Assessment of Indian Ocean narrow-barred Spanish mackerel (*Scomberomorus commerson*) using data poor catch-based methods

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IOTC Secretariat[1]

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[1] sarah.martin@iotc.org; rishi.sharma@iotc.org

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. In 2014, data-poor approaches using only catch information were used to assess the status of Indian Ocean narrow-barred Spanish mackerel (*Scomberomorus commerson*) (IOTC–2014–WPNT04–26). These approaches are updated here based on the recent new catch information.

This paper uses two methods were used to assess the status of *S. commerson*: (i) Stock reduction analysis or Catch MSY method (Kimura and Tagart 1982; Walters et. al. 2006; Martell and Froese 2012) and (ii) a recently developed posterior-focussed catch method OCOM (Zhou et al., 2013). Other neritic species investigated using the same methods in 2015 were: Indian Ocean Kawakawa (*Euthynnus affinis*) (IOTC-2015-WPNT05-21), Longtail tuna (*Thunnus tonggol*) (IOTC-2015-WPNT05-22) and Indo-Pacific king mackerel *(Scomberomorus guttatus)* (IOTC-2015-WPNT05-24). Catch data for Bullet tuna (*Auxis rochei*) and frigate tuna (*Auxis thazard*) were considered too incomplete for the use of catch-based assessment methods.

Basic biology

The Narrow-barred Spanish mackerel (*Scomberomorus commerson*) (Lacépède, 1800) is part of the Scombridae family. It is an epipelagic predator which is distributed widely in the Indo-Pacific region (Figure 1) from shallow coastal waters to the edge of the continental shelf where it is found from depths of 10-70m (McPherson 1985). It is relatively large for a neritic species with a maximum fork length of 240 cm. Narrow-barred Spanish mackerel is primarily caught by gillnet fleets operating in coastal waters with the highest reported catches form Indonesia, India and Iran (Pierre et al. 2014). Most research has been focussed in these areas where there are important fisheries for the species, with the most common methods used to estimate growth being through length-frequency studies, although a number of otolith ageing studies have also been undertaken.

Estimates of growth parameters for *S. commerson*, using either length or age-based information, vary between geographic locations. Estimates of the growth parameter *K* of the von Bertalanffy equation range from 0.12 (Edwards et al. 1985) to 0.78 (Pillai et al. 1993), however, the majority of studies suggest relatively rapid growth of juveniles (IOTC Secretariat, 2015). Differences may be due to regional differences in growth patterns, but may also be due to the different selectivity patterns of gears used to obtain the samples as a variety of drifting gillnets, hooks and lines, trolling and trawl gear are used to catch Narrow-barred Spanish mackerel.

Fisheries and Catch Trends

Nominal catch data were extracted from the IOTC Secretariat database for the period 1950 - 2013, given that records for 2014 were still incomplete at the time of writing. Gillnet fleets are responsible for the majority of reported catches of *S. commerson* followed by line and purse seine gear, with the majority of catches taken by coastal country fleets (Figure 1). Figure 2 shows the increase in total catches since 1950, reaching a maximum of 160 000 t in 2012 and falling slightly in 2013 to 153 000 (

Table **1**).

Some revisions have been made to the nominal catch series since the assessment that took place in 2014, including an increase in the estimated catch for 2012 from 143 000 t to 160 000 t and a new catch estimate for 2013. These are show in (Figure 3).

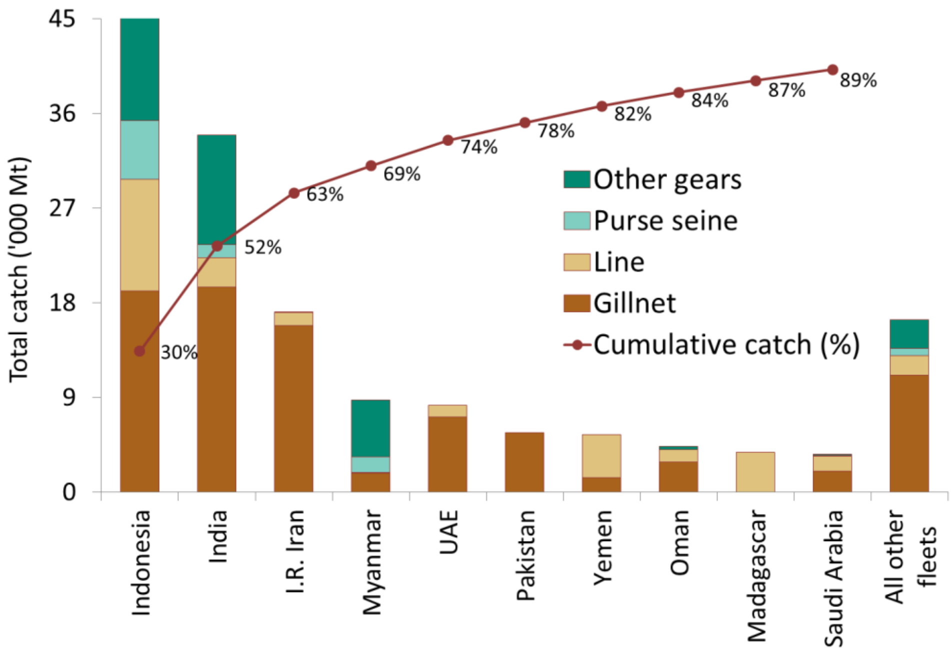

Figure 1. *Average catches in the Indian Ocean over the period 2010-2012, by country. Countries are ordered from left to right, according to the level of catches of Spanish mackerel reported. The red line indicates the (cumulative) proportion of catches of Spanish mackerel for the countries concerned, over the total combined catches of this species reported from all countries and fisheries.*

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

Year	Catch (t)	Year	Catch (t)
1950	9,188	1982	65,724
1951	9,827	1983	57,647
1952	9,707	1984	64,550
1953	9,687	1985	79,184
1954	11,055	1986	87,184
1955	10,060	1987	93,123
1956	14,291	1988	100,023
1957	13,740	1989	83,801
1958	12,553	1990	74,451
1959	13,076	1991	76,674
1960	13,262	1992	83,324
1961	15,325	1993	81,509
1962	17,046	1994	87,213
1963	17,600	1995	97,745
1964	19,766	1996	88,404
1965	19,618	1997	95,755
1966	23,354	1998	101,600
1967	25,327	1999	100,019
1968	26,430	2000	104,708
1969	25,043	2001	97,295
1970	23,470	2002	100,544
1971	25,387	2003	103,474
1972	30,455	2004	103,551
1973	27,370	2005	103,404
1974	36,180	2006	117,609
1975	36,269	2007	124,914
1976	41,451	2008	123,322
1977	49,986	2009	134,998
1978	49,528	2010	135,868
1979	55,831	2011	144,390
1980	53,927	2012	160,487
1981	56,937	2013	153,342

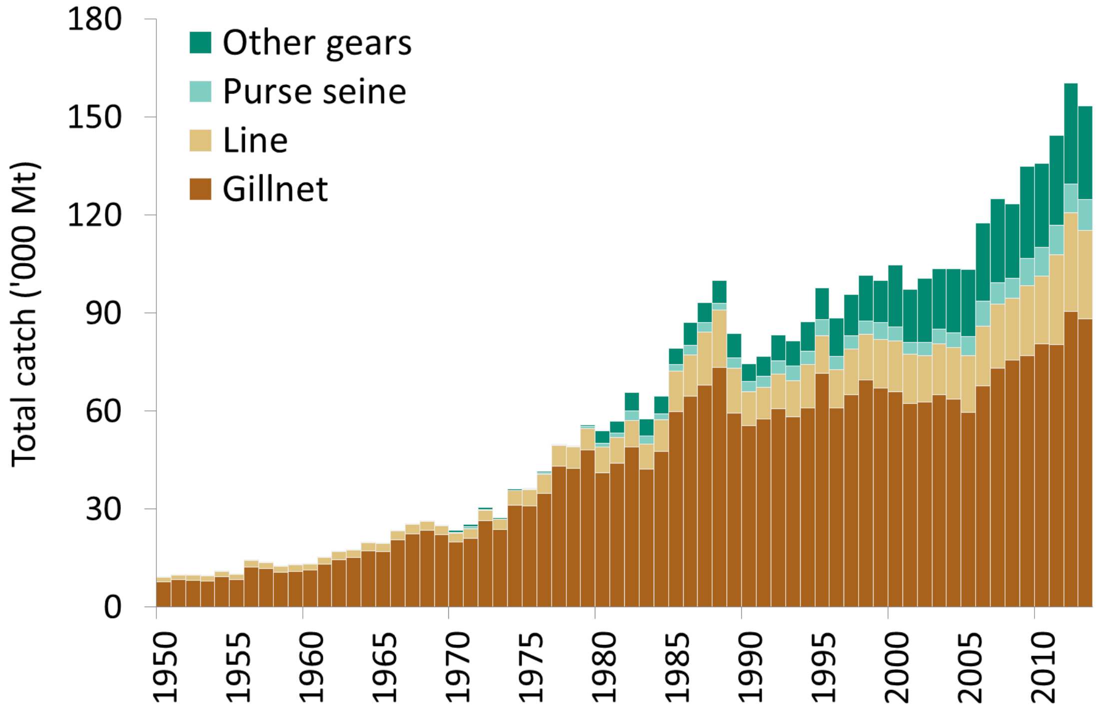

Figure 2. Annual catches of Spanish mackerel tuna by gear as recorded in the IOTC Nominal Catch database (1950–2013)

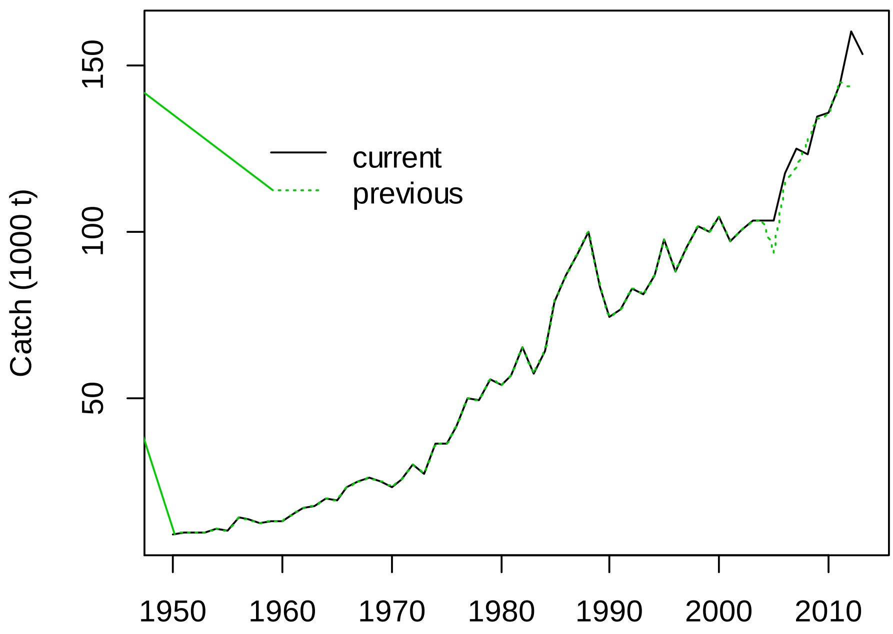

Figure 3. Revisions to the *S. commerson* nominal catch time series since the assessments in 2014

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, all of the neritic species assessed have 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 for each species 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)*
Spanish mackerel - run 1	0.5 - 0.9	0.5 – 0.9	0.6 - 1.5	160 – 8024
Spanish mackerel - run 2			0.6 – 1.8	271 - 656

Geometric means were used for the outputs of *r*, *k* and *MSY*, where management quantities were calculated based on the standard Schaefer model equations, i.e.:

$$MSY = \frac{rk}{4},\ B_{MSY} = \frac{k}{2} \text{ and } F_{MSY} = \frac{r}{2}$$

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 the literature (IOTC–2015–WPNT05–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 $\log(M) = 0.566 - 0.718 Log(L_\infty) + 0.02T$ (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 0.28 to 2.47 with a mean of 0.98± 0.52 (2 s.d.). Values which were more or less than 2 s.d. removed from the mean were dropped so that (0.46 ≥ r ≤ 1.51). 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 each species (OCOM method)

Species	**Initial *B/k***	**Final *B/k***	***r***	***K (1000 t)***
Spanish mackerel	1	0.05 – 0.8	0.1 – 2	160 – 8024
		0.05 – 0.7	0.46 – 1.51	
		0.05 – 0.6		
		0.05 – 0.5		

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

While median B_{MSY} and F_{MSY} were calculated from the equations $\quad B_{MSY} = \frac{K}{2}$ 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 25^{th} - 75^{th} 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 based 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, instead ranging from 301 126 to 1 083 487 t while possible r values spanned through the full range possible under the assumptions (0.6 – 1.5). 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 tail of the distribution (Figure 4 and Figure 5) and the range for *r* was expanded to 1.2 multiplied by the maximum *r* (0.6 - 1.8). The model results from this gave a more normal distribution of *r* (Figure 5) with little change in *MSY*. This was taken as the base model run and the results for this simulation are presented.

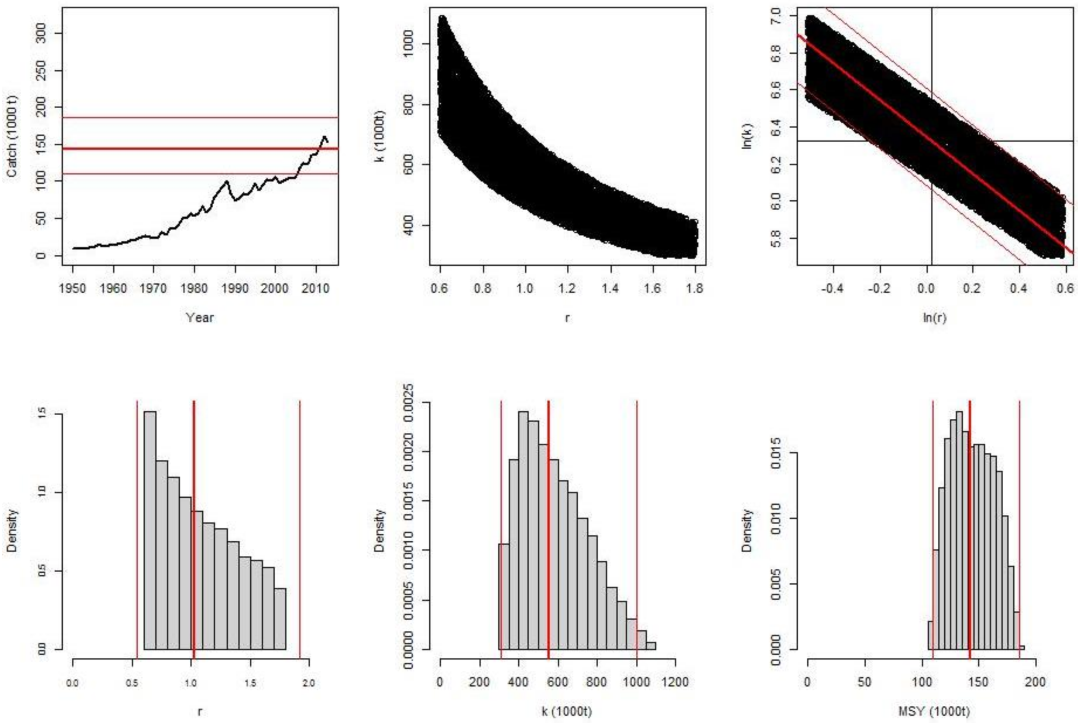

Figure 4. All feasible *r* and *K* combinations resulting from model simulations based on the original parameter constraints

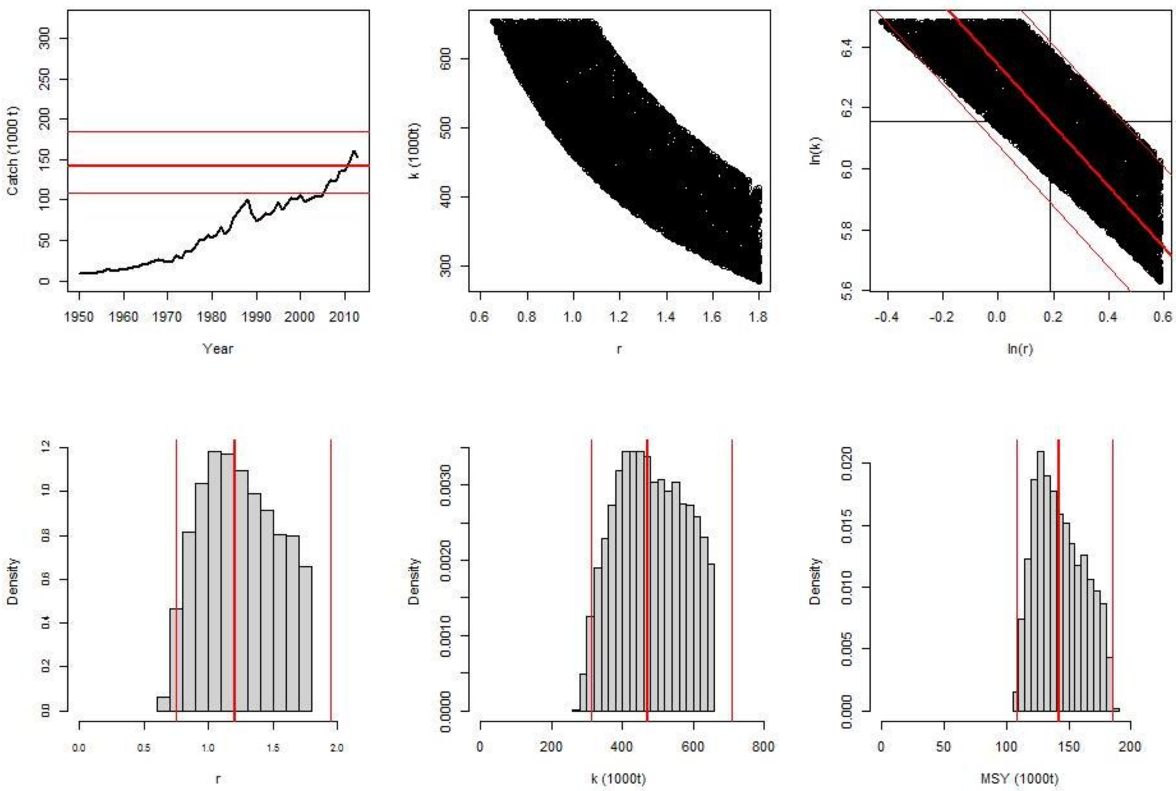

Figure 5. All feasible *r* and *K* combinations with further parameter constraints on max(K)

Results are presented for the simulated biomass trajectories for all plausible *r, K* and starting biomass combinations. The ranges are quite variable across the prior ranges set for the initial and final biomass levels and emulate the catch trajectory with a dip prior to 1990. The results all suggest a relatively rapid decline in biomass since the mid-2000s. 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 137 201 t across all starting biomass levels. Management quantities based on geometric means and plausible ranges are provided in Table 8 which give a slightly higher average MSY, 137 828, than the median.

The IOTC target and limit reference points for *S. commerson* have not yet been defined, so the values applicable for all other IOTC species are used as in Table 5. These are indicated on the KOBE matrix plot which indicates that based on these model results, *S. commerson* is subject to overfishing ($F_{current}/F_{MSY}$ = 1.07) but is not overfished ($B_{current}/B_{MSY}$ =1.01). There are, however wide uncertainty intervals as evident in Table 8 and Figure 6.

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

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 for *S. commerson* for all starting depletion levels (0.5-0.9)

Quantile	K	r	B_{MSY}	MSY	B_{2013}	Final D
0%	280 810	0.65	140 405	107 303	86 385	0.31
25%	446 227	0.95	223 113	124 316	203 939	0.46
50%	**519 668**	**1.10**	**259 834**	**135 758**	**267 737**	**0.52**
75%	585 959	1.27	292 979	152 220	333 110	0.57
100%	656 327	1.80	328 163	186 620	454 218	0.69

Table 7. Key biological parameters for *S. commerson* under four assumed starting depletion levels

Initial D	Quantile	K	r	B_{MSY}	MSY	B_{2013}	Final D
0.8	0%	344771	0.65	172386	107 303	104825	0.30
0.8	25%	465115	0.93	232557	123 420	210130	0.45
0.8	50%	530574	1.07	265287	134 865	274597	0.52
0.8	75%	591379	1.22	295689	151 354	339730	0.57

Initial D	Quantile	K	r	B_{MSY}	MSY	B_{2013}	Final D
0.8	100%	656327	1.42	328163	181 066	454218	0.69
0.7	0%	314629	0.65	157315	107 303	95549	0.30
0.7	25%	437381	0.96	218690	125 165	204450	0.47
0.7	50%	507284	1.14	253642	137 201	267630	0.53
0.7	75%	577856	1.32	288928	154 008	331251	0.57
0.7	100%	656327	1.57	328163	182 784	454218	0.69
0.6	0%	280810	0.65	140405	107 303	86385	0.31
0.6	25%	397556	0.98	198778	125 770	187173	0.47
0.6	50%	487219	1.17	243610	136 569	248838	0.51
0.6	75%	572036	1.42	286018	152 609	314342	0.55
0.6	100%	656327	1.80	328163	186 083	454218	0.69
0.5	0%	345294	0.65	172647	107 303	104825	0.30
0.5	25%	466956	0.93	233478	123 210	210289	0.45
0.5	**50%**	532565	1.07	266283	134 530	274815	0.52
0.5	75%	592575	1.22	296287	150 988	340103	0.57
0.5	100%	656327	1.41	328163	181 056	454218	0.69

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

Management Quantity	**Aggregate Indian Ocean**
Most recent catch estimate (2013)	153 341 t
Mean catch from 2009–2013	143 998 t
MSY (plausible range)	137 828 (107 303 to 186 620)
Data period used in assessment	1950 - 2013
F_{MSY} (plausible range)	0.43 (0.28 - 0.64)
B_{MSY} (plausible range)	252 829 (140 405 – 328 163)
F_{2013t}/F_{MSY} (plausible range)	1.07 (0.66 – 2.02)
B_{2013}/B_{MSY} (plausible range)	1.01 (0.60 – 1.40)
SB_{2013}/SB_{MSY} (80% CI)	n.a
B_{2013}/B_0 (plausible range)	0.51 (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

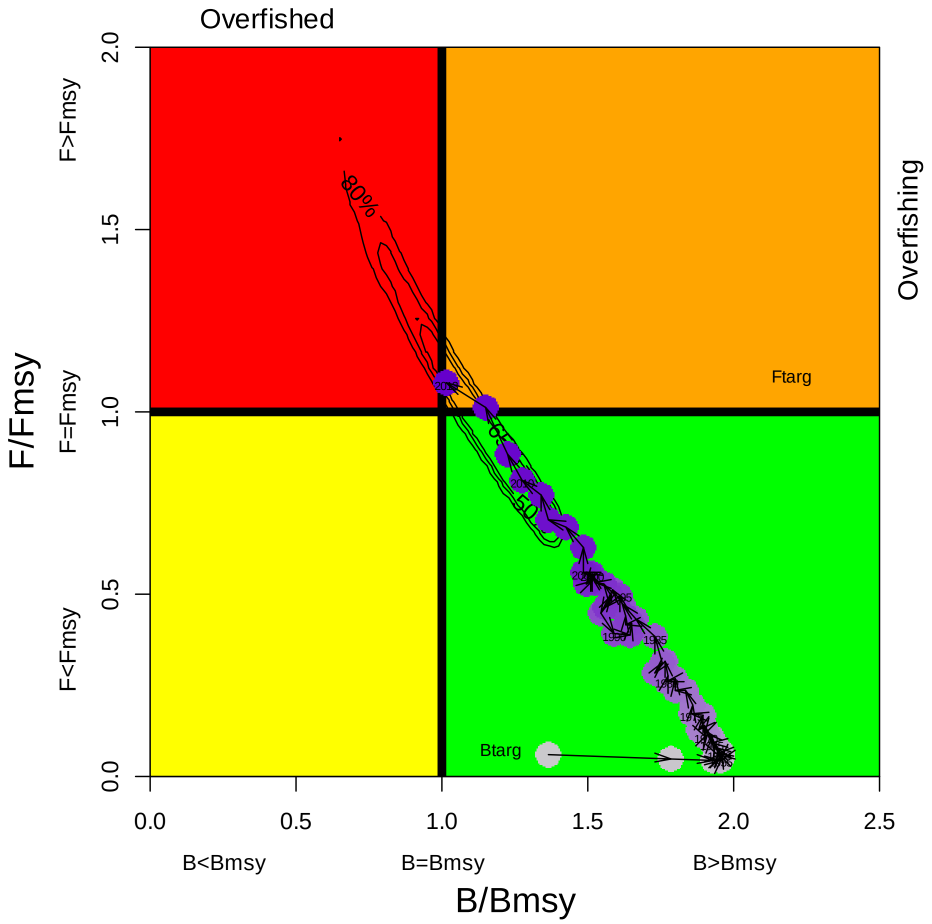

Figure 6. Narrow-barred Spanish mackerel. Catch-MSY Indian Ocean assessment for *S. commerson.* The Kobe plot presents the trajectories for the range of plausible model options included in the formulation of the final management advice. The trajectory of the geometric mean of the plausible model options is also presented.

OCOM method

Figure 7 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 8. The mean value of estimates ± 2 s.d. was used as the most plausible range, resulting in *r* priors of 0.46 to 1.5.

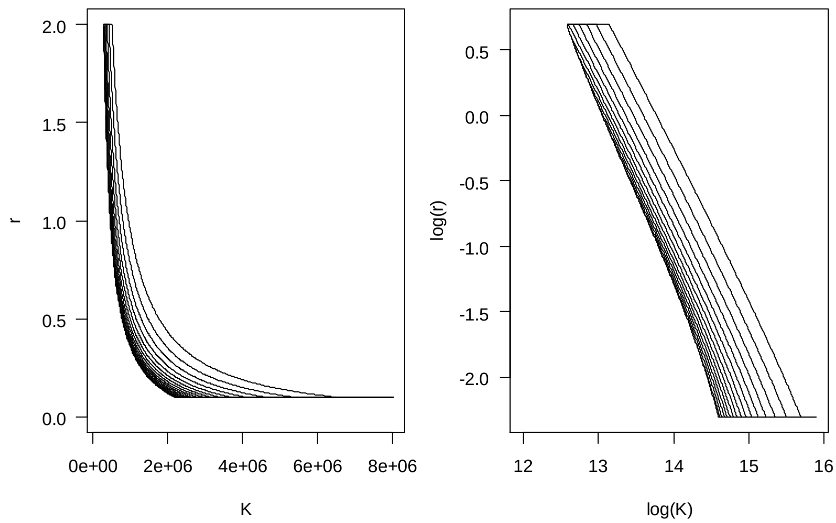

Figure 7. Initial plausible range of r and K values (non-informative priors)

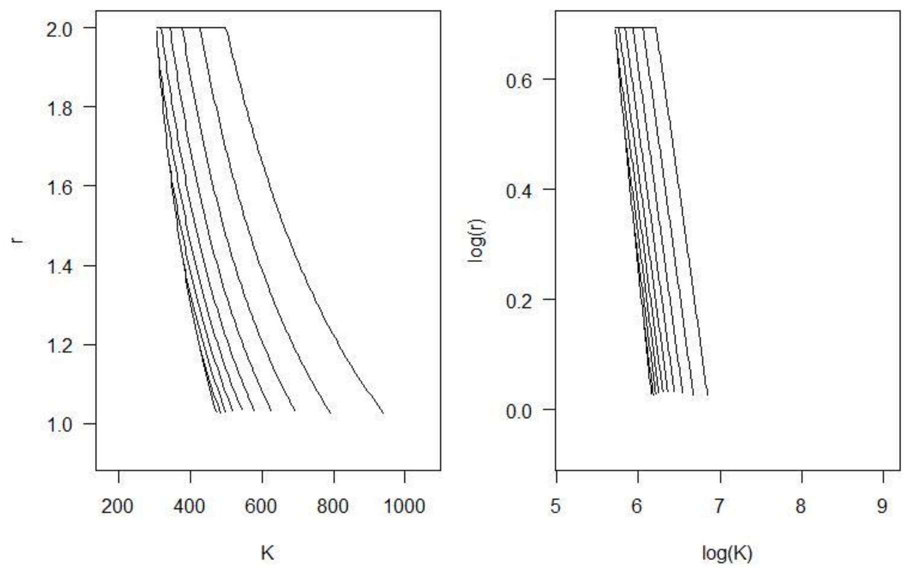

Figure 8. Plausible range of r and K with informative priors on r (0.46-1.5)

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 9). There were no feasible solutions found when the depletion level was assumed to be lower than 0.1.

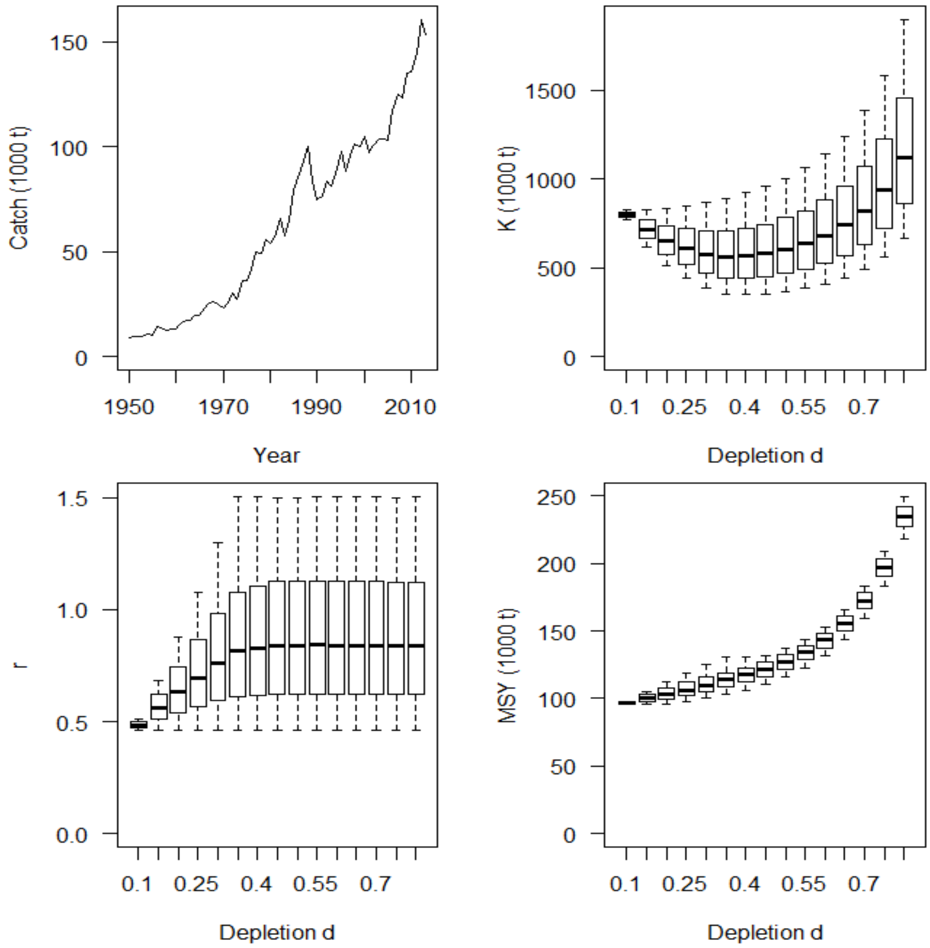

Figure 9. *S. commerson* catch history, feasible carrying capacity, population growth rate and MSY at each assumed depletion level. There is no feasible solution when the depletion is assumed to be below 0.1.

Base case model results (for a maximum depletion level of 0.7) indicate that the biomass was approximately 640 000 t in 1950 and declined to approximately 300 000 t in 2013 (Figure 10). The estimated MSY associated with this projection is 125 299 t and ranges from approximately 96 000 t to 184 000 t based on the assumed depletion level (Table 9).

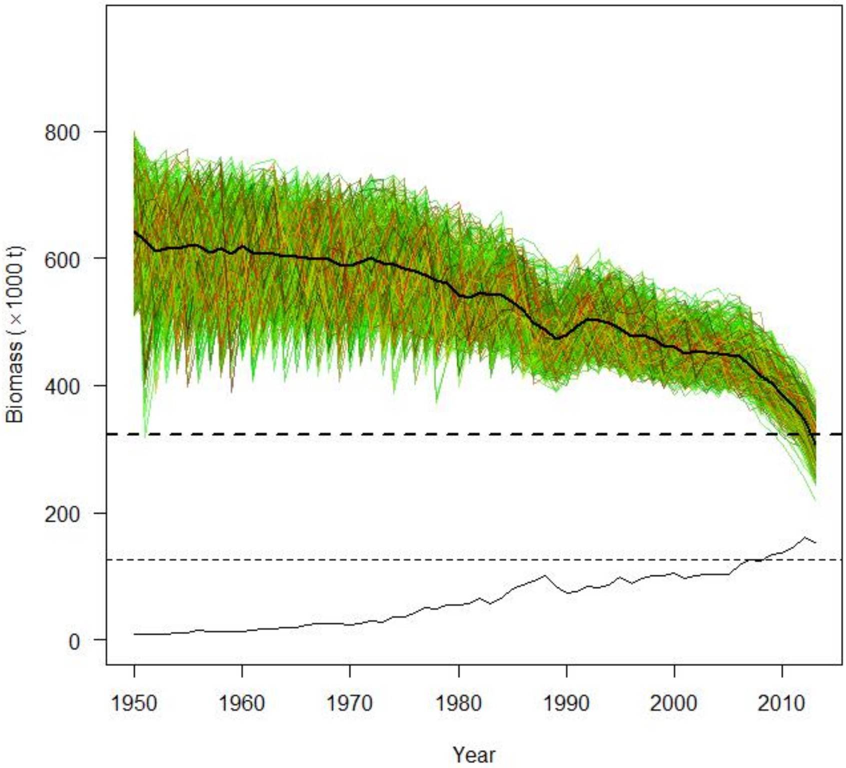

Figure 10. *S. commerson* biomass trajectories from 500 simulations with upper depletion = 0.7

Table 9. Posterior key biological parameters for *S. commerson* under four assumed upper depletion levels[2]

Upper d	Quantile	K	r	MSY	B_{2013}	D
0.8	0%	348 747	0.46	95 759	283 547	0.40
0.8	25%	534 654	0.60	115 075	355 466	0.51
0.8	50%	689 801	0.79	131 070	375 042	0.54
0.8	75%	859 126	1.07	163 364	398 470	0.57
0.8	100%	1896 429	1.50	249 204	478 030	0.69
0.7	0%	348 747	0.46	95 759	220 835	0.34
0.7	25%	508 088	0.60	112 191	291 734	0.45
0.7	**50%**	**642 808**	**0.78**	**125 299**	**308 763**	**0.47**
0.7	75%	799 035	1.06	143 569	325 647	0.50
0.7	100%	1385 947	1.50	183 542	391 570	0.59
0.6	0%	348 747	0.46	95 759	184 204	0.30
0.6	25%	488 557	0.59	109 755	238 669	0.38
0.6	50%	618 098	0.77	120 061	254 278	0.41

[2] NB While K, R and MSY are derived from the optimisation model, B_{2013} and the final depletion level, 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
0.6	75%	763 811	1.04	131 052	268 361	0.43
0.6	100%	1139 273	1.50	153 251	321 077	0.50
0.5	0%	348 747	0.46	95 759	132 572	0.22
0.5	25%	480 956	0.58	106 960	194 625	0.32
0.5	50%	608 482	0.75	115 086	210 067	0.35
0.5	75%	740 230	1.00	123 088	225 749	0.37
0.5	100%	1004 967	1.50	137 164	262 305	0.43

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 11). 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 12).

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 13) as well as a fixed future catch rate equal to the optimum rate for achieving the target biomass, i.e. MSY/ B_{MSY} (Figure 14). 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.

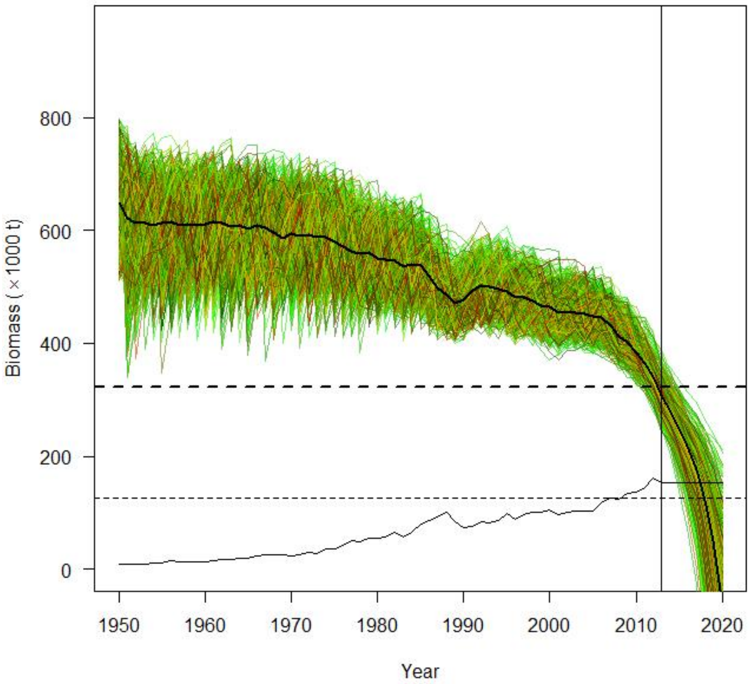

Figure 11. Projected *S. commerson* biomass trajectories under hypothetical annual catches equivalent to those of the final year (C2013) until 2020. The vertical line is the last year (2013) for which catch data are available.

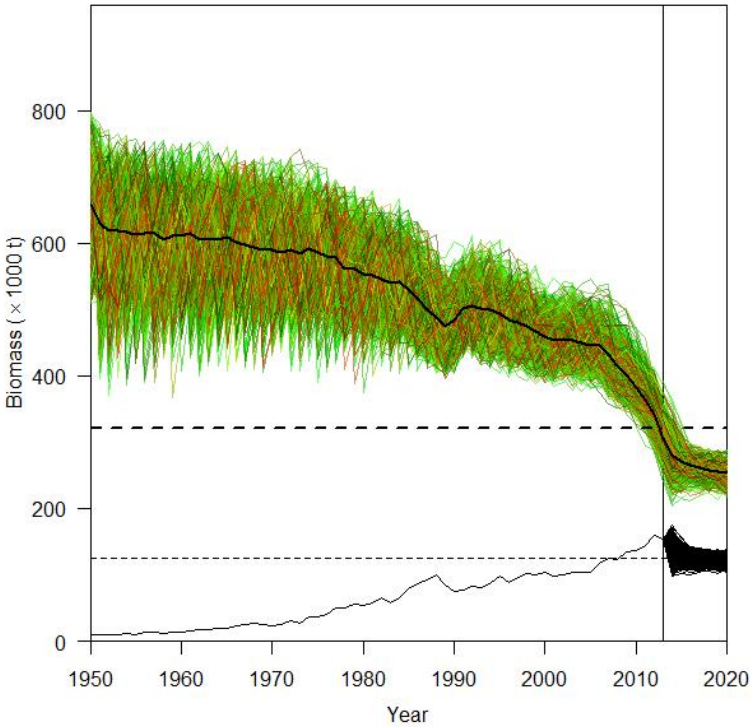

Figure 12. Projected *S. commerson* biomass trajectories under hypothetical annual catch rate (C2013/B_{MSY}) at 2013 level until 2020. The vertical line is the last year (2013) for which catch data are available.

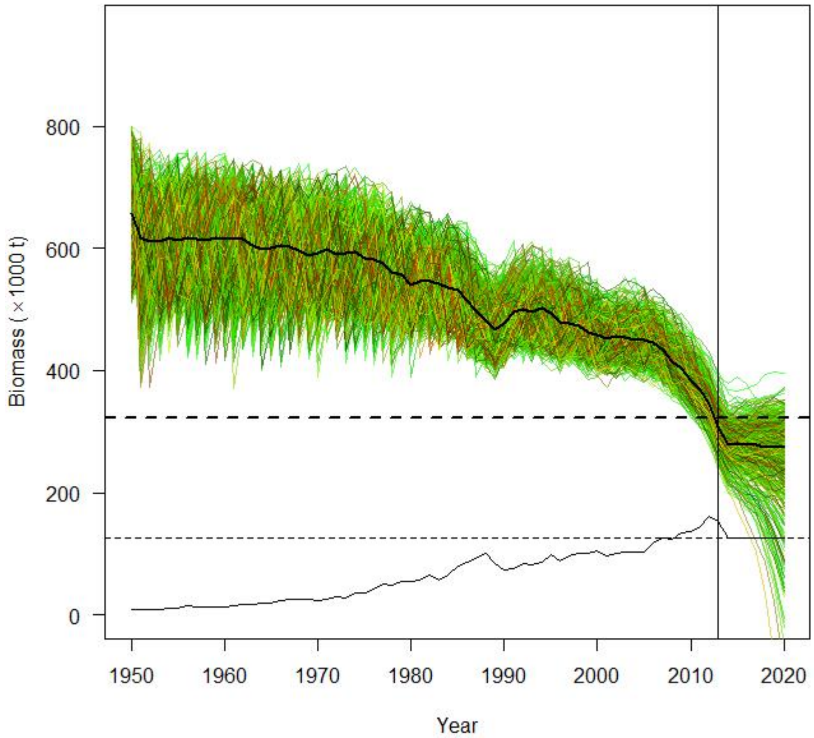

Figure 13. Projected *S. commerson* biomass trajectories under hypothetical future annual catch equivalent to MSY until 2020. The vertical line is the last year (2013) for which catch data are available.

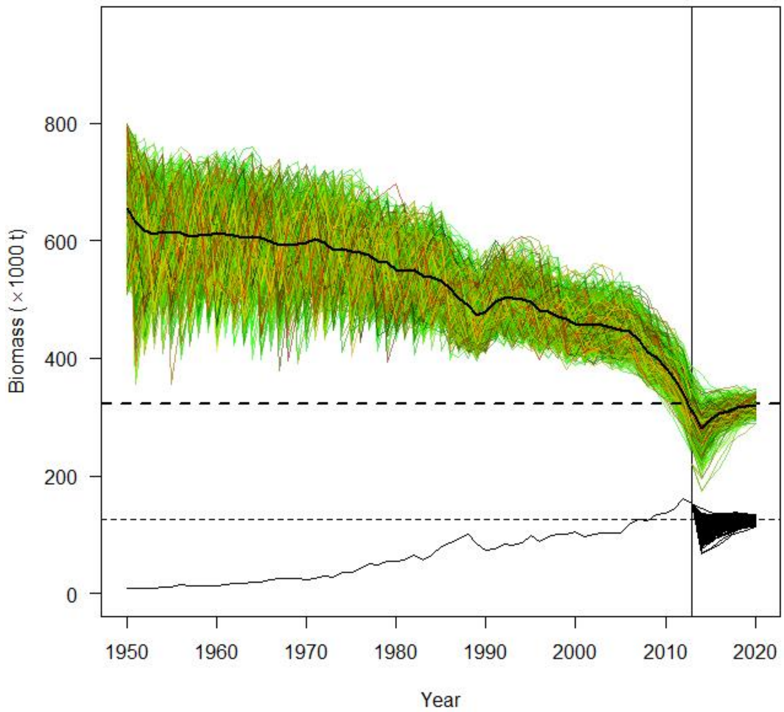

Figure 14. Projected *S. commerson* biomass trajectories under hypothetical annual catch rate at MSY level (C_{MSY}/B_{MSY}) until 2020. The vertical line is the last year (2013) for which catch data are available.

Management quantities based on geometric means and plausible are provided in Table 10. The geometric mean MSY, 127 731 t, is slightly higher than the median, 125 299 t. The KOBE matrix plot results indicates that based on the OCOM model results, *S. commerson* is currently both overfished (B_{2013} /BMSY = 0.96) and subject to overfishing (F_{2013}/FMSY = 1.22) (Figure 15).

Table 10. Narrow-barred Spanish mackerel. Key management quantities from the OCOM assessment for Indian Ocean *S. commerson*, 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)	153 342 t
Mean catch from 2009–2013	144 170 t
MSY (plausible range)	127 731 t (95759 – 183 542)
Data period used in assessment	1950 - 2013
F_{MSY} (plausible range)	0.33 (0.21 – 0.56)
B_{MSY} (plausible range)	320 664 (174 374 – 692 974)
F_{2013t}/F_{MSY} (plausible range)	1.21 (0.99 – 1.58)
B_{2013}/B_{MSY} (plausible range)	0.96 (0.69 - 1.22)
SB_{2013}/SB_{MSY} (80% CI)	n.a
B_{2013}/B_0 (plausible range)	0.53 (0.30 – 1.04)
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

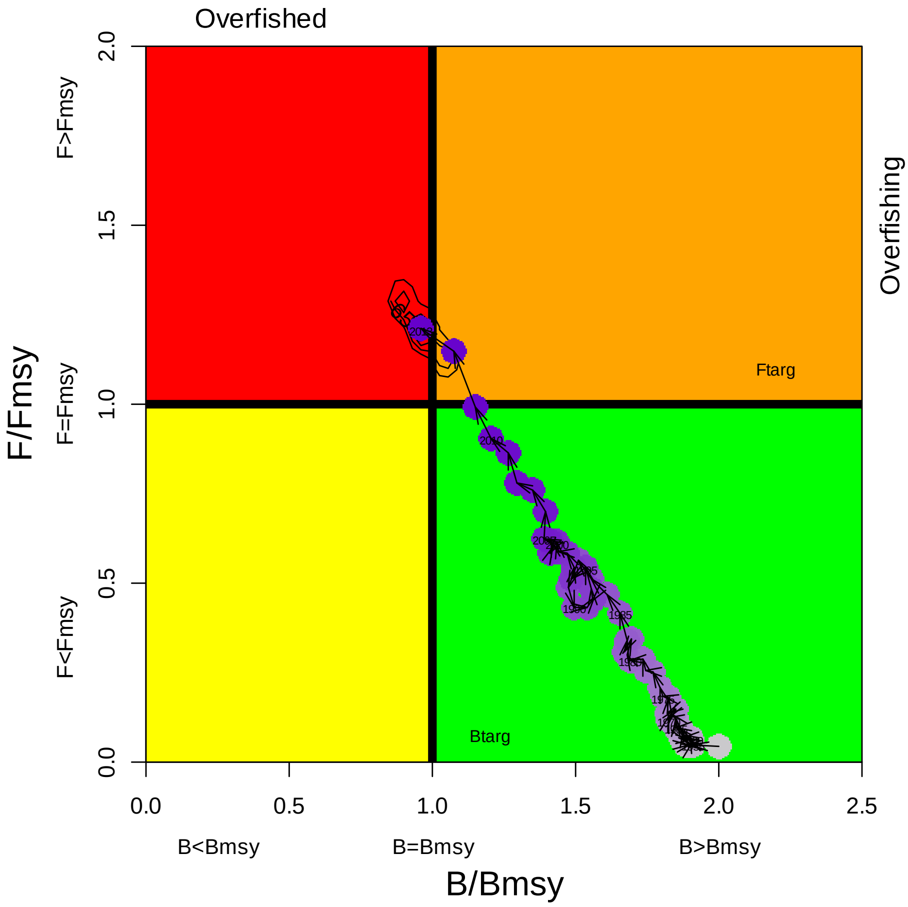

Figure 15. *S. commerson* OCOM Indian Ocean assessment Kobe plot. The Kobe plot presents the trajectories for the range of plausible model options included in the formulation of the final management advice. The trajectory of the geometric mean of the plausible model options is also presented.

Discussion

The assessment results for the two methods provided fairly different estimates of maximum sustainable yield. The Catch-MSY model estimated the geometric mean MSY at 137 828 (~136k median) while the OCOM model estimated the geometric mean MSY at 127 731 t (median ~125k). These findings were very similar to the 2014 assessment results which estimated MSY at 136 000 t and 124 000 t for the Catch-MSY and OCOM methods respectively. These results all indicate that current catch levels (153 324 t in 2013) are above the estimated maximum sustainable yield.

Estimates of current stock status were, however, less positive compared with the 2014 assessments which predicted the biomass relative to optimum levels ($B_{current}/B_{MSY}$) at 1.17 and the fishing mortality relative to optimum levels ($F_{current}/F_{MSY}$) at 0.98. The current assessments predicted slightly lower biomass $B_{current}$ /B_{MSY} at 1.01 (Catch-MSY) and 0.96 (OCOM), and a higher fishing mortality, $F_{current}/F_{MSY}$ 1.07 (Catch-MSY) and 1.21 (OCOM). This is quite likely to be due to the increased estimate of the catches in 2012 and the additional catches in 2013 which were again above the MSY levels estimated by all models. Based on the weight-of-evidence currently available, and using the precautionary lower estimates, the stock is considered to be '*overfished*' and '*subject to overfishing'*, though there are substantial uncertainties which are described throughout this paper.

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