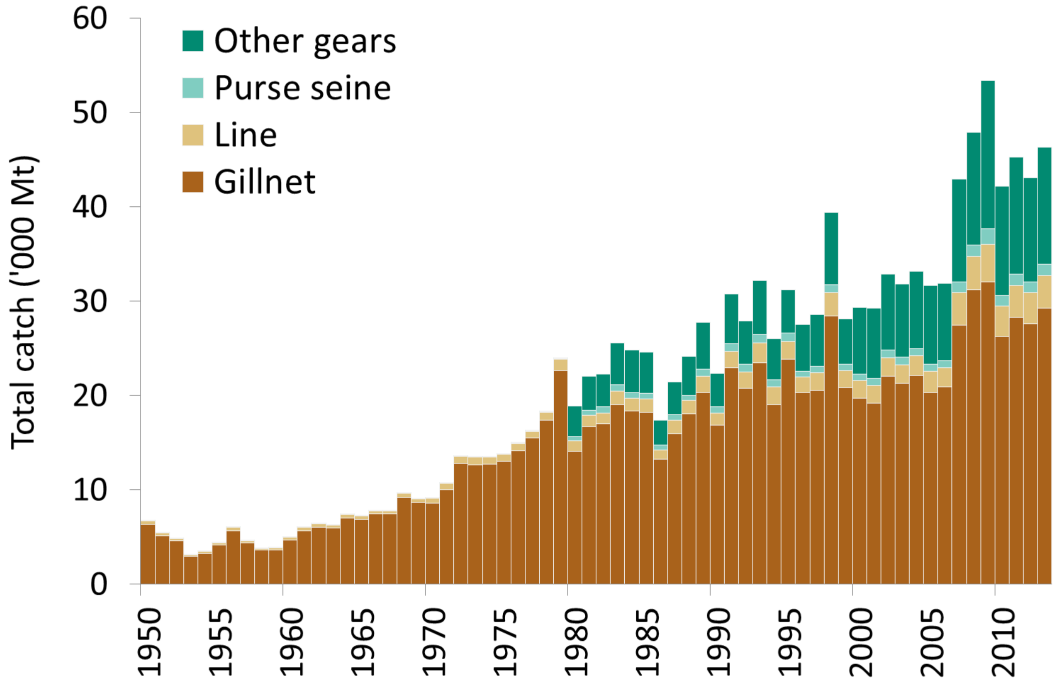

Figure 3. Annual catches of *S. guttatus* by gear as recorded in the IOTC Nominal Catch database (1950–2013)

Table 1. Catch data for *S. guttatus* in the Indian Ocean, 1950-2013 (source IOTC Nominal Catch Database)

Year	Catch (t)	Year	Catch (t)
1950	6,744	1982	22,265
1951	5,431	1983	25,563
1952	4,871	1984	24,798
1953	3,083	1985	24,603
1954	3,461	1986	17,420
1955	4,368	1987	21,431
1956	6,035	1988	24,140
1957	4,636	1989	27,759
1958	3,824	1990	22,363
1959	3,844	1991	30,783
1960	4,971	1992	27,877
1961	6,026	1993	32,219
1962	6,414	1994	26,046
1963	6,282	1995	31,213
1964	7,415	1996	27,559
1965	7,230	1997	28,601
1966	7,780	1998	39,385
1967	7,803	1999	28,113
1968	9,678	2000	29,326

1969	9,081	2001	29,280
1970	9,132	2002	32,898
1971	10,740	2003	31,803
1972	13,587	2004	33,144
1973	13,484	2005	31,689
1974	13,497	2006	31,889
1975	13,847	2007	42,923
1976	15,040	2008	47,881
1977	16,307	2009	53,386
1978	18,331	2010	42,166
1979	24,015	2011	45,274
1980	18,878	2012	43,054
1981	22,074	2013	46,354

Neritic species are often caught together by the same fisheries, given their overlapping distributions. This results in mixed species catches and issues with differentiating between some of the neritic species mean that catches are commonly reported as aggregates. In these situations, nominal catches of each species must be estimated from the best estimates available, which is usually the proportional representation of species caught by the fleet in previous years, or based on proportional catches by similar fleets which are used as proxies. Particularly notable areas of catch estimation include those for Indonesia where species identification issues have been reported. For these catches, the total reported catches are multiplied by proportional catches estimated by a consultant who has been working on these issues for the IOTC. Catches reported by Myanmar are reported as seerfish aggregates so these are separated into *S. commerson* and *S. guttatus* using proxy fleet ratios. The same process is used for aggregate catches reported by Thailand, Malaysia and Bangladesh. Iran has been reporting catches by species since 1982, however, prior to this species are disaggregated using the proportional catches between 1982 and 1985. For Pakistan, and Yemen (prior to 2004) there are no reported catches of *S. guttatus* so the reported *S. commerson* are disaggregated into catches of each species.

These similar distributions, sizes and susceptibility to fishing gear issues with species identification and reporting leading to the need for species catch estimation methods all results in the nominal catches of the neritic species being closely correlated (Figure 4). As would be expected from the catch estimation methods described, 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.

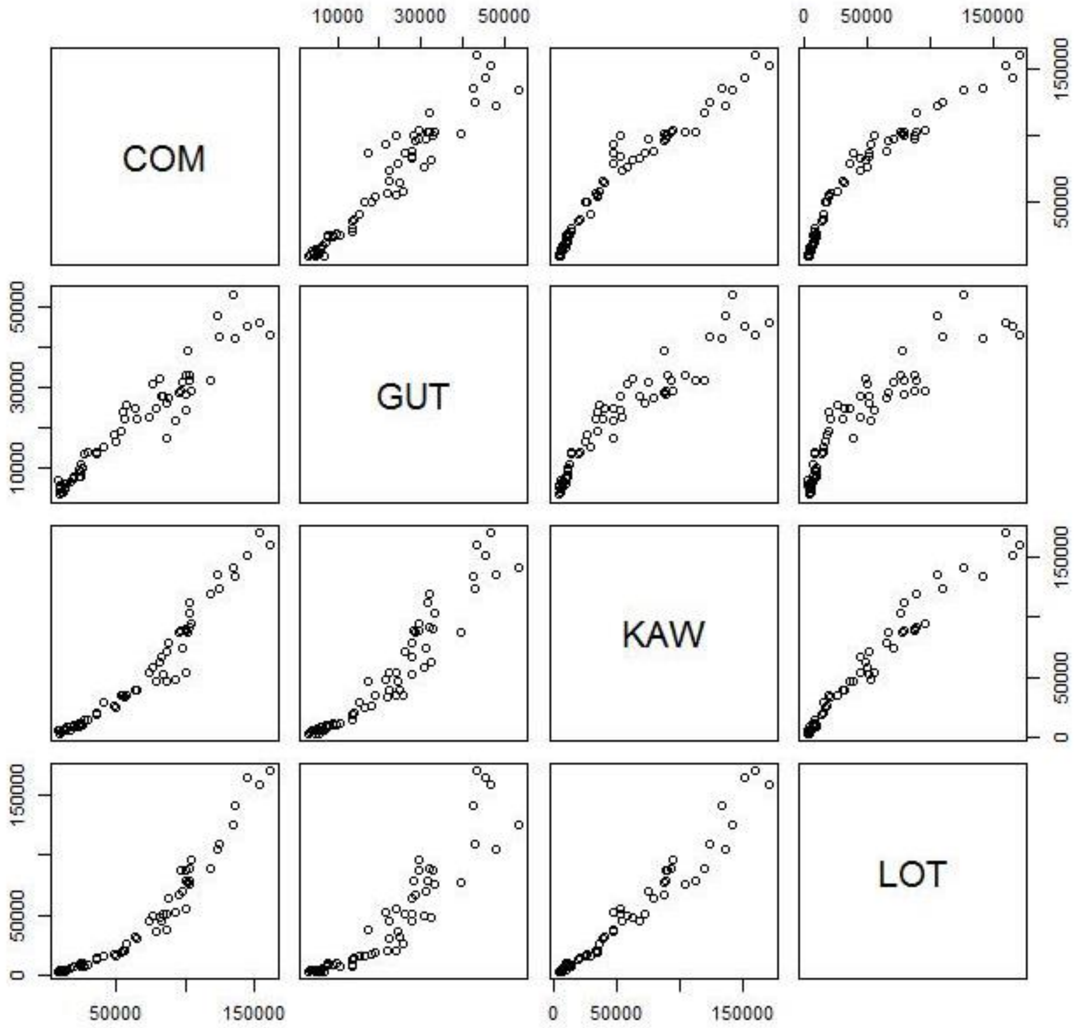

Figure 4. Scatterplot matrix showing the relationship between the four neritic tuna species to undergo assessment in 2015: COM *(Scomberomorus commerson)*, GUT *(Scomberomorus guttatus*), KAW *(Euthynnus affinis)* and LOT *(Thunnus tonggol)*.

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 – 2013, 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* = min(C) – 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 high 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	0.5 – 0.9	0.6 - 1.5	53 - 2669
			0.6 - 1.8	90 - 212

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

$MSY = \frac{rk}{4}$, $B_{MSY} = \frac{k}{2}$ 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 $r \sim K$ 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 are produced and the improbable values are then excluded, so the method is 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 $|B_{2013} - DK|$ where B_{2013} is the biomass in the final year). 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.

Max 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 to obtain a higher density of low K 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 model assumed that the biomass in 1950 was 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_{2013} 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 derived from FishBase (78.5 and 0.34 respectively). 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 $\log(M) = 0.566 - 0.718 Log(L_\infty) + 0.02T$ (www.Fishbase.org);

$r = 2\ \omega M$, 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_∞) + ln(κ) (Gislason et al. 2010).

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

This resulted in a set of estimated r values ranging from 0.9 to 1.5 with a mean of 1.08 ± 0.14 (2 s.d.). Values which were more or less than 2 s.d. removed from the mean were dropped so that (0.8 $\geq$ r $\leq$ 1. 37). 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)

Species	Initial *B/k*	Final *B/k*	*r*	*K (1000 t)*
Indo-Pacific king mackerel	1	0.05 – 0.8	0.1 - 2	53 - 2669
		0.05 – 0.7	0.80 - 1.37	
		0.05 – 0.6		
		0.05 – 0.5		

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 $D \leq 0.7$ which seemed a fairly reasonable assumption.

Results

Catch-MSY method

The feasible *K* values did not reach the maximum available limit, 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* corresponding to the lowest r values to remove the les probable tail of the distribution, 213 287 (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). This resulted in slightly higher *r* and lower *K* estimates with little change in MSY (initial estimate 44 192 t compared with a revised estimate of 44 474 t) (Figure 6). This was taken as the base model run and the results for this simulation are presented.

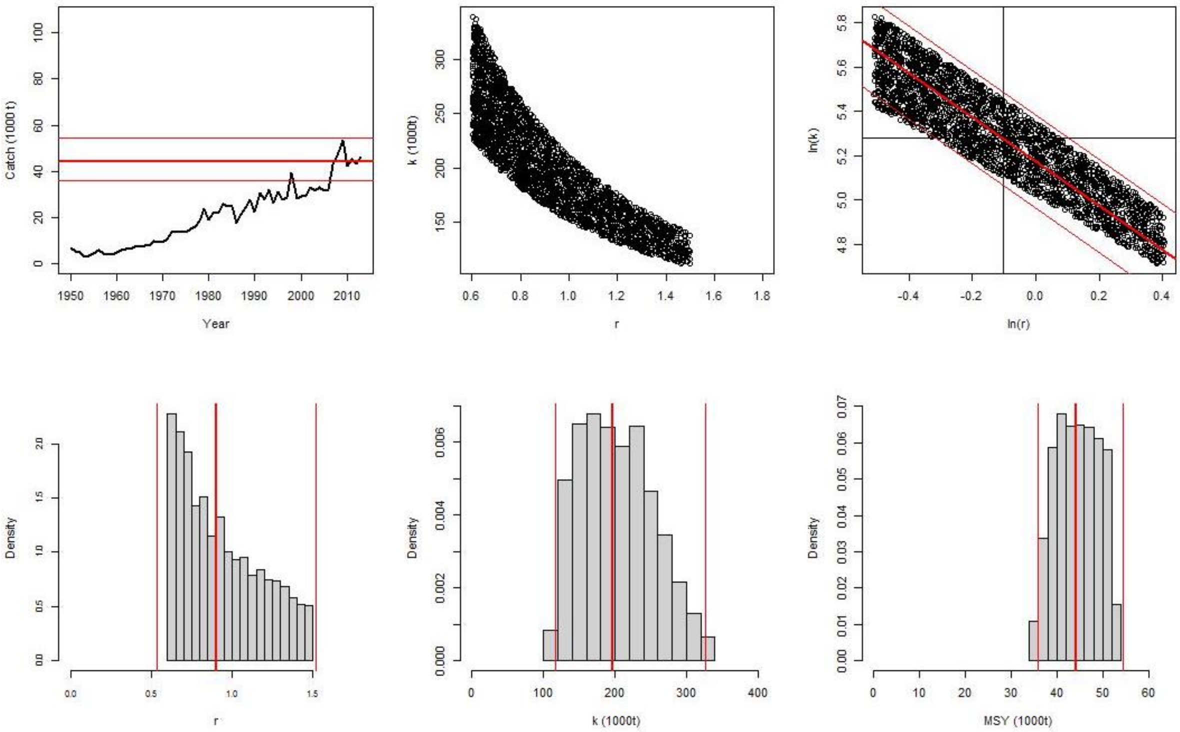

Figure 5. All feasible *r* and *K* combinations resulting from model simulations based on the original parameter constraints

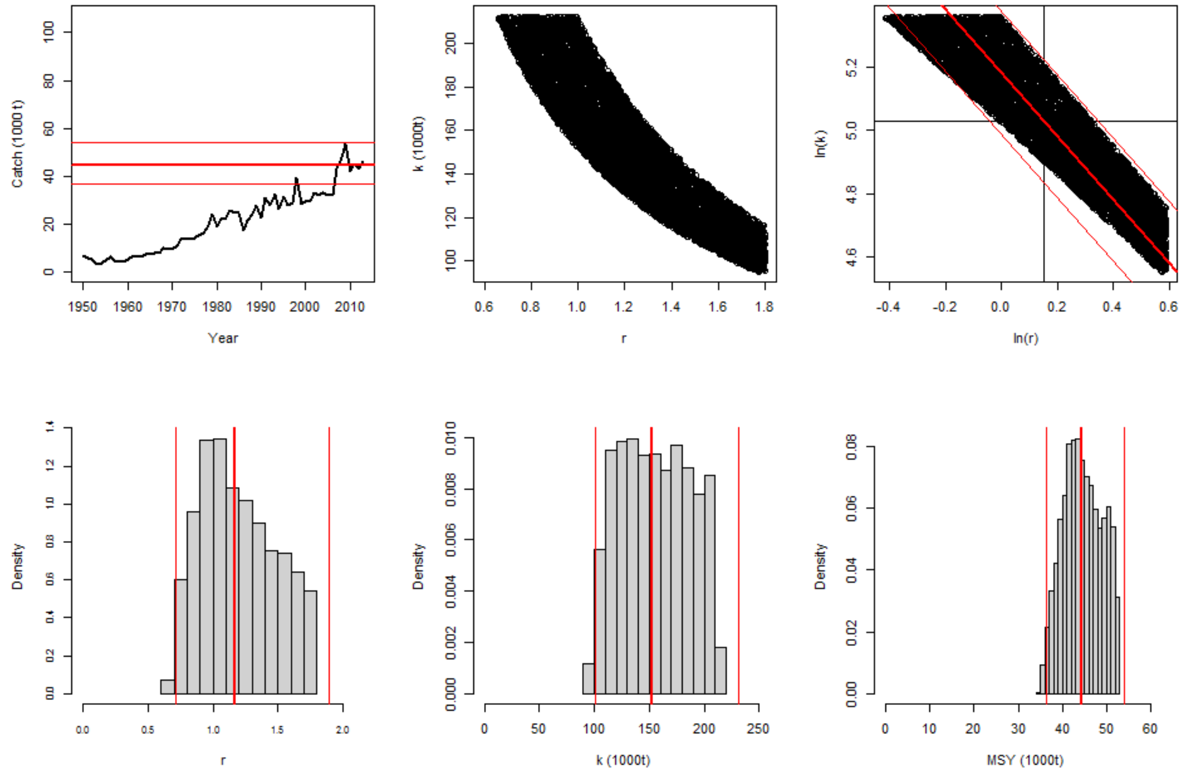

Figure 6. All feasible *r* and *K* combinations with further parameter constraints on max*(K)*

Results are presented for the simulated biomass trajectories for all plausible *r*, *K* and starting biomass combinations. This suggests there was a rapid decrease in biomass up to 2009 at which time the catches decreased and the stock trajectory stabilised. This corresponds to the rise in catches to the peak in 2009 in the nominal catch series (Table 1). Table 6 provides a summary of the distributions of the key biological parameters across all feasible runs at all starting depletion levels. Table 7 provides a further breakdown of these results based on the assumed initial biomass level with median values highlighted in bold. The similarity of these results indicates the robustness of this approach to the assumed starting biomass level, particularly with respect to the key reference point median MSY estimate which remains at approximately 44 000 t across all starting biomass levels. Management quantities based on geometric means and plausible ranges are provided in Table 8. 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 Table 5. The KOBE matrix plot indicates that based on the Catch-MSY model results, *S. guttatus* is not overfished (B_{2013}/Bmsy = 1.04) or subject to overfishing (F_{2013}/Fmsy = 1.00) (Figure 7).

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}

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

Quantile	K	r	Bmsy	MSY	Bend	Final D
0%	95 041	0.66	47 520	34 939	29 185	0.31
25%	133 934	0.96	66 967	41 097	65 597	0.49
50%	**158 775**	**1.13**	**79 388**	**44 050**	**83 921**	**0.53**
75%	184 089	1.36	92 044	47 822	103 343	0.56
100%	212 374	1.80	106 187	52 842	147 907	0.70

Table 7. Key biological parameters from the Catch-MSY model assessment under four assumed starting depletion levels

Initial D	Quantile	K	r	B_{MSY}	MSY	Bend	Final D
0.8	0%	100 469	0.66	50 235	34 939	30 519	0.30
0.8	25%	137 018	0.95	68 509	40 950	66 386	0.48
0.8	50%	161 086	1.11	80 543	43 900	85 312	0.53
0.8	75%	185 122	1.33	92 561	47 680	104 379	0.56
0.8	100%	212 374	1.66	106 187	52 842	147 907	0.70
0.7	0%	95 994	0.66	47 997	34 939	29 185	0.30
0.7	25%	131 947	0.96	65 974	41 207	65 477	0.50
0.7	50%	157 269	1.14	78 635	44 168	83 514	0.53
0.7	75%	183 486	1.39	91 743	47 930	102 694	0.56
0.7	100%	212 374	1.76	106 187	52 842	147 907	0.70
0.6	0%	95 041	0.66	47 520	34 939	29 185	0.31
0.6	25%	128 748	0.97	64 374	41 338	65 089	0.51
0.6	50%	154 935	1.16	77 467	44 382	82 144	0.53
0.6	75%	182 263	1.42	91 131	48 119	101 699	0.56
0.6	100%	212 374	1.80	106 187	52 842	147 907	0.70
0.5	0%	105 957	0.66	52 978	34 939	33 282	0.31
0.5	25%	142 143	0.93	71 072	40 704	67 592	0.48
0.5	50%	164 946	1.08	82 473	43 648	87 056	0.53
0.5	75%	186 985	1.28	93 492	47 423	106 393	0.57
0.5	100%	212 374	1.57	106 187	52 842	147 907	0.70

Table 8. Key management quantities from the Catch MSY assessment for Indian Ocean *S. guttatus*. Geometric means and plausible ranges across all feasible model runs. n.a. = not available.

Management Quantity	**Aggregate Indian Ocean**
Most recent catch estimate (2013)	46 340 t
Mean catch from 2009–2013	49 886 t
MSY (plausible range)	44 167 (34 939-52 842)
Data period used in assessment	1950-2013
F_{MSY} (plausible range)	0.45 (0.29-0.64)
B_{MSY} (plausible range)	77 925 (47 520–106 187)
F_{2013}/F_{MSY} (plausible range)	1.00 (0.67-1.91)
B_{2013}/B_{MSY} (plausible range)	1.04 (0.60-1.40)
SB_{2013}/SB_{MSY} (80% CI)	n.a
B_{c2013}/B_0 (plausible range)	0.55 (0.30-0.70)
SB_{2013}/SB_0 (80% CI)	n.a
$B_{2013}/B_{0,\ F=0}$ (80% CI)	n.a
$SB_{2013}/SB_{0,\ F=0}$ (80% CI)	n.a

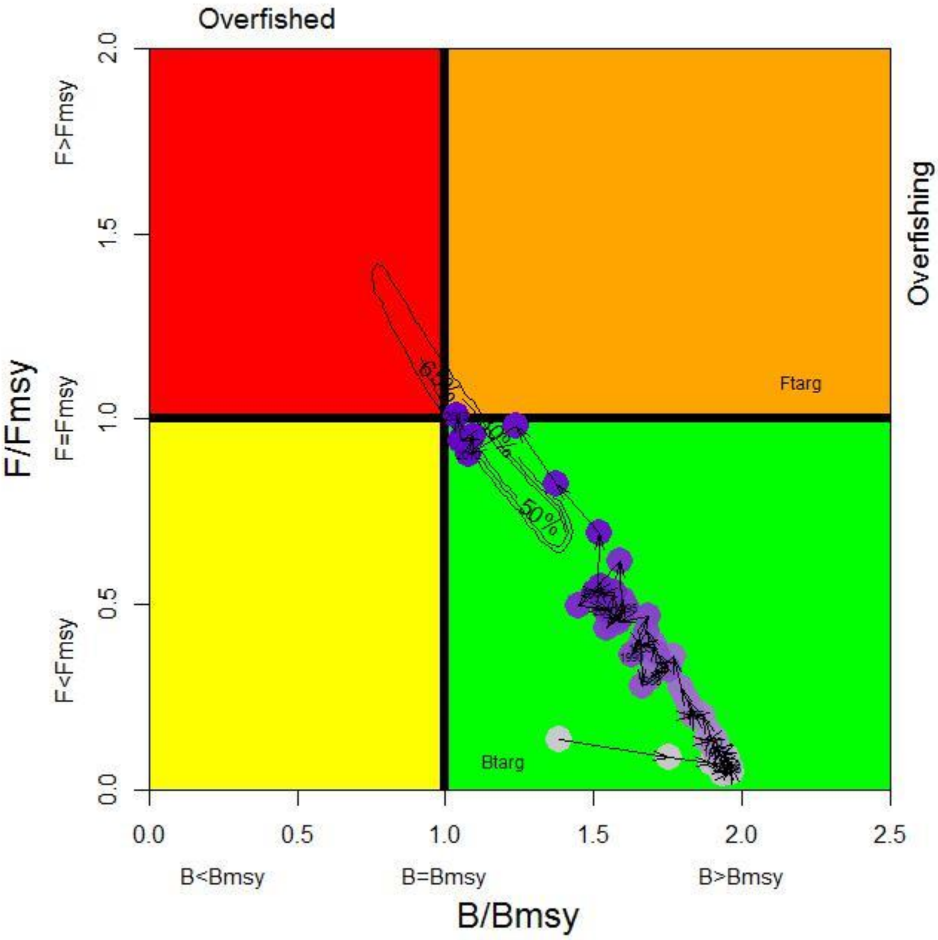

Figure 7. Indo-Pacific king mackerel. Catch-MSY assessment for Indian Ocean *S. guttatus*. The Kobe plot presents the trajectories for the range of plausible model options included in the formulation of the final management advice. The trajectory of the geometric mean of the plausible model options is also presented.

OCOM method

Figure 8 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 9 which resulted an *r* range of 0.80 - 1.37.

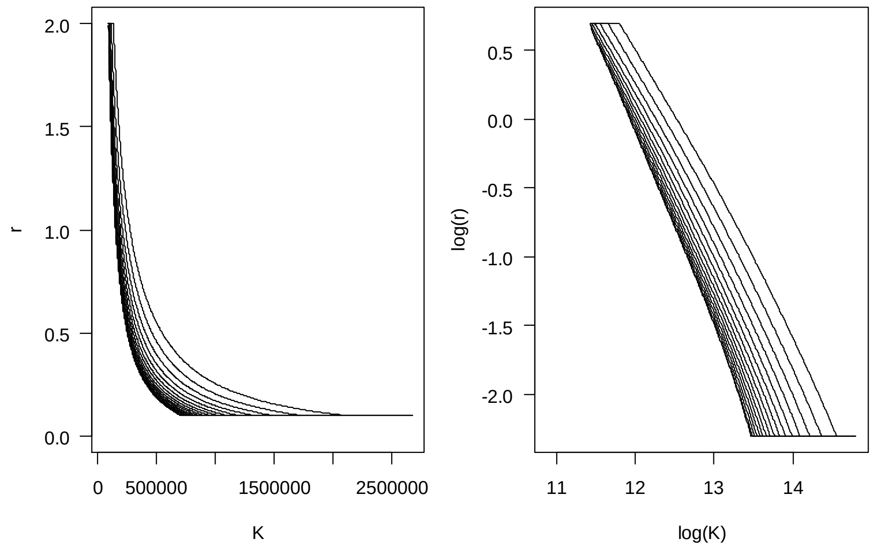

Figure 8. Initial plausible range of r and K values (non-informative priors)

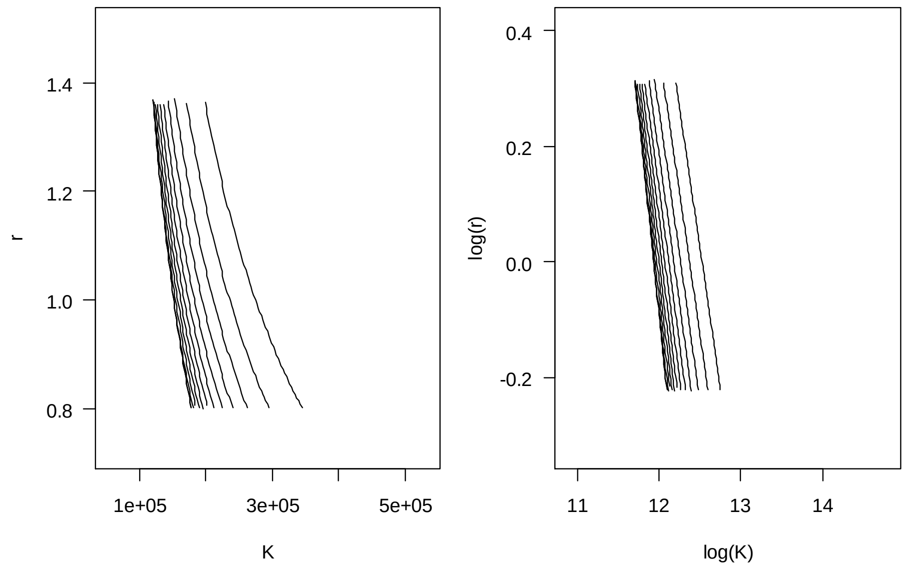

Figure 9. Plausible range of r and K with informative priors on r (0.80 - 1.37)

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 10). There were no feasible solutions found when the depletion level was assumed to be lower than 0.2. This is fairly intuitive as it is unlikely that the stock is lower than 20% of the original biomass.

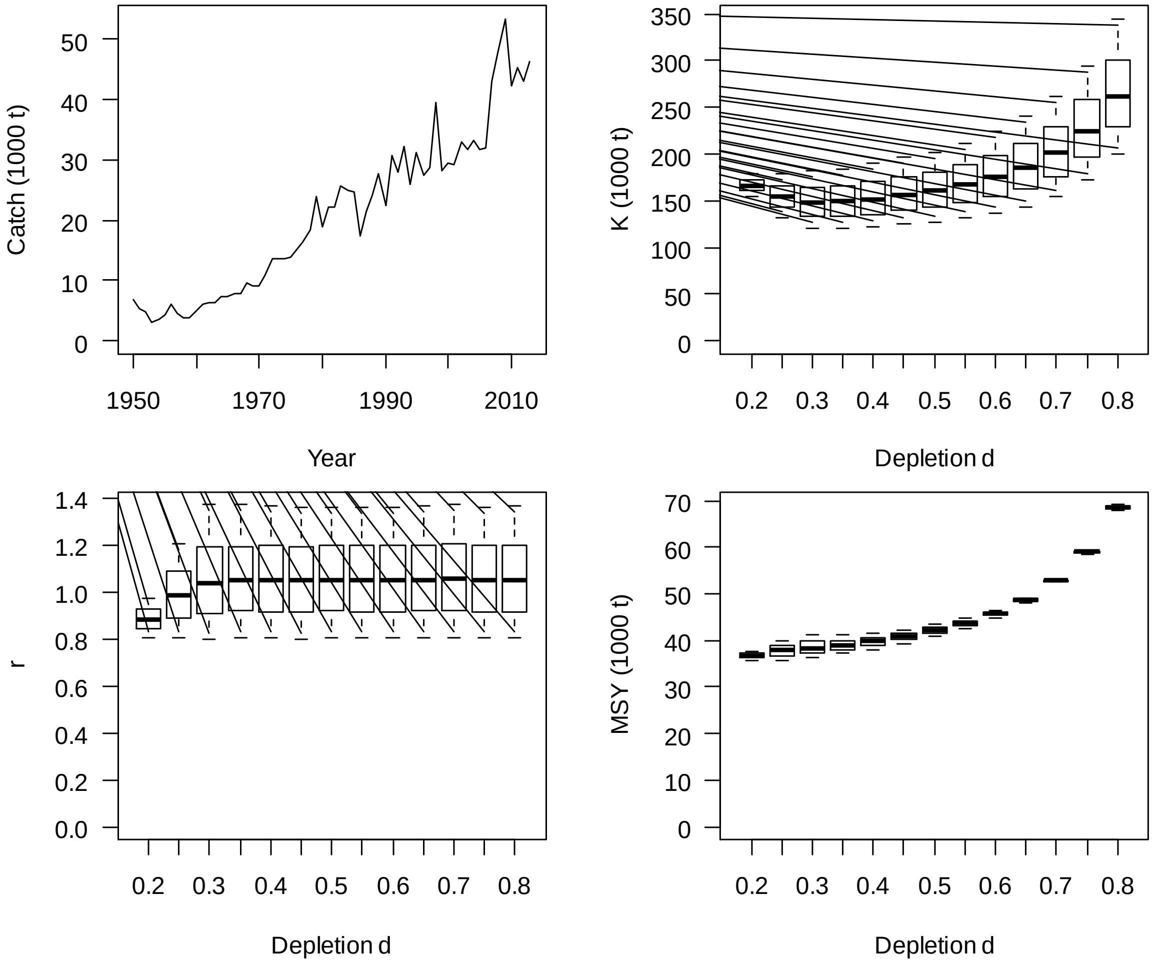

Figure 10. *S. guttatus* catch history, feasible carrying capacity, population growth rate and MSY at each assumed depletion level. There is no feasible solution when the depletion is assumed to be below 0.2.

Base case model results (for a maximum depletion level of 0.7) indicate that the biomass was approximately 164 000 t in 1950 and declined to approximately 84 000 t in 2013 (Figure 11). This projection corresponds well with the biomass projection estimated using the Catch-MSY model and is based on the rise in catches up to the peak in 2009 (Table 1). The estimated MSY associated with this projection is 42 001 t and ranges from approximately 36 000 t to 53 000 t based on the assumed depletion level (Table 9).

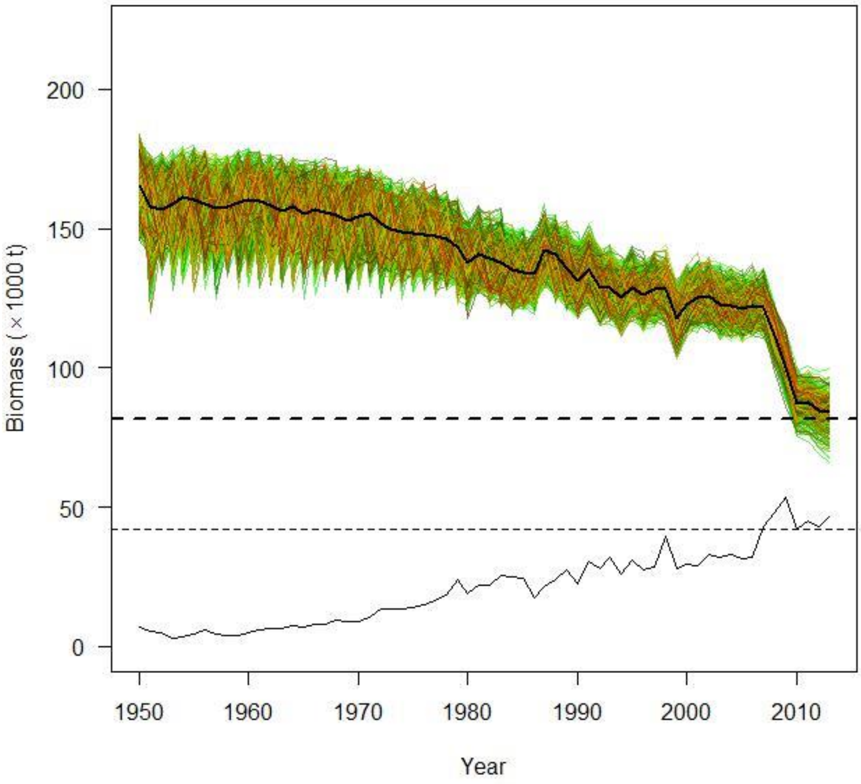

Figure 11. ***S. guttatus*** **biomass trajectories from 500 simulations with upper depletion = 0.7.**

Table 9. OCOM key biological parameters for *S. guttatus* under four assumed upper depletion levels[3]

Upper d	Quantile	K	r	MSY	B_{2013}	D
0.8	0%	120 649	0.80	35 752	84 596	0.47
0.8	25%	150 264	0.91	39 995	99 366	0.56
0.8	50%	173 038	1.04	43 732	104 199	0.59
0.8	75%	204 005	1.19	52 757	108 613	0.61
0.8	100%	344 953	1.37	69 099	134 221	0.75
0.7	0%	120 649	0.80	35 752	66 322	0.40
0.7	25%	145 625	0.91	39 470	81 152	0.49
0.7	**50%**	**163 798**	**1.03**	**42 001**	**84 370**	**0.51**
0.7	75%	184 238	1.18	46 232	87 484	0.53
0.7	100%	262 176	1.37	52 857	99 815	0.60
0.6	0%	120 649	0.80	35 752	56 721	0.36
0.6	25%	142 240	0.90	38 874	68 129	0.43
0.6	50%	158 741	1.03	40 854	71 227	0.45
0.6	75%	175 773	1.18	43 149	74 324	0.47
0.6	100%	224 129	1.37	46 466	82 776	0.52

[3] NB While K, R and MSY are derived from the optimisation model, B_{2013} and D are highly dependent on the fixed assumptions and so the values presented here are from a further, unconstrained model run.

Upper d	Quantile	K	r	MSY	B_{2013}	D
0.5	0%	120 649	0.80	35 752	44 791	0.29
0.5	25%	138 934	0.90	38 232	56 566	0.37
0.5	50%	155 051	1.02	39 769	59 720	0.39
0.5	75%	170 346	1.17	41 151	62 373	0.40
0.5	100%	202 412	1.37	43 337	70 614	0.46

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 2013, and resulted in a very rapid decline of the stock (Figure 12). This is an unlikely scenario given that catch rates generally decline with decreasing biomass, so as an alternative this was also simulated as the catch relative to the target biomass level remains at the current level, i.e. a constant catch rate of $C2013/B_{MSY}$. This is more intuitive than projecting a constant catch level into the future as factors such as changing catchability based on availability are likely to affect the rate at which a stock can decrease, so a catch rate projection provides a more realistic scenario. This projection predicts that the catch decreases from the 2013 level but remains at a relatively high level, resulting in a stock biomass which stabilises somewhat below B_{MSY} (Figure 13).

The second set of projections were based on the assumption that a constant catch of MSY was achieved annually. This was also simulated as a fixed future catch level (Figure 14) as well as a fixed future catch rate equal to the optimum rate for achieving the target biomass, i.e. MSY/ B_{MSY} (Figure 15). While both of these projections result in a biomass which rapidly stabilises at the corresponding B_{MSY} level there is more uncertainty associated with the fixed catch level compared with the fixed catch rate. This is due to the high uncertainty in the biomass level and so here a fixed catch level is more indicative of a management scenario, whereas achieving a fixed catch rate would be extremely difficult to achieve in practice and so provides a less realistic scenario.

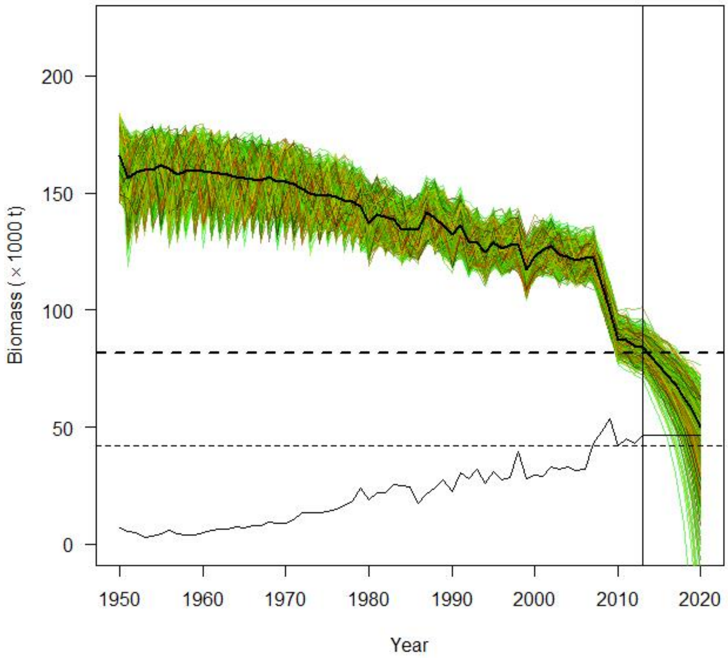

Figure 12. Projected *S. guttatus* biomass trajectories under hypothetical annual catches equivalent to those of the final year (C2013) until 2020. The vertical line is the last year (2013) for which catch data are available.

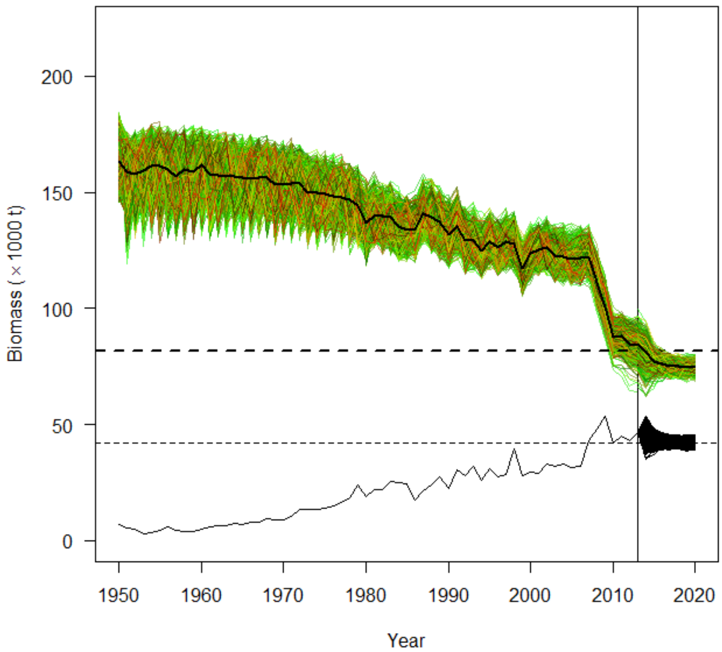

Figure 13. Projected *S. guttatus* biomass trajectories under hypothetical annual catch rate (C2013/B_{MSY}) at 2013 level until 2020. The vertical line is the last year (2013) for which catch data are available.

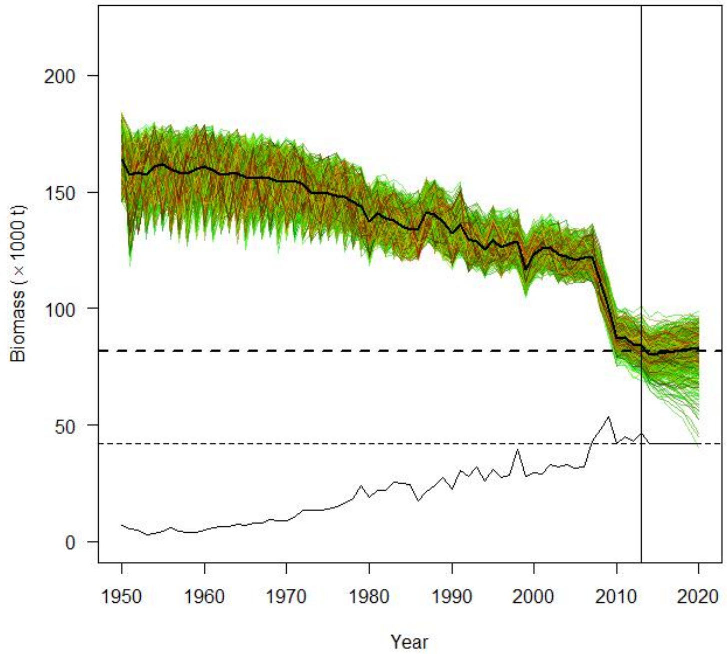

Figure 14. Projected *S. guttatus* biomass trajectories under hypothetical future annual catch equivalent to MSY until 2020. The vertical line is the last year (2013) for which catch data are available.

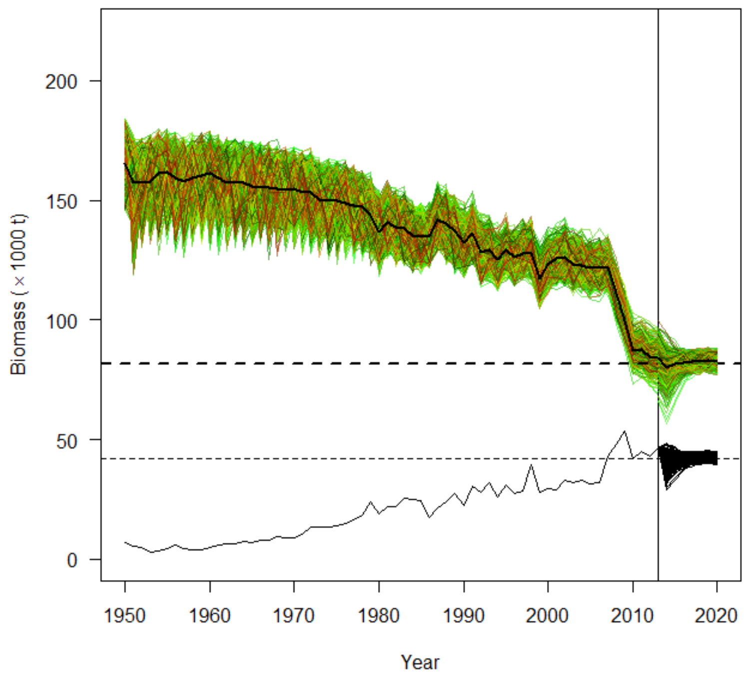

Figure 15. Projected *S. guttatus* biomass trajectories under hypothetical annual catch rate at MSY level (C_{MSY}/B_{MSY}) until 2020. The vertical line is the last year (2013) for which catch data are available.

Management quantities based on geometric means and plausible ranges based on the OCOM model results are provided in Table 10, indicating that the geometric mean MSY is 42 978 t. The KOBE matrix plot indicates that based on these model results, *S. guttatus* is not currently overfished (B_{2013}/B_{MSY} = 1.01) and is subject to overfishing (F_{2013}/F_{MSY} = 1.05) (Figure 16).

Table 10. 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	**Indian Ocean**
Most recent catch estimate (2013)	46 354 t
Mean catch from 2009–2013	49 870 t
MSY (plausible range)	42 978 t (35 752 - 52 857)
Data period used in assessment	1950 – 2013
F_{MSY} (plausible range)	0.42 (0.34 - 0.52)
B_{MSY} (plausible range)	82 846 (60 324 - 131 088)
F_{2013}/F_{MSY} (plausible range)	1.05 (0.91 - 1.27)
B_{2013}/B_{MSY} (plausible range)	1.01 (0.80 - 1.20)
SB_{2013}/SB_{MSY} (80% CI)	n.a
B_{c2013}/B_0 (plausible range)	0.52 (0.34 - 0.74)
SB_{2013}/SB_0 (80% CI)	n.a
$B_{2013}/B_{0,\ F=0}$ (80% CI)	n.a
$SB_{2013}/SB_{0,\ F=0}$ (80% CI)	n.a

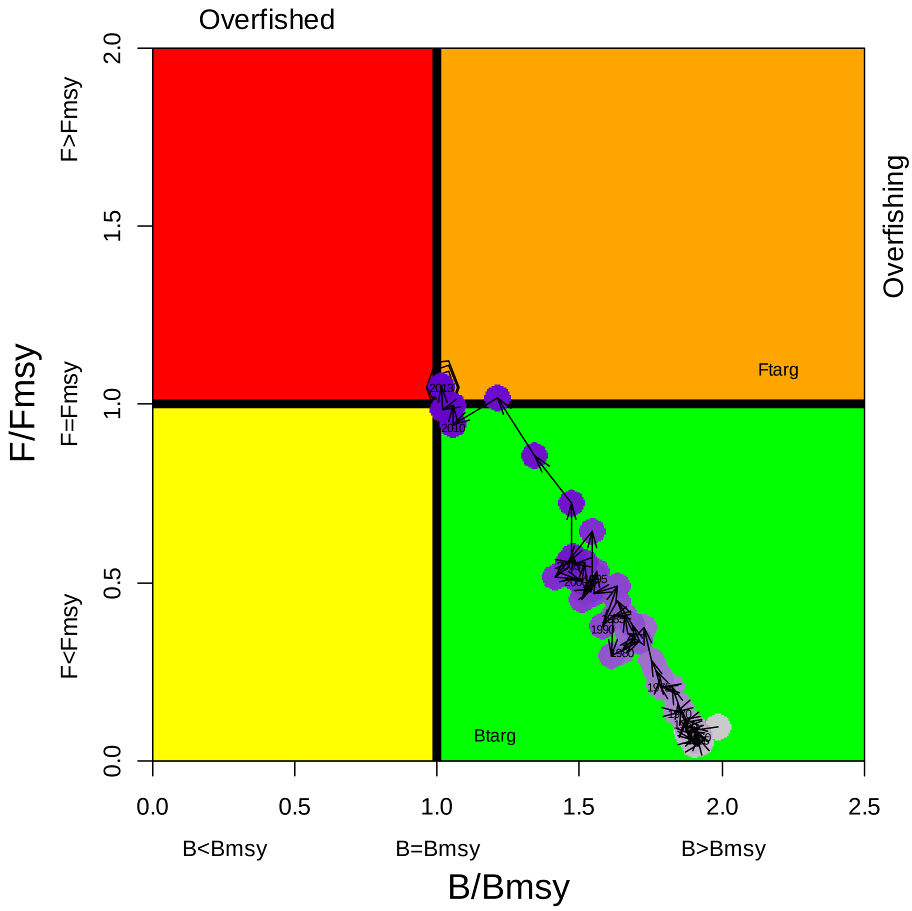

Figure 16. *S. guttatus* OCOM Indian Ocean assessment Kobe plot. The Kobe plot presents the trajectories for the range of plausible model options included in the formulation of the final management advice. The trajectory of the geometric mean of the plausible model options is also presented.

Discussion

Results between the two models were very similar with MSY estimated at 44 000 t based on the Catch-MSY model and 43 000 t based on the OCOM model. Both models indicated that *S. guttatus* is '*not overfished*' (B_{2013}/Bmsy = 1.04; 1.01), and as F_{2013}/Fmsy = 1.00 and 1.05 for the two model approaches used, the stock is considered to be '*subject to overfishing*'. The catch in 2013 was reported to be 46 354 t which, while lower than the average of the previous 5 years (49 870 t), is still higher than both estimates of MSY.

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