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

6th June 2016

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. In 2014 and 2015, data-poor approaches using basic catch information were used to assess the status of Indian Ocean narrow-barred Spanish mackerel (*Scomberomorus commerson*) (IOTC–2014–WPNT04–26; IOTC-2015-WPNT05-23). 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). The other neritic species investigated using the same methods in 2016, as requested by the Scientific Committee, was Longtail tuna (*Thunnus tonggol*) (IOTC-2016-WPNT06-17).

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 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 I.R. Iran (Geehan et al. 2016). 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. Estimate**s** 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-2015-WPNT05-DATA14). 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

Disaggregated nominal catch data were extracted from the IOTC Secretariat database for the period 1950 - 2014, given that records for 2015 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 157 636 t in 2012 and falling slightly in 2013 and 2014 to 149 018 t and 154 732 t, respectively (Table 1).

Some revisions have been made to the nominal catch series each year since 2014. These are shown in Figure 3.

There is a relatively high uncertainty associated with the catch data for the neritic tuna species due to the difficulties in differentiating amongst the different species resulting in reported data in highly aggregate form, often as seerfishes or other groupings. The IOTC Secretariat uses methods of disaggregating these catches by species for assessment purposes. Figure 4 shows the relationship between the catches over time of each of the six neritic tunas and the close correlations between them. The high level of correlation amongst the species is likely to be partly because they are often caught together and partly due to difficulty with species identification but also because of the estimation procedures used to assign proportions of catch amongst the various species. Species-specific reporting has improved over time, leading to a lower level of correlation in more recent years.

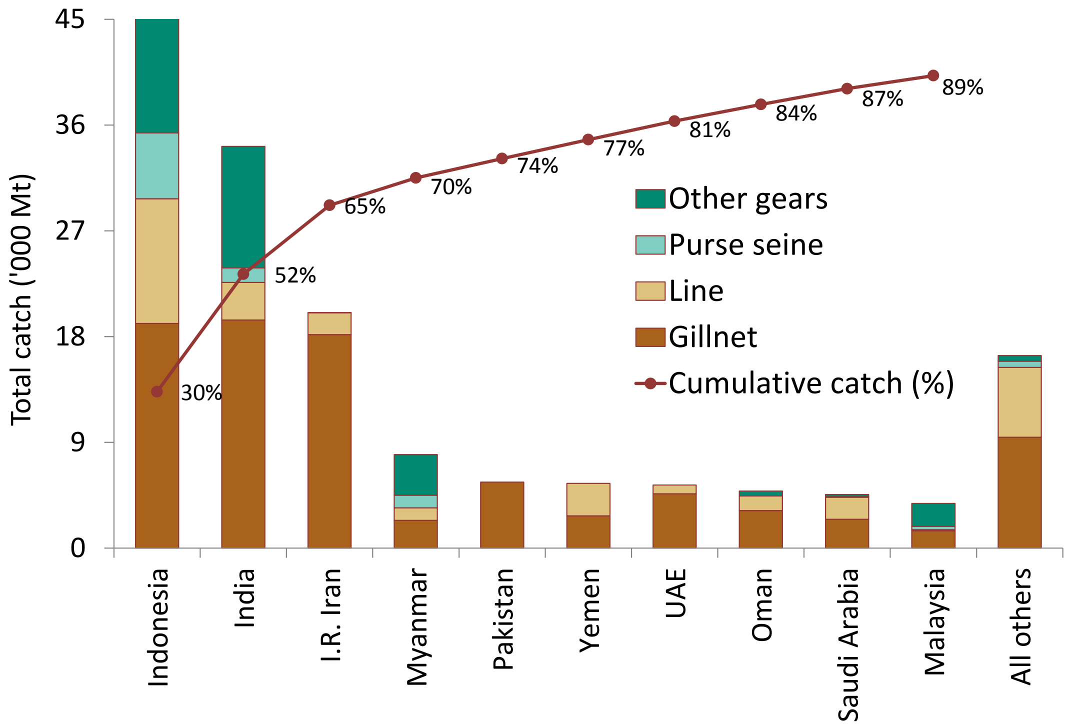

Figure 1. Average catches in the Indian Ocean over the period 2012-2014, by country. Countries are ordered from left to right, according to the level of catches of Spanish mackerel reported. The red line indicates the (cumulative) proportion of catches of Spanish mackerel for the countries concerned, 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, 1950-2014 (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	123,297
1977	49,986	2009	135,028
1978	49,528	2010	137,148
1979	55,831	2011	144,523
1980	53,927	2012	157,636
1981	56,937	2013	149,018
		2014	154,723

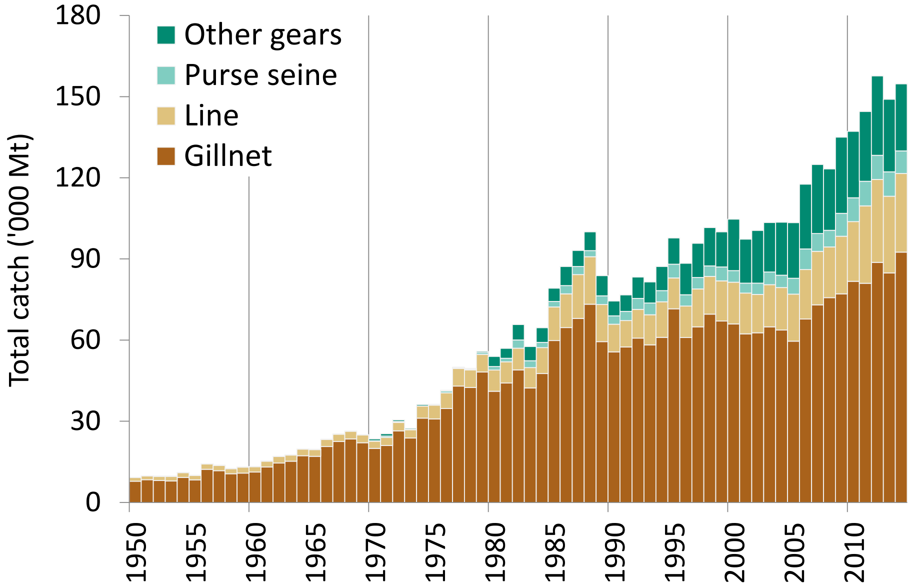

Figure 2. Annual catches of Spanish mackerel tuna by gear as recorded in the IOTC Nominal Catch database (1950–2014)

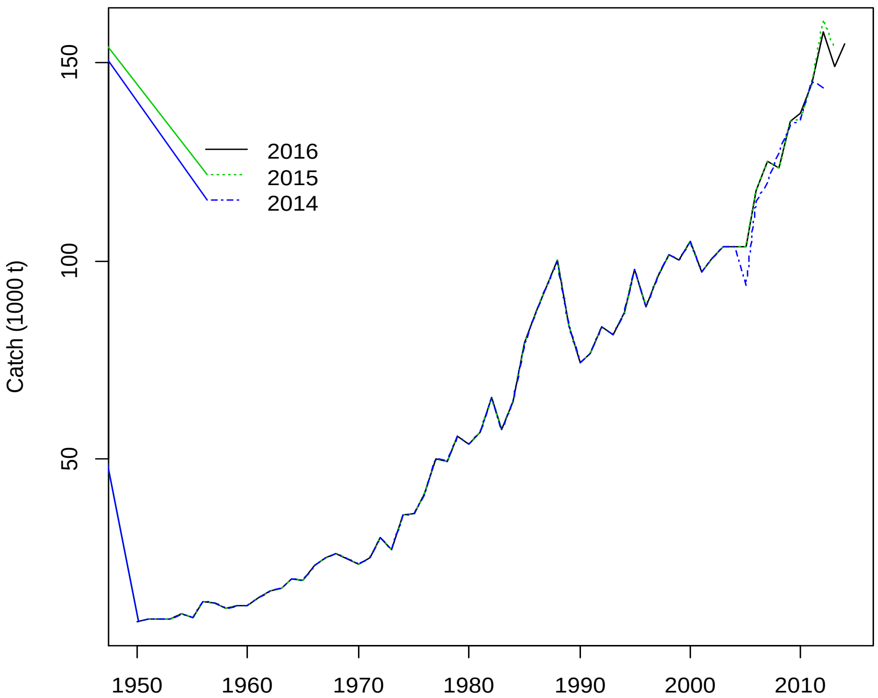

Figure 3. Revisions to the *S. commerson* nominal catch time series 2014-2016

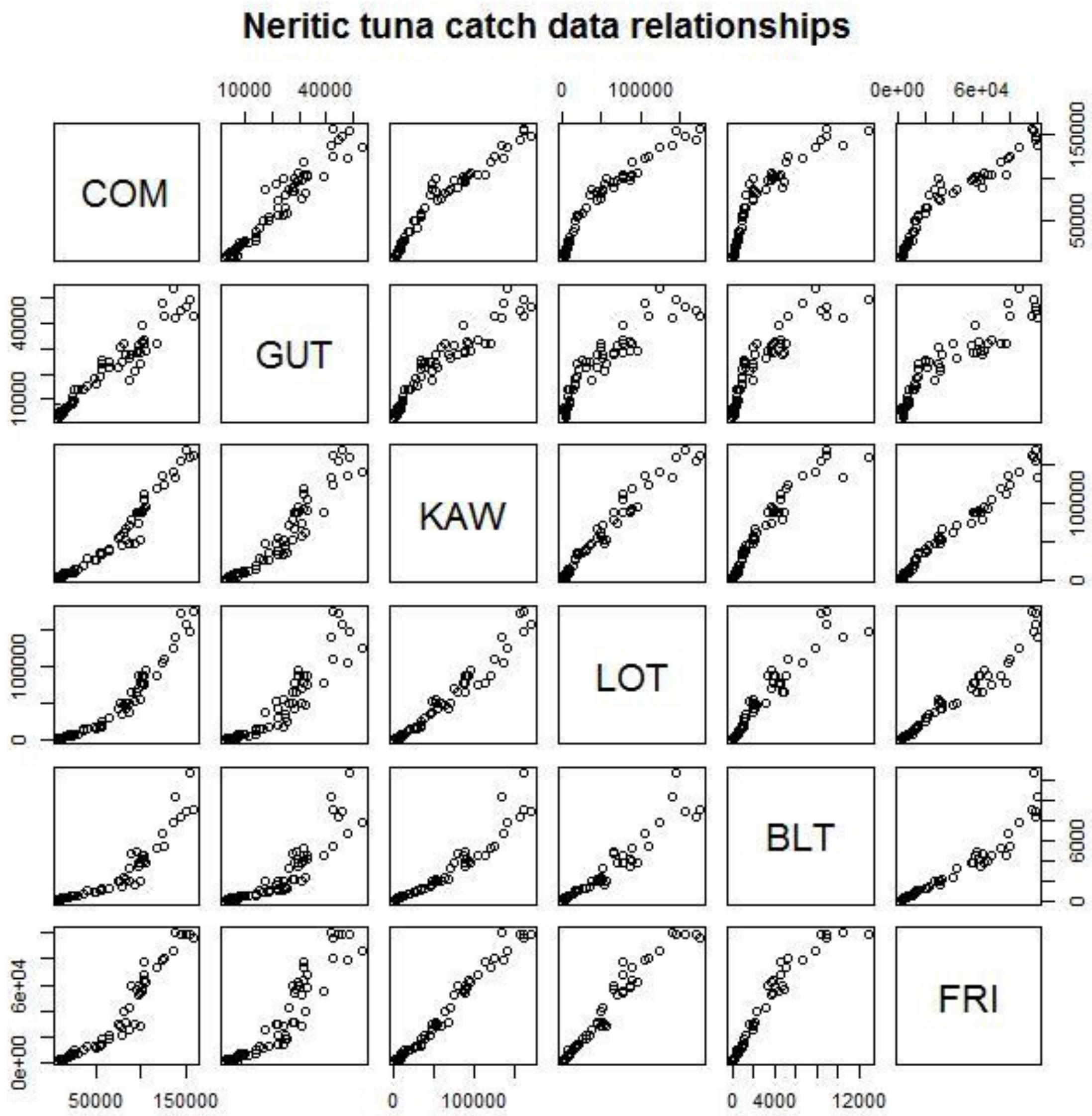

Figure 4. Correlations across the catch series of neritic tuna species

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, 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 maximum 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 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	0.3 – 0.7	0.6 - 1.5	158 – 7882
Spanish mackerel - run 2			0.6 – 1.8	277 - 679

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.:

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

2) Optimised Catch Only Method (OCOM)

The Optimised Catch-Only Method was developed by Zhou *et al*. (2013) can also use only a catch 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 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 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 $\log(M) = -0{\cdot}0066 - 0{\cdot}279 \log L\infty + 0{\cdot}6543 \log K + 0{\cdot}4634 \log T$ (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).

Taking the mean ±2 s.d. resulted in a set of estimated r values ranging from 0.46 to 1.51.

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 0.36 to 0.92 ($0.27 \leq M \leq 0.87$). 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 model simulations (OCOM method)

Initial *B/K*	Final *B/k*	*r*	*K (1000 t)*	*Method*
1	0.05 – 0.8	0.46 – 1.51	158 – 7882	5 equation average
	0.05 – 0.7	0.36 – 0.92		Then et al. (2014)
	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 = 0.7*.

Results

Catch-MSY method

The feasible *K* values did not reach the maximum available limit, instead ranging from 341 918 to 1 112 338 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* value to remove the tail of the distribution (Figure 5 and Figure 6) 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 6) with little change in *MSY*. This was taken as the base model run and the results for this simulation are presented.

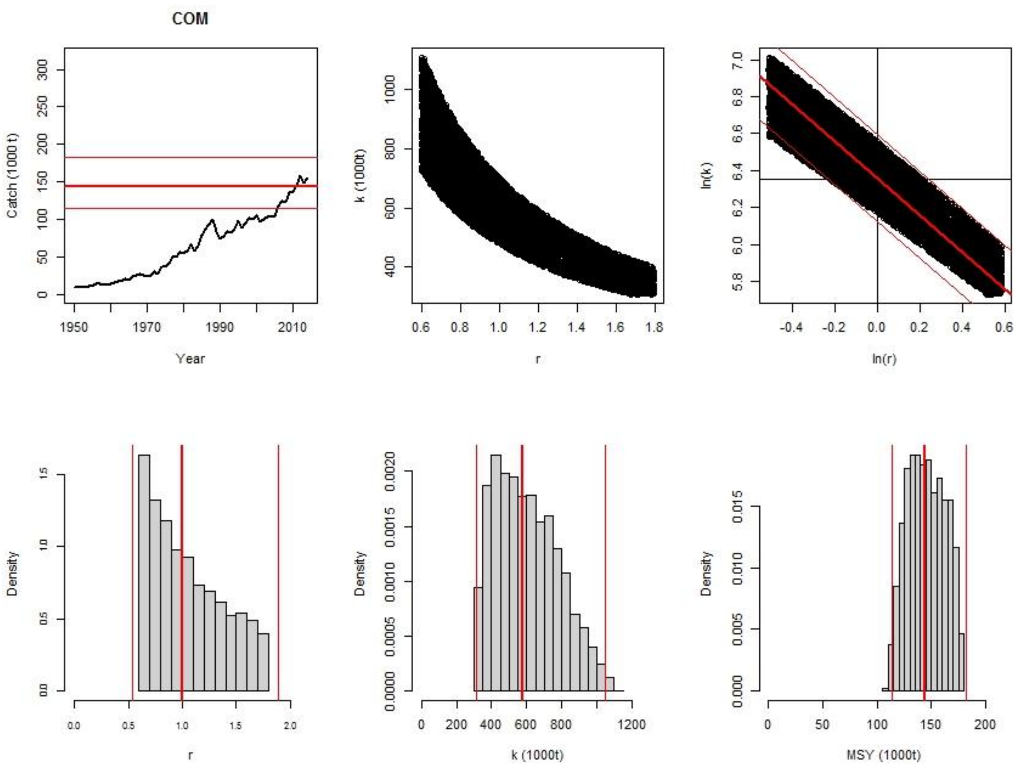

Figure 5. All feasible *r* and *K* combinations resulting from model simulations based on the original parameter constraints

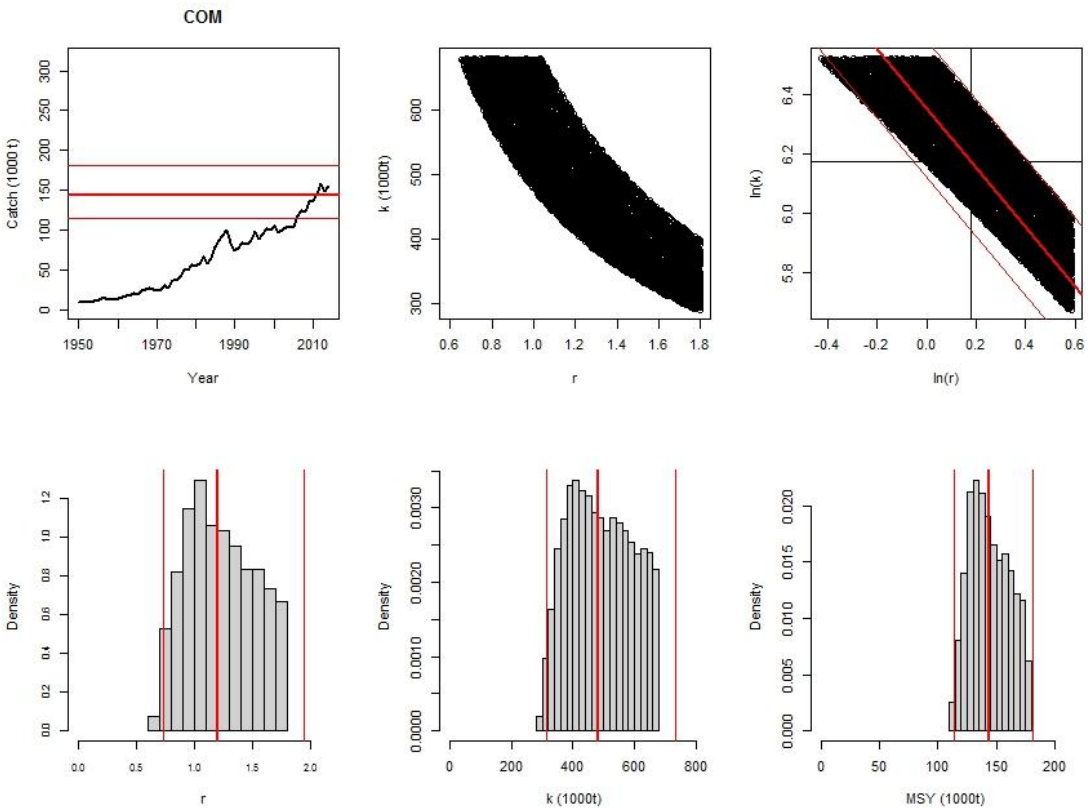

Figure 6. All feasible *r* and *K* combinations with further parameter constraints on max(K)

Figure 7 shows that the simulated biomass trajectories for all plausible *r*, *K* and starting biomass combinations exhibit high variability across the prior ranges set for the initial and final biomass levels but emulate the catch trajectory with a dip prior to 1990. Results are presented for the simulated biomass trajectories for all plausible *r*, *K* and starting biomass combinations. The approach is highly robust to the initial level of biomass assumed, while the final depletion range has a determinative effect on the estimated final D. 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. Management quantities based on geometric means and plausible ranges are provided in Table 7 for this assessment, compared with assessments run in previous years. Estimates of MSY are similar, ranging from 136 000 t to 141 000 t, however, the estimated mean B ratio has declined from 1.17 to 1.02 and the estimated mean F ratio has increased from 0.98 to 1.06.

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 (Figure 8), *S. commerson* is subject to overfishing (F_{2014}/FMSY = 1.06) but is not overfished (B_{2014}/B_{MSY} =1.02). These estimates are, however, very close to wide uncertainty intervals as evident in Table 7 and Figure 8.

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}

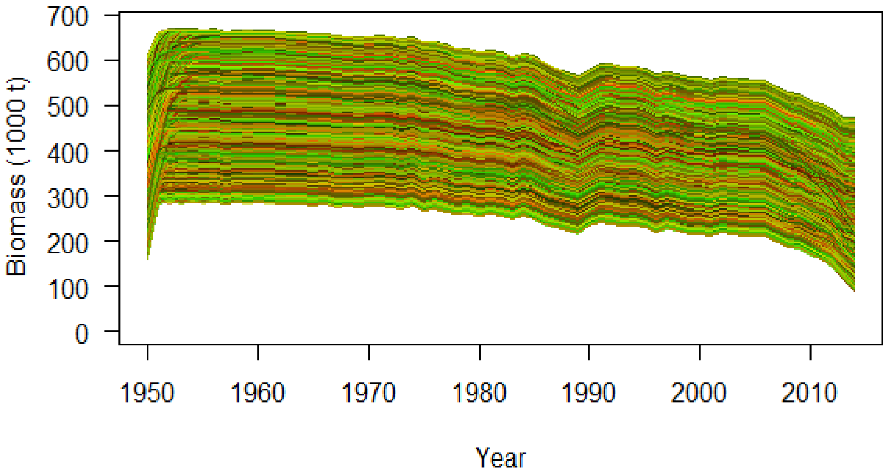

Figure 7. Simulated biomass trajectories based on the Catch-MSY method (Martell and Froese, 2012)

Table 6. Key biological parameters for *S. commerson* for all starting depletion levels (0.5-0.9)

Quantile	K	r	B_{MSY}	MSY	B_{2014}	Final D
0%	291 528	0.66	145 764	110 984	88 216	0.30
25%	459 223	0.94	229 611	128 194	211 728	0.46
50%	**533 814**	**1.08**	**266 907**	**139 054**	**275 691**	**0.52**
75%	601 451	1.26	300 726	154 324	342 811	0.57
100%	678 819	1.80	339 410	179 090	472 818	0.70

Table 7. Key management quantities from the Catch MSY assessments for aggregate Indian Ocean in 2014, 2015 and 2016. Geometric means and plausible ranges across all feasible model runs. n.a. = not available.

Management Quantity	**2014**	**2015**	**2016**
Most recent catch estimate (year)	143 333 t (2012)	153 341 t (2013)	154 723 t (2014)
Mean catch – most recent 5 years[2]	137 116 t (2008 – 2012)	145 817 t (2009 – 2013)	148 610 t (2010 – 2014)
MSY (plausible range)	136 344 (107 926 to 172 245)	137 828 (107 303 to 186 620)	140 638 (110 984 to 179 090)
Data period used in assessment	1950 – 2012	1950 – 2013	1950 – 2014
F_{MSY} (plausible range)	n.a	0.43 (0.28 - 0.64)	0.43 (0.28 - 0.64)
B_{MSY} (plausible range)	229 487 (152 266 to 345 869)	252 829 (140 405 – 328 163)	260 084 (145 764 – 339 410)
$F_{current}/F_{MSY}$ (plausible range)	0.98 (0.53 – 1.41)*	1.07 (0.66 – 2.02)	1.06 (0.67 – 1.98)
$B_{current}/B_{MSY}$ (plausible range)	1.17 (0.79 – 1.49)	1.01 (0.60 – 1.40)	1.02 (0.60 – 1.40)
$SB_{current}/SB_{MSY}$ (80% CI)	n.a	n.a	n.a
$B_{current}/B_0$ (plausible range)	n.a	0.51 (0.30 - 0.70)	0.51 (0.30 - 0.70)
$SB_{current}/SB_0$ (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

*: Arithmetic mean

[2] Data at time of assessment

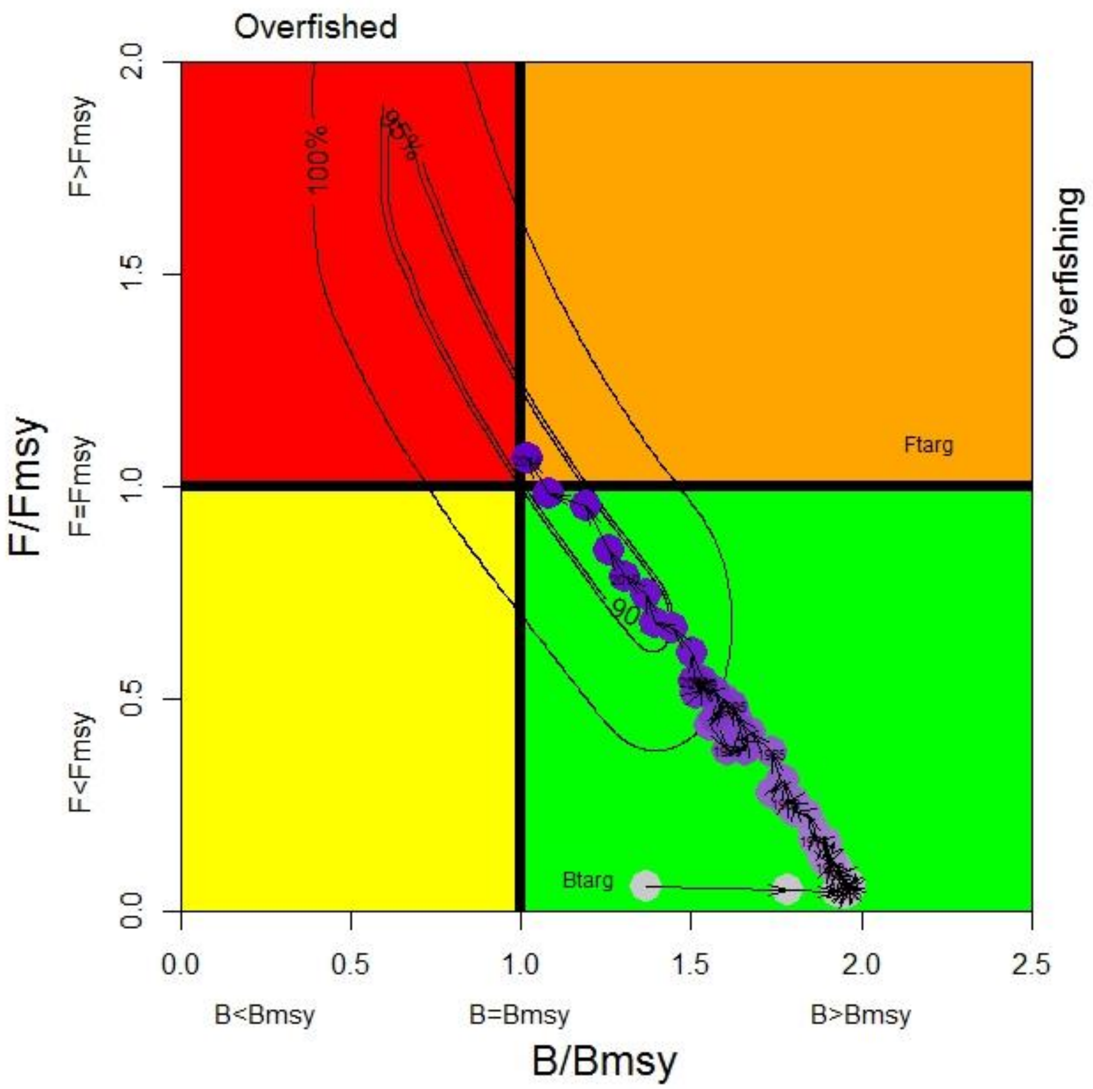

Figure 8. Narrow-barred Spanish mackerel. Catch-MSY Indian Ocean assessment for *S. commerson.* The Kobe plot presents the trajectories for the range of plausible model options included in the formulation of the final management advice. The trajectory of the geometric mean of the plausible model options is also presented.

OCOM method

Figure 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. 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.

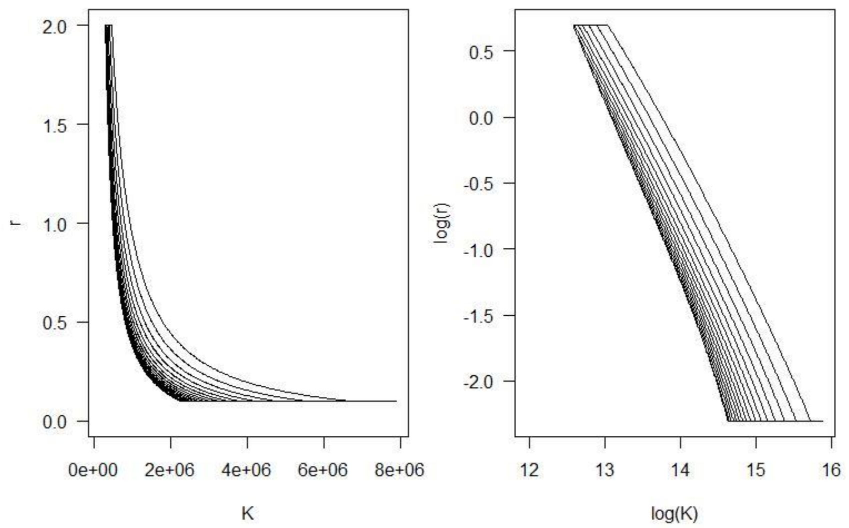

Figure 9. Initial plausible range of r and K values (non-informative priors)

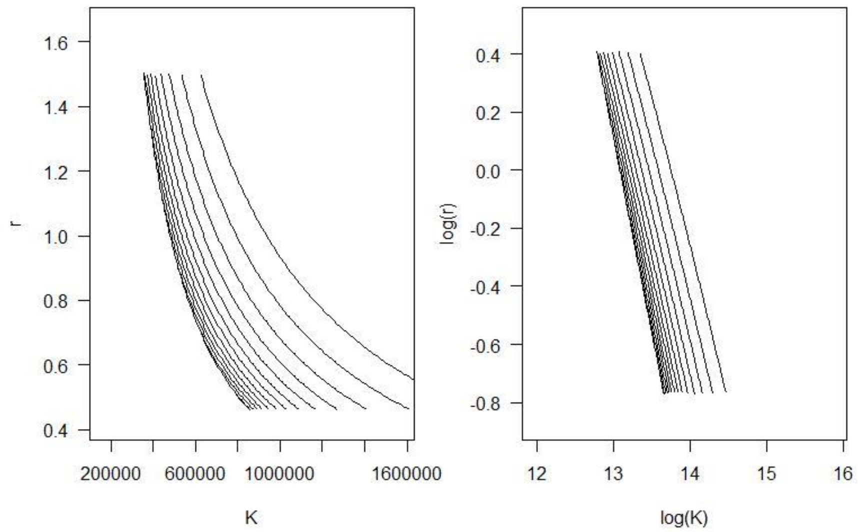

Figure 10. Plausible range of r and K with informative priors on r (0.46-1.5)

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 11). There were no feasible solutions found when the depletion level was assumed to be lower than 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 had declined to nearly 310 000 t by 2014 (Figure 12). The estimated median MSY associated with this projection is 129 000 t and ranges from approximately 99 000 t to 179 000 t (Table 8).

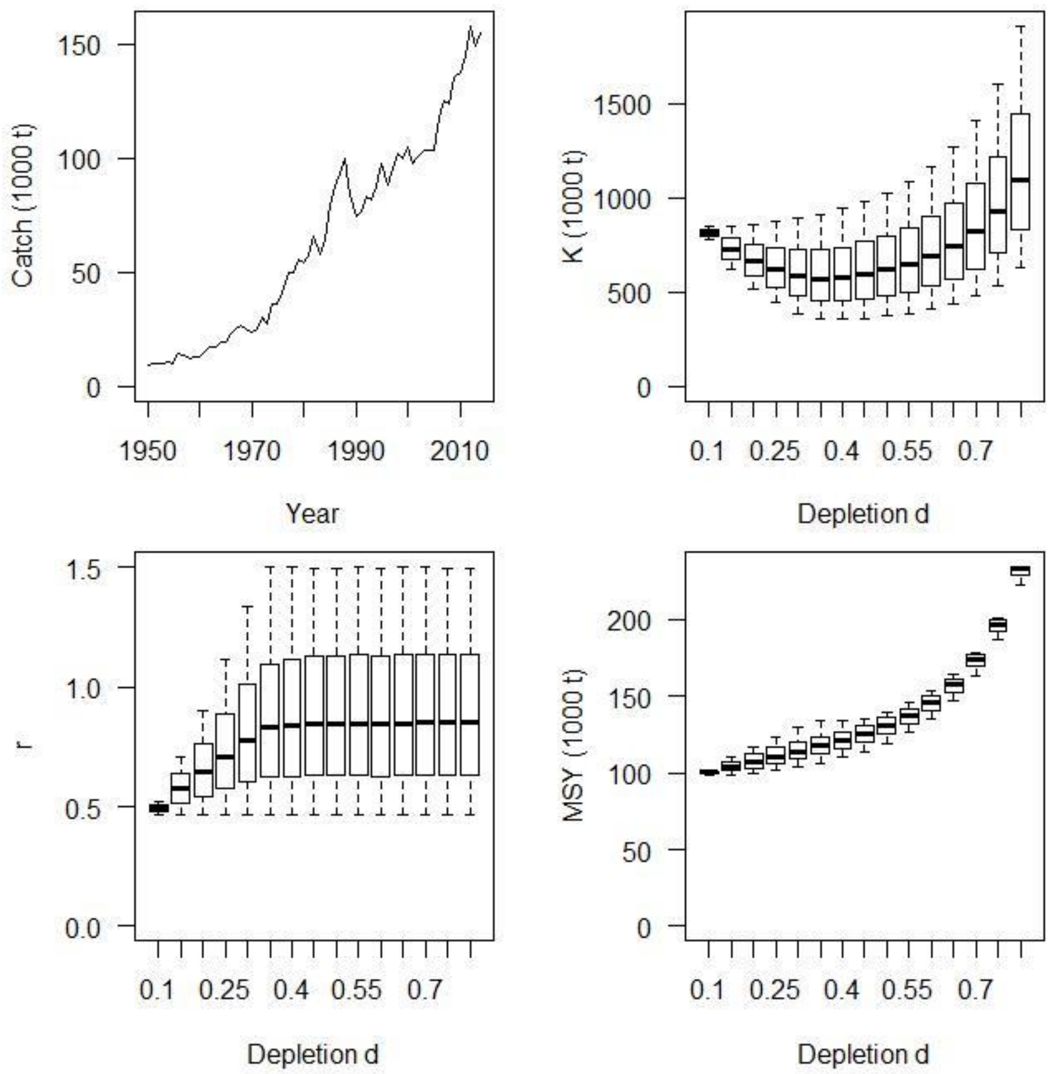

Figure 11. *S. commerson* catch history, feasible carrying capacity, population growth rate and MSY at each assumed depletion level. There is no feasible solution when the depletion is assumed to be below 0.1.

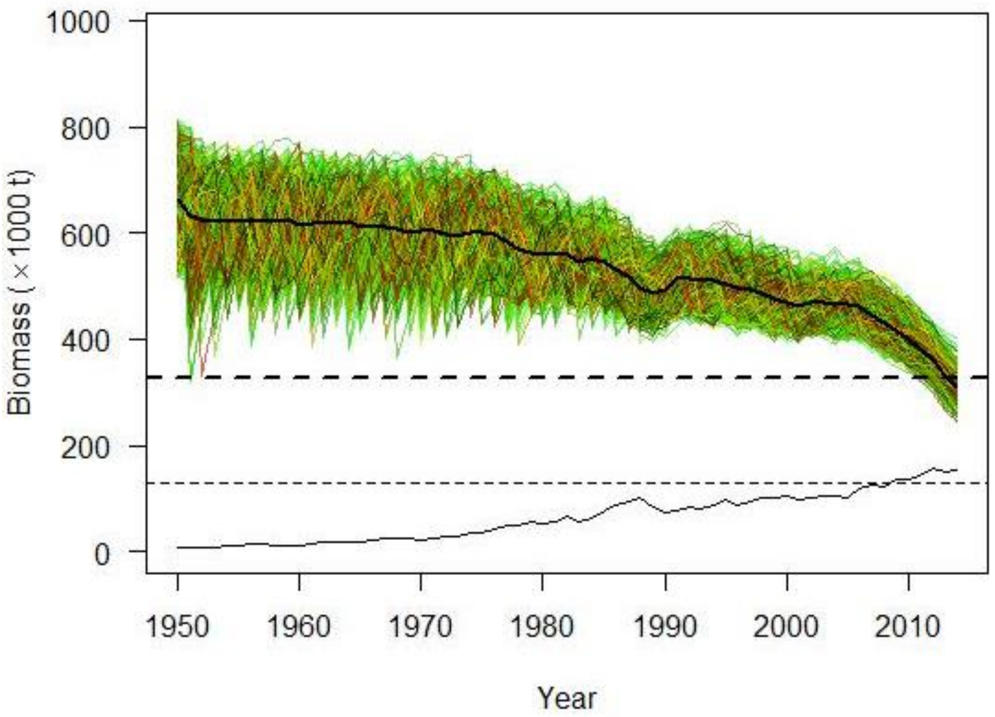

Figure 12. *S. commerson* biomass trajectories from 500 simulations with upper depletion = 0.7

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 very rapid decline of the stock (Figure 13). 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 C_{2014}/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 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). Projecting a constant catch rate here results in a biomass which rapidly stabilises at the corresponding B_{MSY} level, however, there is more uncertainty associated with projecting a fixed catch level due to the uncertainty in the current biomass status. Given that the stock is predicted to have already declined below B_{MSY} a lower catch may be required for a few years for rebuilding to occur as shown in Figure 16.

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

Upper d	Quantile	K	r	MSY	B_{2014}	D
0.8	0%	356245	0.46	98717	295426	0.43
0.8	25%	544008	0.61	119303	356193	0.51
0.8	50%	693669	0.80	134785	375948	0.53
0.8	75%	870743	1.08	165425	401690	0.57
0.8	100%	1907063	1.51	234881	469579	0.65
0.7	0%	356245	0.46	98717	245521	0.36
0.7	25%	514958	0.60	116281	292675	0.44
0.7	**50%**	**656627**	**0.79**	**129105**	**310584**	**0.47**
0.7	75%	811423	1.07	146612	327423	0.49
0.7	100%	1404688	1.51	178800	402468	0.60
0.6	0%	356245	0.46	98717	181478	0.28
0.6	25%	499060	0.59	113663	236271	0.37
0.6	50%	631386	0.78	123951	253484	0.40
0.6	75%	780232	1.05	134335	270547	0.42
0.6	100%	1163766	1.51	153290	328696	0.50
0.5	0%	356245	0.46	98717	128299	0.21
0.5	25%	491296	0.59	110635	189895	0.30
0.5	50%	621564	0.75	119121	208951	0.33
0.5	75%	762095	1.02	126942	224863	0.36
0.5	100%	1026573	1.51	139670	285802	0.45

[3] NB While K, R and MSY are derived from the optimisation model, B_{2014} 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.

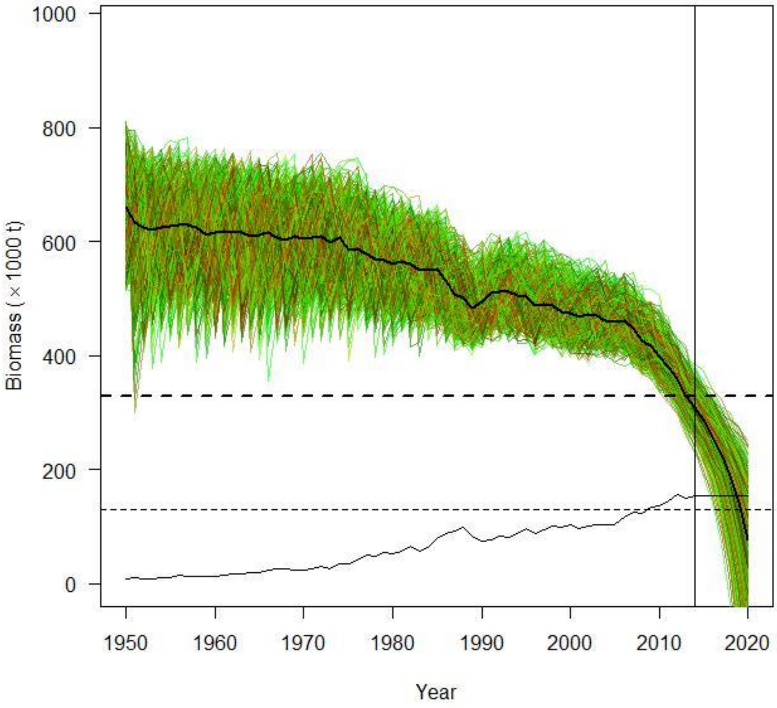

Figure 13. Projected *S. commerson* biomass trajectories under hypothetical annual catches equivalent to those of the final year (C_{2014}) until 2020. The vertical line is the last year (2014) for which catch data are available.

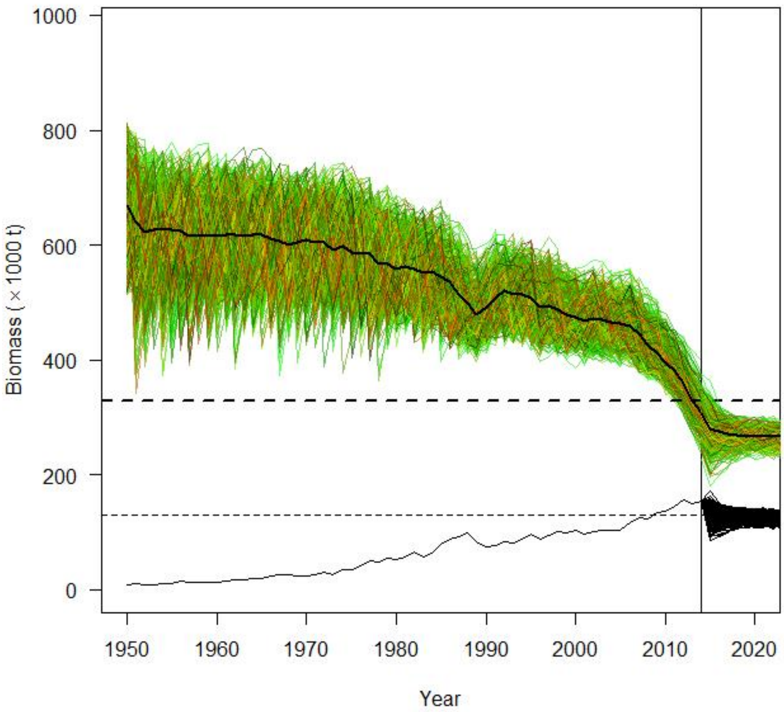

Figure 14. Projected *S. commerson* biomass trajectories under hypothetical annual catch rate (C_{2014}/B_{MSY}) at 2014 level until 2020. The vertical line is the last year (2014) for which catch data are available.

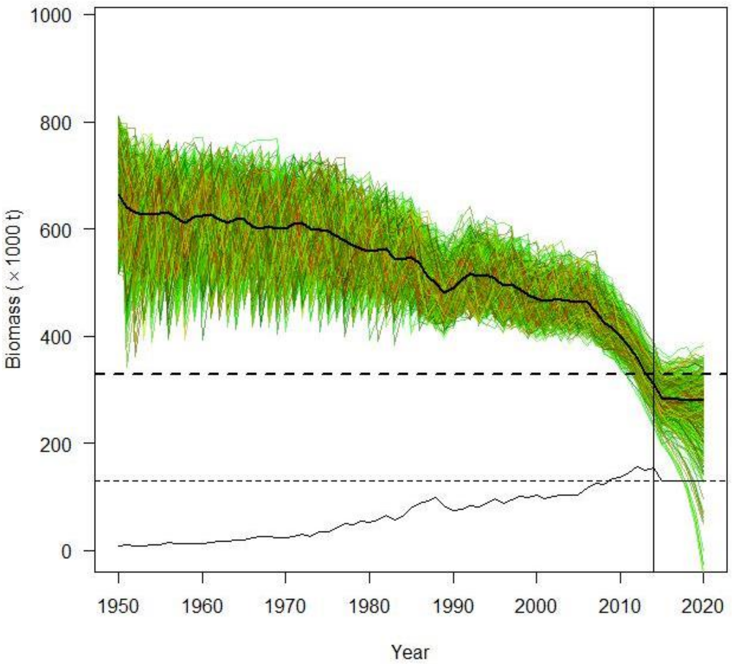

Figure 15. Projected *S. commerson* biomass trajectories under hypothetical future annual catch equivalent to MSY until 2020. The vertical line is the last year (2014) for which catch data are available.

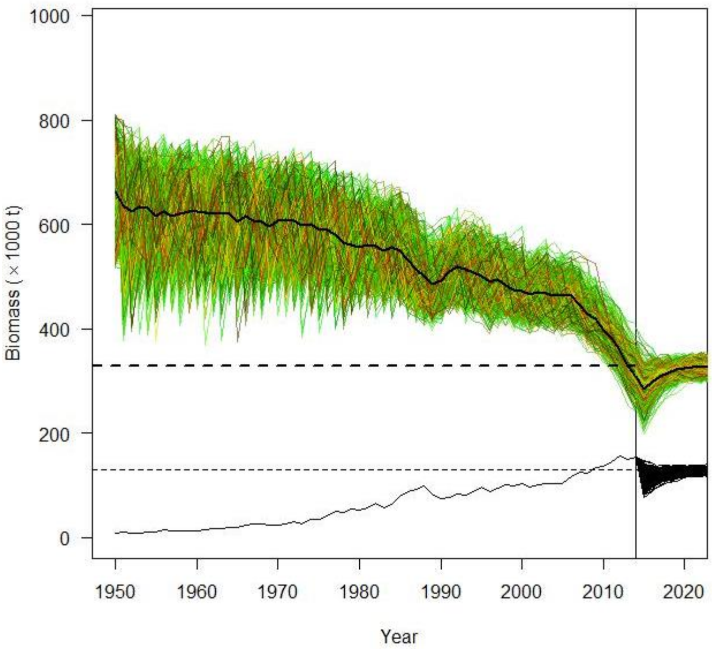

Figure 16. Projected *S. commerson* biomass trajectories under hypothetical annual catch rate at MSY level (C_{MSY}/B_{MSY}) until 2020. The vertical line is the last year (2014) for which catch data are available.

Management quantities based on geometric means and plausible are provided in (Table 9). The geometric mean MSY, 131 053 t, is slightly higher than the median, 129 105 t. The KOBE matrix plot results indicates that based on the OCOM model results, *S. commerson* is currently both overfished (B_{2014} /B_{MSY} = 0.95) and subject to overfishing (F_{2014}/FMSY = 1.21) (Figure 17). The status remains the same based on the model runs with the alternative prior range for r based on the equation recommended by Then et al. (2014), with an even higher F ratio and lower B ratio due to the lower growth rate estimated using this method.

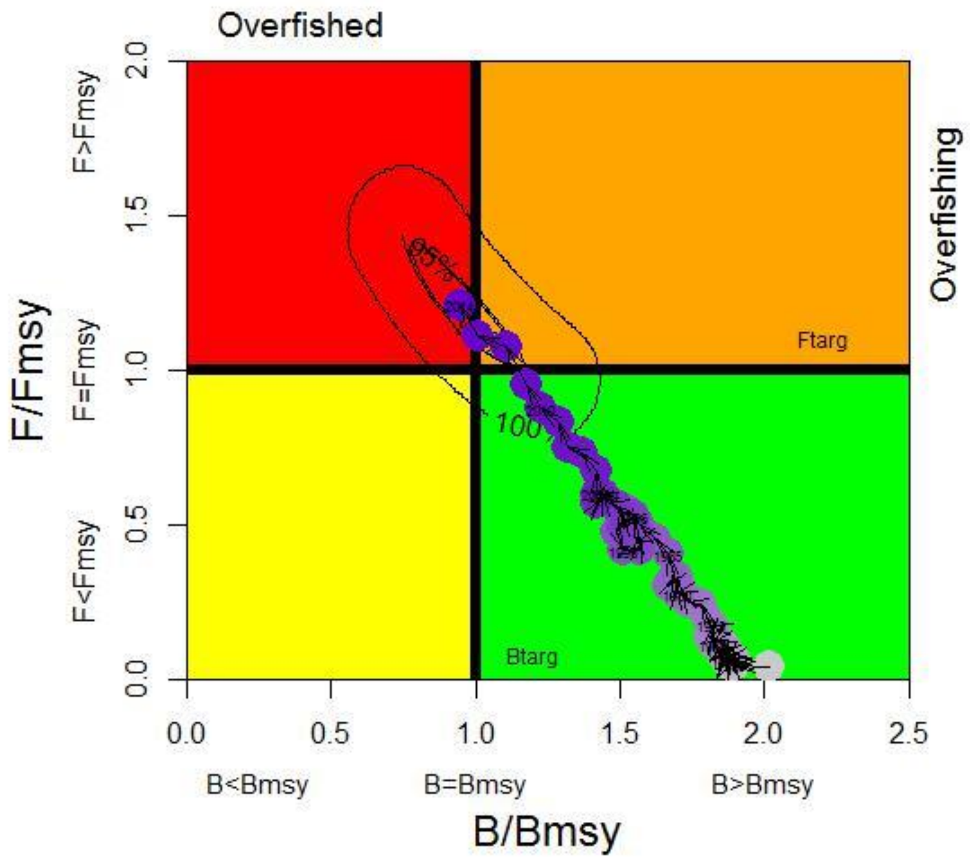

Figure 17. *S. commerson* OCOM Indian Ocean assessment Kobe plot. The Kobe plot presents the trajectories for the range of plausible model options included in the formulation of the final management advice. The trajectory of the geometric mean of the plausible model options is also presented.

Table 9. 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	**2014**	**2015**	**2016**	**2016 (alternative run)**
Most recent catch estimate (year)	143 333 t (2012)	153 341 t (2013)	154 723 t (2014)	154 723 t (2014)
Mean catch – most recent 5 years [4]	137 116 t (2008 – 2012)	145 817 t (2009 – 2013)	148 610 t (2010 – 2014)	148 610 t (2010 – 2014)
MSY (plausible range)	124 367 t[5]	127 731 t[6]	131 053 t (98 717 – 178 800)	122 027 t (92 492 – 174 852)
Data period used in assessment	1950 - 2012	1950 - 2013	1950 - 2014	1950 - 2014
F_{MSY} (plausible range)	0.42	0.33	0.34 (0.21 – 0.56)	0.25 (0.17 – 0.38)
B_{MSY} (plausible range)	240 940	320 664	326 217 (178 122 – 702 344)	426 547 (255 468 – 867 917)
$F_{current}/F_{MSY}$ (plausible range)	1.10	1.21	1.21 (0.95 – 1.48)	1.32 (1.10 - .58)
$B_{current}/B_{MSY}$ (plausible range)	1.03	0.96	0.95 (0.74 - 1.27)	0.93 (0.74 – 1.14)
$SB_{current}/SB_{MSY}$ (80% CI)	n.a	n.a	n.a	n.a.
$B_{current}/B_0$ (plausible range)	0.51	0.53	0.47 (0.37 – 0.63)	0.47 (0.33 – 0.88)
$SB_{current}/SB_0$ (80% CI)	n.a	n.a	n.a	n.a
$B_{current}/B_{0, F=0}$ (80% CI)	n.a	n.a	n.a	n.a
$SB_{current}/SB_{0, F=0}$ (80% CI)	n.a	n.a	n.a	n.a

[4] Data at time of assessment
[5] median
[6] 125 299 (median)

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 140 638 t (~139k median) while the OCOM model estimated the geometric mean MSY at 131 053 t (median ~129k) (Table 10). These findings were similar to the 2015 assessment results which estimated MSY at 138 000 t and 128 000 t for the Catch-MSY and OCOM methods respectively. The alternative OCOM model run with lower growth rate, however, led to a more pessimistic estimate of MSY at 122 000 t. Nevertheless, these results all suggest that current catch levels (154 723 t in 2014) are above the maximum sustainable yield.

Table 10. Key management quantities from the Catch-MSY and OCOM[7] assessments for narrow-barred Spanish 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)	154 723 t (2014)	154 723 t (2014)
Mean catch 2010–2014	148 610 t (2010 – 2014)	148 610 t (2010 – 2014)
MSY (plausible range)	140 638 (110 984 to 179 090)	131 053 t (98 717 – 178 800)
Data period used in assessment	1950 – 2014	1950 - 2014
F_{MSY} (plausible range)	0.43 (0.28 - 0.64)	0.34 (0.21 – 0.56)
B_{MSY} (plausible range)	260 084 (145 764 – 339 410)	326 217 (178 122 – 702 344)
F_{2014}/F_{MSY} (plausible range)	1.06 (0.67 – 1.98)	1.21 (0.95 – 1.48)
B_{2014}/B_{MSY} (plausible range)	1.02 (0.60 – 1.40)	0.95 (0.74 - 1.27)
SB_{2014}/SB_{MSY} (80% CI)	n.a	n.a
B_{2014}/B_0 (plausible range)	0.51 (0.30 - 0.70)	0.47 (0.37 – 0.63)
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

Estimates of current stock status were also very similar to those derived from the 2015 assessments. In 2015, the predicted biomass relative to optimum levels ($B_{current}/B_{MSY}$) was 1.01 for Catch-MSY and 0.96 for OCOM, while in 2016 the ratios were 1.02 and 0.95, respectively (Table 10). In terms of fishing mortality relative to optimum levels ($F_{current}/F_{MSY}$), the ratios in 2015 were 1.07 for Catch-MSY and 1.21 for OCOM (Martin and Sharma, 2015), while in 2016 the ratios were at 1.06 and 1.21, respectively. This may be due to the fact that the current (2014) catch (154 723 t) was similar to the current, i.e. 2013, catch (153 341 t) used in the previous assessment. Both the most recent catch estimate and the average catch since 2010 (148 670 t) have been in excess of the MSY levels estimated by all models. Based on the weight-of-evidence currently available, this suggests that the stock is considered to be '*subject to overfishing*', though the current stock status is less clear. While

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

there are substantial uncertainties that are described throughout this paper, both models suggest that fishing mortality is above F_{MSY} indicating that higher catches could not be sustained and so 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.

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