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

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IOTC Secretariat[1]

[1] sarah.martin@iotc.org; dan.fu@iotc.org

Introduction

Assessing the status of the stocks of neritic tuna species in the Indian Ocean is fairly challenging due to the data limitations. There is limited information available on stock structure, a lack of standardised (or nominal) CPUE series and biological information is also sparse. Since 2014, data-poor approaches using basic catch information have been used to assess the status of Indian Ocean narrow-barred Spanish mackerel (*Scomberomorus commerson*) (Zhou and Sharma, 2014; Martin and Sharma 2015; Martin and Robinson, 2016). These assessments are updated in this paper based on the latest catch information. Two methods are used to assess the status of *S. commerson*: (i) an updated Catch-MSY method (Kimura and Tagart 1982; Walters et. al. 2006; Martell and Froese 2012; Froese et al. 2016) and (ii) an Optimised Catch-Only Method OCOM (Zhou et al., 2013; Zhou et al., 2016). The other neritic species investigated in 2017, as requested by the Scientific Committee, using the same methods was longtail tuna (*Thunnus tonggol*) (Fu and Martin, 2017).

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 10-70 m (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., 2017). 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 are variable for the Indian Ocean, ranging 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).

Fisheries and Catch Trends

Disaggregated nominal catch data were extracted from the IOTC Secretariat database for the period 1950 - 2015, given that records for 2016 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). Indonesia, India and I.r.Iran together account for 65% of catches. Figure 2 shows the total catch of narrow-barred Spanish mackerel since 1950, which increased to 2007 and has remained relatively stable since with the most recent catches in 2015 estimated at approximately 150,000 t (

Table **1**). Very few revisions have been made to the nominal catch series since the last assessment was conducted in 2016 (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. The high level of correlation amongst the species is likely to be because they are often caught together, due to difficulty with species identification and also because of the estimation procedures used to assign proportions of catch amongst the various species. Species-specific reporting has improved over time, leading to a lower level of correlation in more recent years.

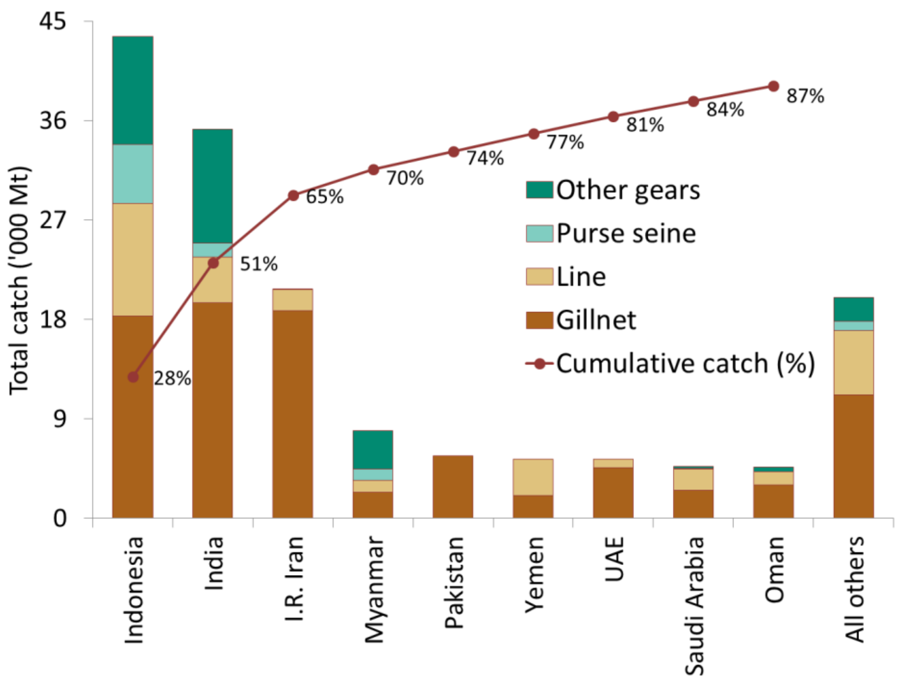

Figure 1. Average catches in the Indian Ocean over the period 2012-2015, by country. The red line indicates the (cumulative) proportion of catches of Spanish mackerel by country.

Table 1. Catch data for *S. commerson* in the Indian Ocean, 1950-2015 (source IOTC Database)

Year	Catch (t)	Year	Catch (t)
1950	9,188	1983	57,647
1951	9,827	1984	64,550
1952	9,707	1985	79,184
1953	9,687	1986	87,184

1954	11,055	1987	93,123
1955	10,060	1988	100,023
1956	14,291	1989	83,801
1957	13,740	1990	74,451
1958	12,553	1991	76,693
1959	13,076	1992	83,324
1960	13,262	1993	81,509
1961	15,325	1994	87,213
1962	17,040	1995	97,745
1963	17,600	1996	88,404
1964	19,766	1997	95,755
1965	19,618	1998	101,600
1966	23,354	1999	100,019
1967	25,327	2000	104,708
1968	26,430	2001	97,295
1969	25,043	2002	100,544
1970	23,470	2003	103,474
1971	25,387	2004	103,551
1972	30,455	2005	103,404
1973	27,370	2006	117,609
1974	36,180	2007	124,914
1975	36,269	2008	123,297
1976	41,451	2009	135,028
1977	49,986	2010	137,148
1978	49,528	2011	144,523
1979	55,831	2012	157,636
1980	53,927	2013	148,988
1981	56,937	2014	152,187
1982	65,724	2015	154,177

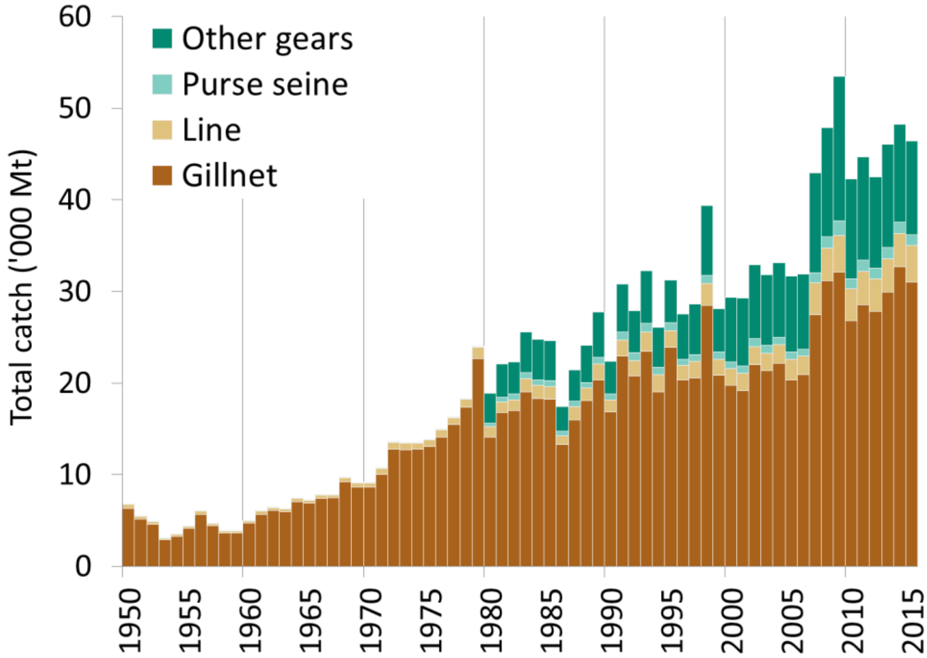

Figure 2. Total nominal catch of Spanish mackerel by gear, 1950-2015 (IOTC Nominal Catch database)

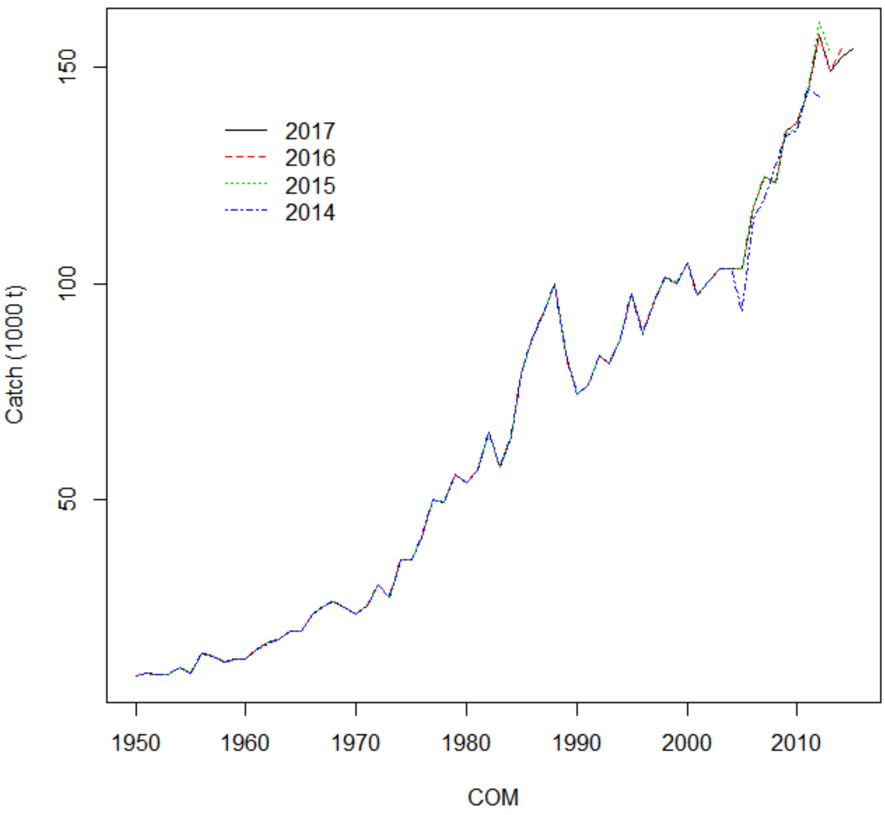

Figure 3. Revisions to the *S. commerson* nominal catch time series since 2014

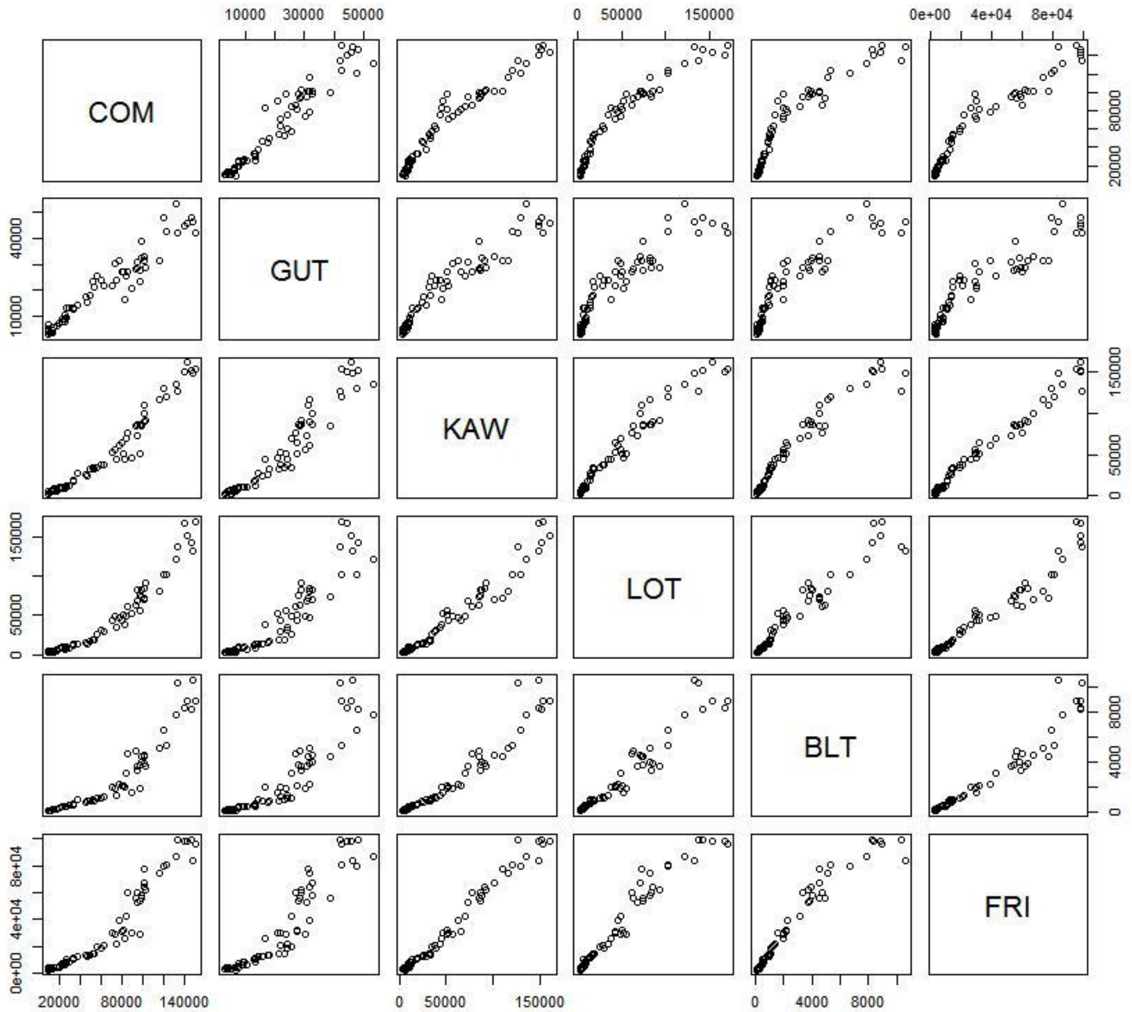

Figure 4. Correlation in catch trends across IOTC neritic tuna species

Methods

1) C-MSY method

We applied the C-MSY method of Froese et al. (2016) to estimate reference points from catch, resilience and qualitative stock status information for longtail. The C-MSY method represents a further development of the Catch-MSY method of Martell and Froese (2012), with a number of improvements to reduce potential bias. Similar to the Catch-MSY method, The C-MSY relies on only a catch time series dataset, which was available from 1950 – 2015, prior ranges of *r* and *K*, and possible ranges of stock sizes in the first and final years of the time series.

The Graham-Shaefer surplus production model (Shaefer 1954) is used (equation 1), but it is combined with a simple recruitment model to account for the reduced recruitment at severely depleted stock sizes (equation 2), where B_t is the biomass in time step *t*, *r* is the population growth rate, B_0 is the virgin biomass equal to carrying capacity, *K*, and C_t is the known catch at time *t*. Annual biomass quantities can then be calculated for every year based on a given set of *r* and *K* parameters.

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

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

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. The prior range of K was determined as

$$k_{low} = \frac{\max(C_t)}{r_{high}}, k_{high} = \frac{4\max(C_t)}{r_{low}} \qquad (3)$$

Where k_{low} and k_{high} are the lower and upper lower bound of the range of *k*, max(C) is the maximum catch in the time series, and r_{low} and r_{high} are lower and upper bound of the range of r values.

The ranges for starting and final depletion levels were assumed to be one of possible three biomass ranges: 0.01–0.4 (low), 0.2–0.6 (medium), and high (0.5–0.9), using a set of rules based on the trend of the catch series (see Froese et al. (2016) for details). With this approach, the prior range for the depletion level can also be assumed optionally for an intermediate year, but we did not explore this option in this report. This resulted in the prior ranges used for key parameters as specified in Table 2.

C-MSY estimates biomass, exploitation rate, MSY and related fisheries reference points from catch data and resilience of the species. Probable ranges for *r* and *k* are filtered with a Monte Carlo approach to detect 'viable' *r*-*k* pairs. The model worked sequentially through the range of initial biomass depletion level and random pairs of *r* and *K* were drawn based on the uniform distribution for the specified ranges. Equation 1 or 2 is used to calculate the predicted biomass in subsequent years, each *r*-*k* pair at each given starting biomass level is considered variable if the stock has never collapsed or exceeded carrying capacity and that the final biomass estimate which falls within the assumed depletion range. All *r*-*k* combinations for each starting biomass which were considered feasible were retained for further analysis. The search for viable *r*-*k* pairs is terminated once more then 1000 pairs are found.

The most probable *r*-*k* pair were determined using the method described by Froese et. al (2016). All viable *r*-values are assigned to 25–100 bins of equal width in log space. The 75th percentile of the mid-values of occupied bins is taken as the most probable estimate of *r*. Approximate 95% confidence limits of the most probable *r* are obtained as 51.25th and 98.75th percentiles of the mid-values of occupied bins, respectively. The most probable value of *k* is determined from a linear regression fitted to *log(k)* as a function of log(r), for *r*-*k* pairs where *r* is larger than median of mid-values of occupied bins. MSY are obtained as geometric mean of the MSY values calculated for each of the *r*-*k* pairs where *r* is larger than the median. Viable biomass trajectories were restricted to those associated with an *r*-*k* pair that fell within the confidence limits of the C-MSY estimates of *r* and *k*.

Table 2. Prior ranges used for longtail for the C-MSY analysis

Species	Initial B/K	Final B/K	*r*	*K (1000 t)*
Longtail	0.5–0.9	0.2–0.6	0.6–1.5	112 – 1120

2) Optimised Catch Only Method (OCOM)

The Optimised Catch-Only Method was developed by Zhou *et al*. (2013; 2016) 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 $|B_{2015} - DK|$ 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 to enhance the method, improved prior ranges for *r* and *K* were used. Estimates of the von Bertalanffy parameters L_∞ and *K* were derived based on a review of the literature (IOTC–2015–WPNT05–DATA13) and a number of empirical methods were used to derive possible range for the intrinsic population growth rate, *r*, updating the methodology used by Zhou and Sharma (2014).

$r = 2\,\omega M$, where:

$M = 4.899 t_{max}^{-0.916}$ (Then et al., 2014[2])

$M = 4.118 k^{0.73} L_{\infty}^{-0.33}$ (Then et al., 2014[3])

$M = 1.65/t_{mat}$ (Jensen 1996).

$\ln(M) = 0.55 - 1.61 \ln(L) + 1.44 \ln(L_{\infty}) + \ln(k)$ (Gislason et al. 2010).

$M = 1.82k$ (Charnov et al. 2013).

where t_{max} is the maximum age, t_{mat} is age at maturation, k and L_{∞} are von Bertalanffy growth parameters and ω is a scaling parameter linking M to r, where $\omega = 0.87$ for teleosts (Zhou et al., 2012; 2016). Taking the mean ±2 s.d. resulted in a set of estimated *r* values ranging from 0.37 to 1.46. 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; 0.5, 0.6 and 0.7.

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

While B_{MSY} and F_{MSY} were calculated from the equations:

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

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

Figure 5 shows Results of CMSY assessment for *S. commerson*. Table 3 provides a summary of the distributions of the key biological parameters across all feasible runs at all starting depletion levels.

[2] An update of Hoenig (1983).
[3] An update of Pauly, 1980

Panel A shows the time series of catches in black and the three-years moving average in blue with indication of highest and lowest catch, as used in the estimation of prior biomass by the default rules. The use of moving average is to reduce the influence of extreme catches.

Panel B shows the explored *r-k* values in log space and the *r-k* pairs found to be compatible with the catches and the prior information. Panel C shows the most probable *r-k* pair and its approximate 95% confidence limits. The probable *r* values did not span through the full prior range, instead ranging from 0.96 – 1.48 t while probable K values ranged from 322 000 – 667 000. Given that r and *K* are confounded, a higher *K* generally gives a lower *r* value. CMSY searches for the most probable r in the upper region of the triangle, which serves to reduce the bias caused by the triangular shape of the cloud of viable r-k pairs (Ferose et al. 2016)

Panel D shows the estimated biomass trajectory with 95% confidence intervals (Vertical lines indicate the prior ranges of initial and final biomass). The method is highly robust to the initial level of biomass assumed (mainly due to the very low catches for the early part of series), while the final depletion range has a determinative effect on the final stock status. 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. The results all suggest a relatively rapid decline in biomass since the mid-2000s.

Panel E shows in the corresponding harvest rate from CMSY. Panel F shows the Schaefer equilibrium curve of catch/MSY relative to *B/k*. However we caution that the fishery was unlikely to be in an equilibrium state in any given year.

Figure 6 shows the estimated management quantities. The upper left panel shows catches relative to the estimate of *MSY* (with indication of 95% confidence limits). The upper right panel shows the total biomass relative to B_{msy}, and the lower left graph shows exploitation rate F relative to F_{msy}. The lower-right panel shows the development of relative stock size (B/B_{msy}) over relative exploitation (F/F_{msy}).

Management quantities (estimated means and 95% confidence ranges) are provided in Table 5, which shows an average MSY of 138 000 t, with a 95% confidence range between 104 000 t and 183 000 t, 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). The KOBE matrix plot indicates that based on the C-MSY model results, *S. commerson* is overfished (B_{2015}/BMSY = 0.94) and is subject to overfishing (F_{2015}/FMSY = 1.19). These estimates are, however, very close to wide uncertainty intervals as evident in Table 5 and Figure 6.

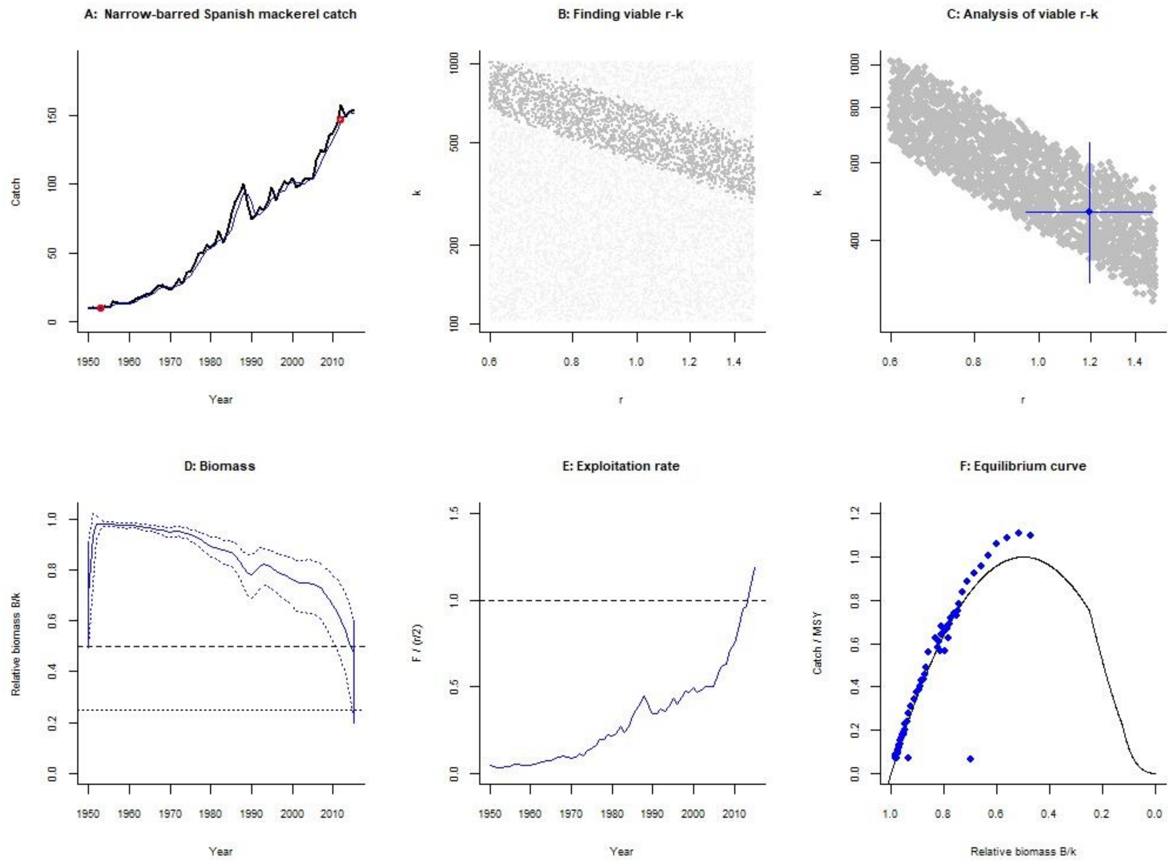

Figure 5. Results of CMSY analyses for *S. commerson*.

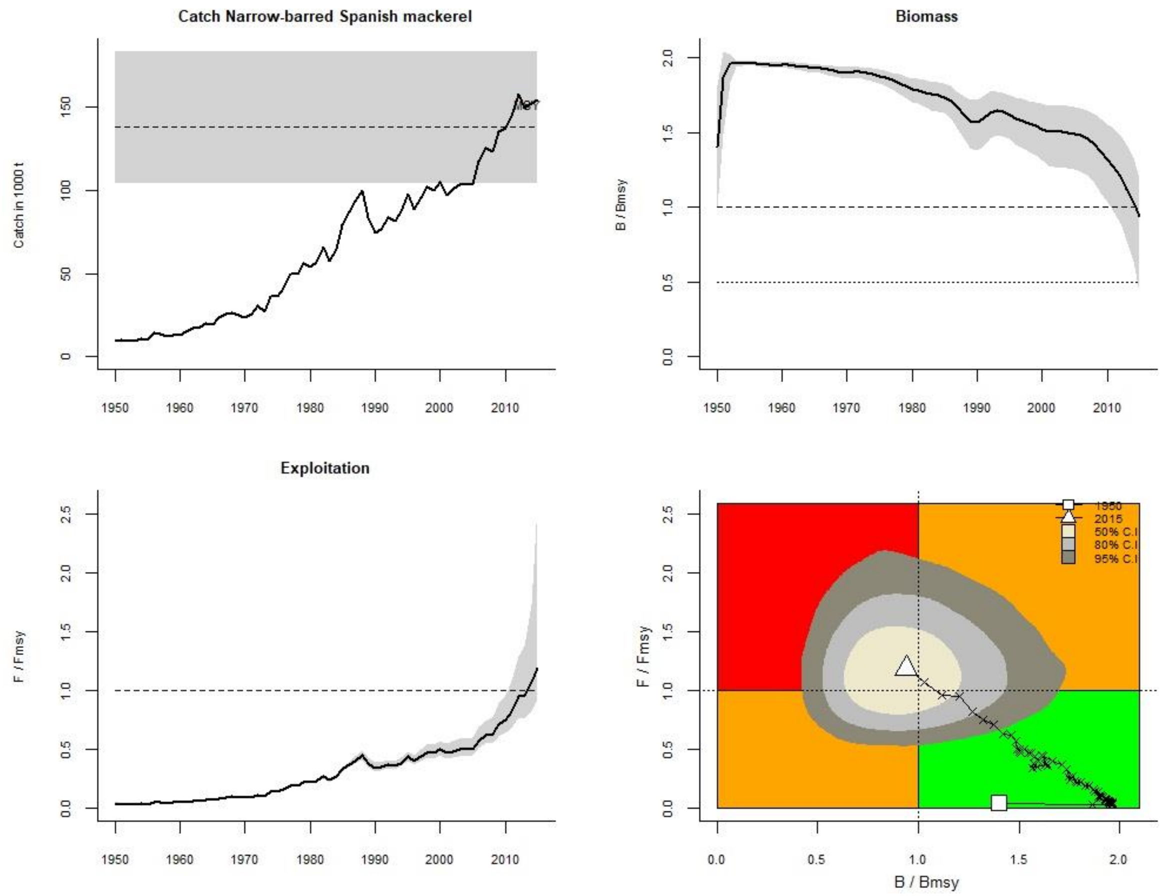

Figure 6. Graphical output of the CMSY analysis of *S. commerson* for management purposes.

Table 3: Key biological parameters (mean and 95% confidence intervals) from the C-MSY assessment assuming final depletion levels (0.2–0.6)

	K (000)	r	Bmsy (000)	Msy (000)	Depletion
Estimate	463 (322 – 667)	1.2 (0.96 – 1.48)	232 (161 – 333)	138 (104 –183)	0.47 (0.22 – 0.60)

Table 4. 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 5. Key management quantities from the C-MSY assessments for aggregate Indian Ocean in 2014, 2015, 2016, and 2017. Geometric means and plausible ranges across all feasible model runs. n.a. = not available.

Management Quantity	**2014**	**2015**	**2016**	**2017**
Most recent catch estimate (year)	143 333 t (2012)	153 341 t (2013)	154 723 t (2014)	154 177 t (2015)
Mean catch – most recent 5 years[4]	137 116 t (2008 – 2012)	145 817 t (2009 – 2013)	148 610 t (2010 – 2014)	151 502 t (2011 – 2015)
MSY (plausible range)	136 344	137 828	140 638	138 000 (104 000 to 183 000)
Data period used in assessment	1950 – 2012	1950 – 2013	1950 – 2014	1950 – 2015
F_{MSY} (plausible range)	n.a	0.43	0.43	0.60 (0.48 - 0.74)
B_{MSY} (plausible range)	229 487	252 829	260 084	232 000 (161 000 – 333 000)
$F_{current}/F_{MSY}$ (plausible range)	0.98	1.07	1.06	1.19 (0.94 – 2.59)
$B_{current}/B_{MSY}$ (plausible range)	1.17	1.01	1.02	0.94 (0.43 – 1.19)
$SB_{current}/SB_{MSY}$ (80% CI)	n.a	n.a	n.a	n.a
$B_{current}/B_0$ (plausible range)	n.a	0.51	0.51	0.47 (0.22 - 0.60)
$SB_{current}/SB_0$ (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

*: Arithmetic mean

[4] Data at time of assessment

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 0.37 to 1.46.

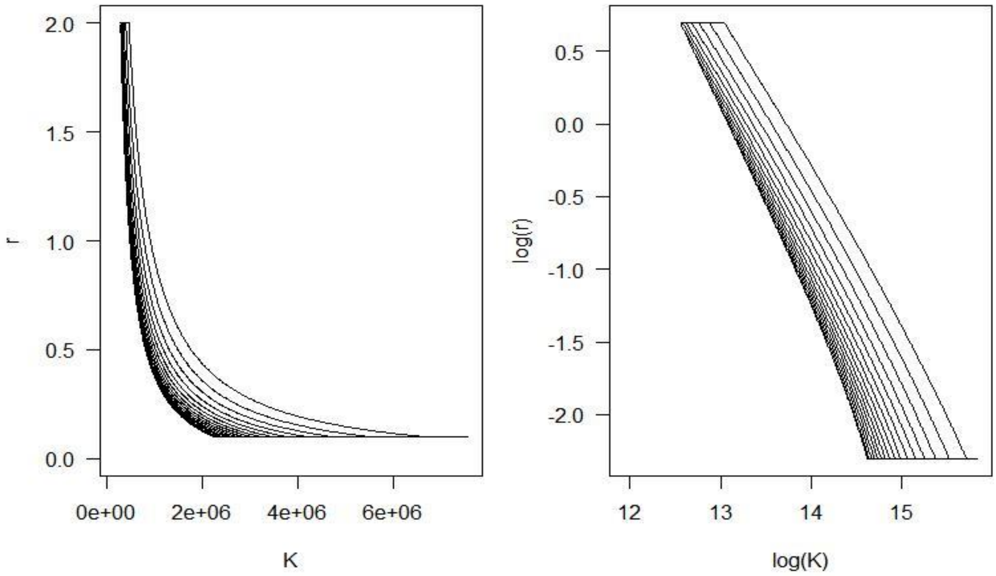

Figure 7. Initial plausible range of r and K values

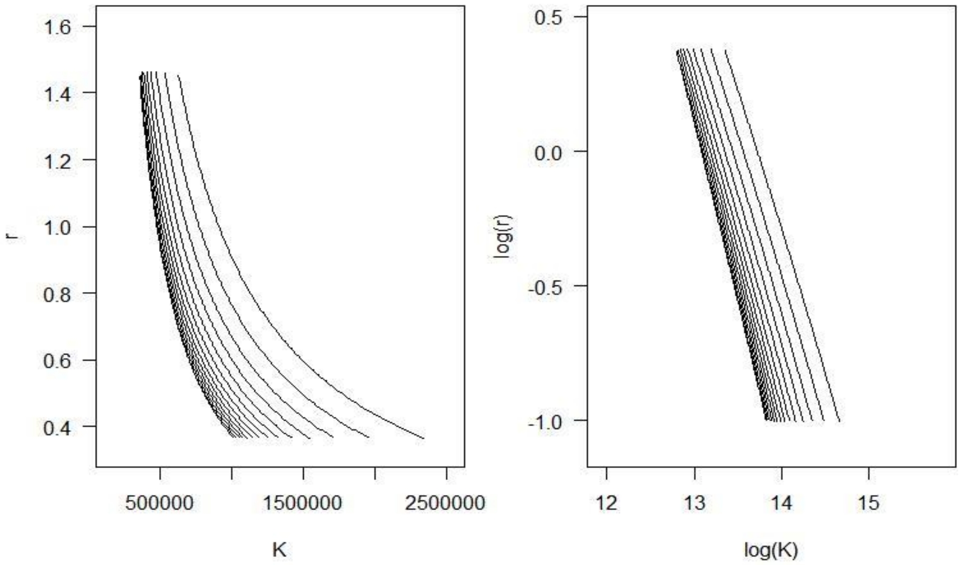

Figure 8. Plausible range of r and K with informative priors on r

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 0.05. Base case model results (for a maximum depletion level of 0.7) indicate that the biomass was approximately 744 000 t in 1950 and had declined to nearly 330 000 t by 2015 (Figure 10). The estimated median MSY associated with this projection is ~130 000 t, ranging from approximately 96 000 t to 180 000 t (Table 6).

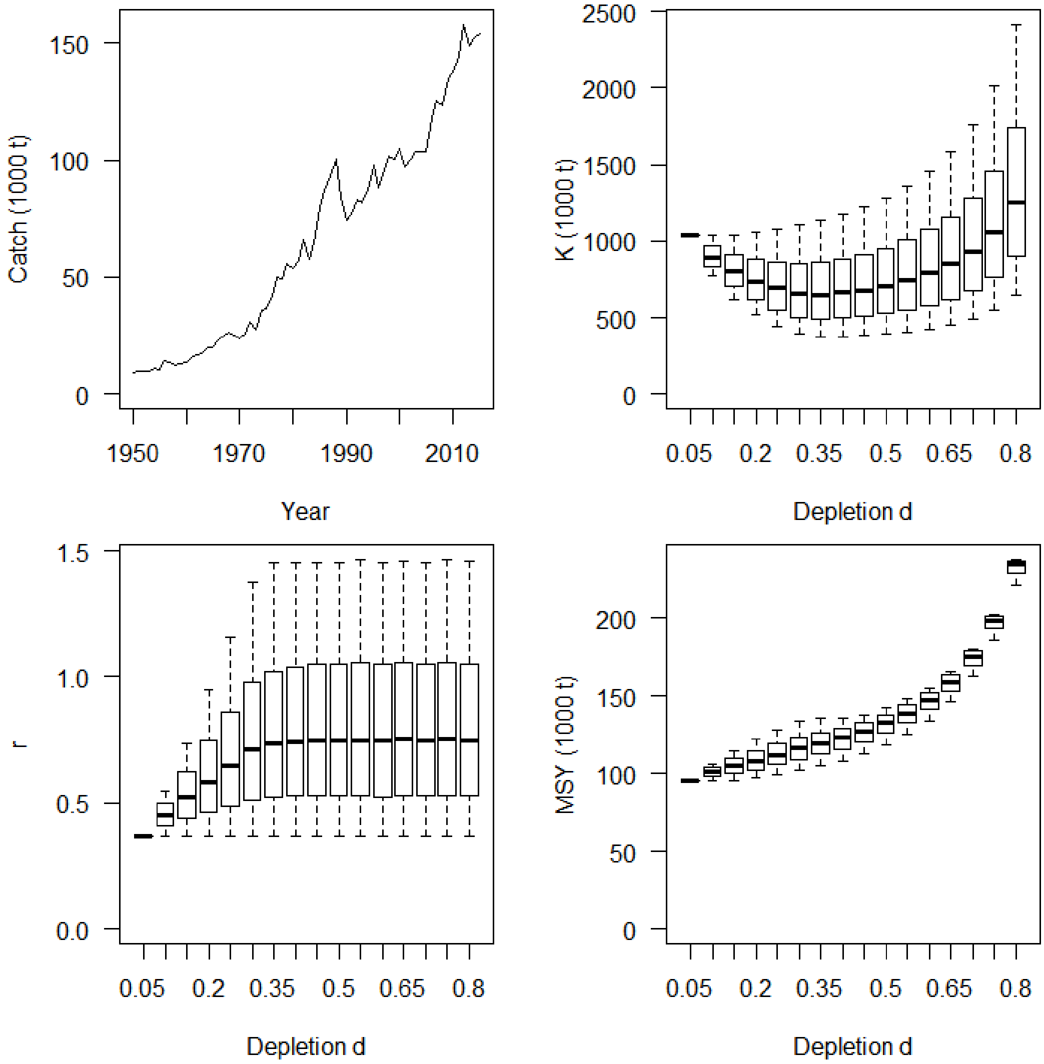

Figure 9. *S. commerson* catch history, feasible carrying capacity, population growth rate and MSY at each assumed depletion level. There is no feasible solution when the depletion is assumed to be below 0.05.

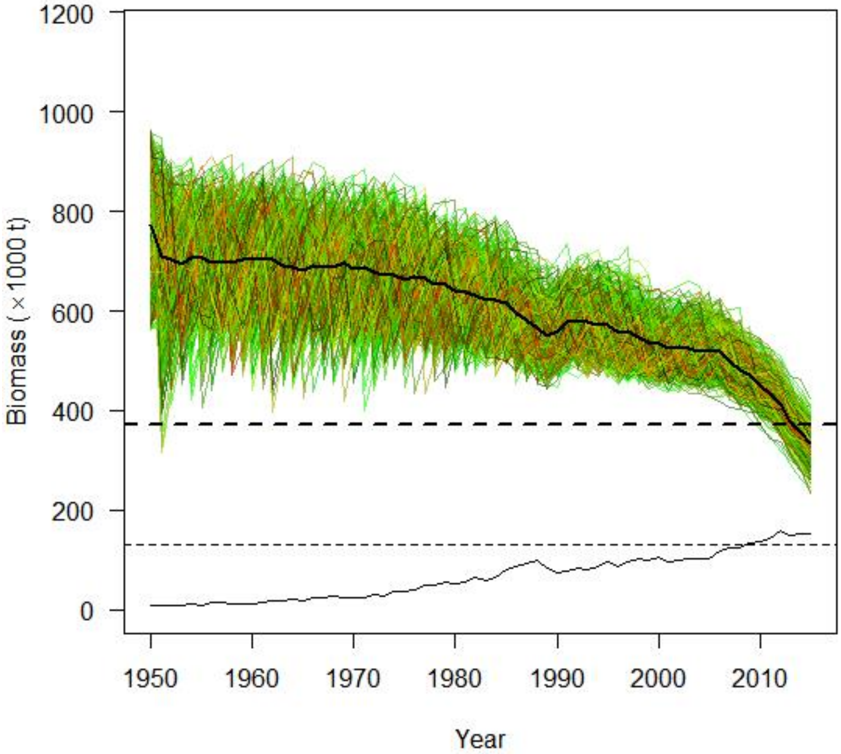

Figure 10. *S. commerson* biomass trajectories from 500 simulations with upper depletion = 0.7

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 2015, 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 biomass level remains at the current level, i.e. a constant catch rate of C_{2015}/B_{2015}. 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 2015 level but remains at a relatively high level, resulting in a stock biomass level somewhat below B_{MSY} (Figure 12).

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 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). 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 14.

Table 6. Posterior key biological parameters for *S. commerson* under four assumed upper depletion levels[5]

Upper d	Quantile	K	r	MSY	B_{2015}	D
0.8	0%	373,403	0.37	95,598	324,391	0.39
0.8	25%	593,005	0.50	118,689	387,259	0.48
0.8	50%	792,563	0.70	134,845	410,438	0.51
0.8	75%	1,026,575	0.99	164,573	437,009	0.54
0.8	100%	2,412,727	1.46	237,364	536,776	0.65
0.7	0%	373,403	0.37	95,598	233,355	0.31
0.7	25%	563,548	0.50	115,678	311,809	0.41
0.7	**50%**	**744,382**	**0.69**	**129,511**	**332,894**	**0.44**
0.7	75%	964,168	0.98	146,580	354,518	0.47
0.7	100%	1,763,268	1.46	180,164	425,843	0.54
0.6	0%	373,403	0.37	95,598	173,499	0.24
0.6	25%	547,220	0.50	112,907	246,822	0.34
0.6	50%	721,401	0.68	124,499	271,806	0.37
0.6	75%	919,865	0.96	135,192	292,170	0.40
0.6	100%	1,460,845	1.46	155,104	360,924	0.49
0.5	0%	373,403	0.37	95,598	64,552	0.09
0.5	25%	540,823	0.49	109,876	194,722	0.27
0.5	50%	710,178	0.66	119,285	216,885	0.30
0.5	75%	898,483	0.93	128,027	239,524	0.33
0.5	100%	1,278,567	1.46	142,208	302,464	0.42

[5] 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.

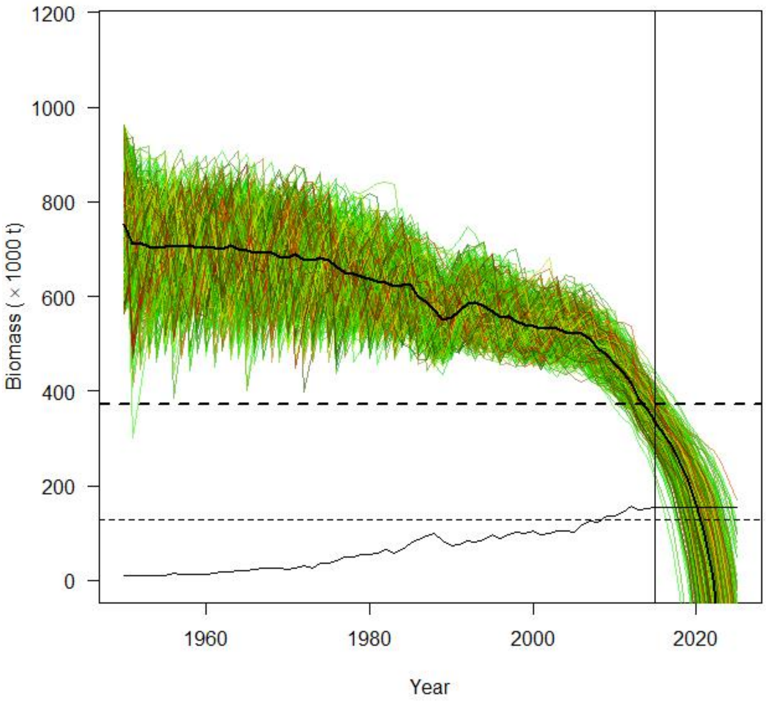

Figure 11. Projected *S. commerson* biomass trajectories under hypothetical annual catches equivalent to those of the final year (C_{2015}) until 2020. The vertical line is the last year (2015) for which catch data are available.

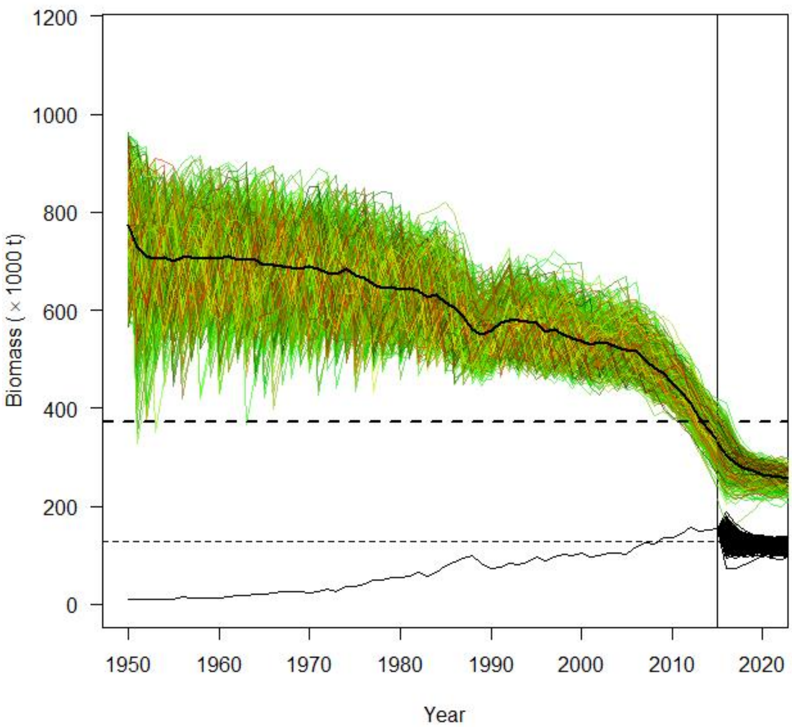

Figure 12. Projected *S. commerson* biomass trajectories under hypothetical annual catch rate (C_{2015}/B_{2015}) at 2015 level until 2020. The vertical line is the last year for which catch data are available.

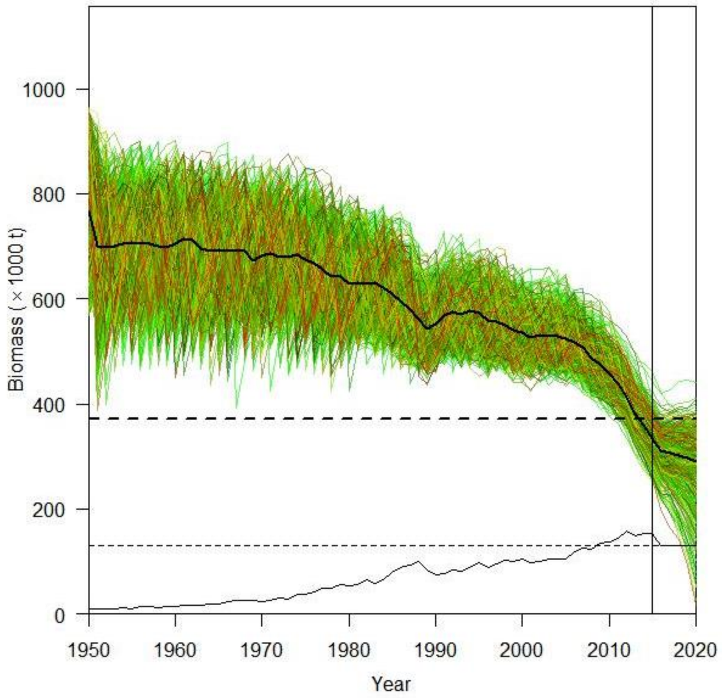

Figure 13. Projected *S. commerson* biomass trajectories under hypothetical future annual catch equivalent to MSY until 2020. The vertical line is the last year (2015) for which catch data are available.

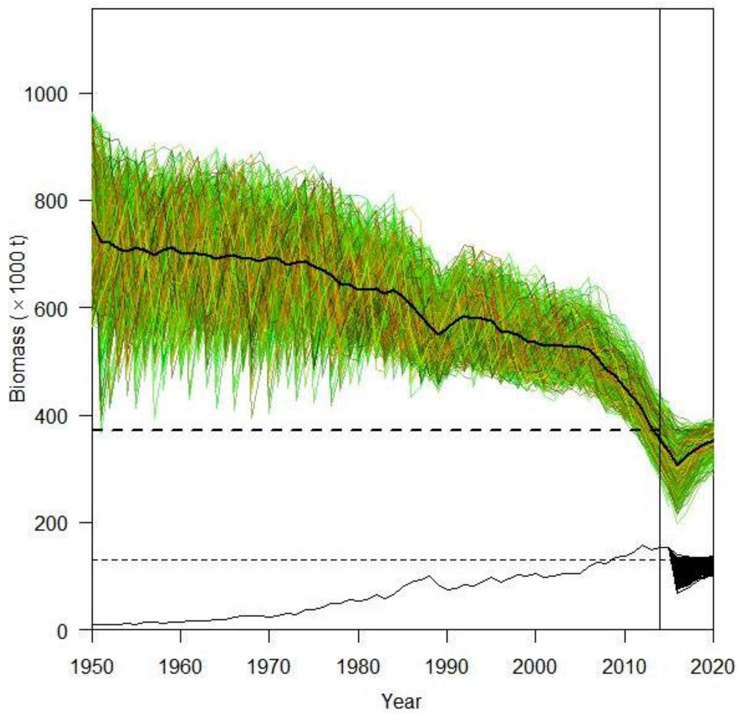

Figure 14. Projected *S. commerson* biomass trajectories under hypothetical annual catch rate at MSY level (C_{MSY}/B_{MSY}) until 2020. The vertical line is the last year (2015) for which catch data are available.

Management quantities are provided in (Table 7). The KOBE matrix results indicates that based on the OCOM model results, *S. commerson* is currently both overfished (B_{2015} /B_{MSY} = 0.89) and subject to overfishing (F_{2015}/FMSY = 1.28) (Figure 15).

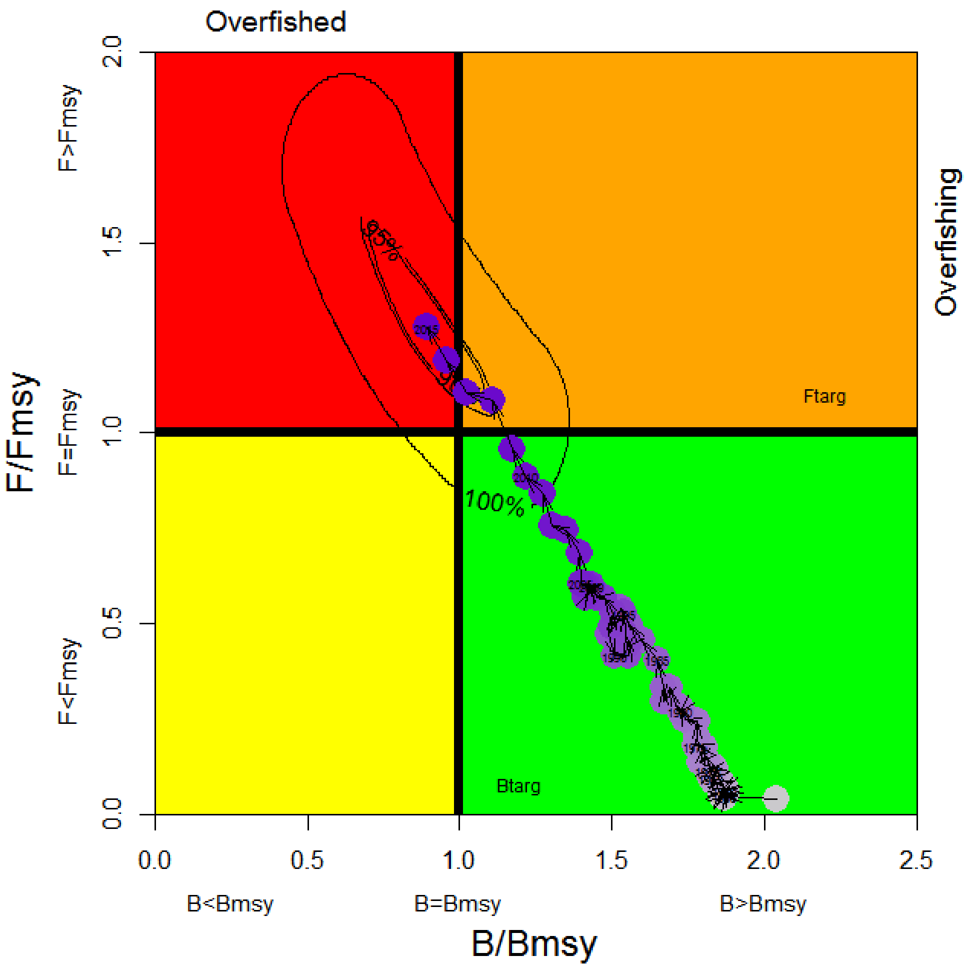

Figure 15. *S. commerson* OCOM Indian Ocean assessment Kobe plot. The Kobe plot presents the trajectories for the range of plausible model options included in the formulation of the final management advice. The trajectory of the geometric mean of the plausible model options is also presented.

Table 7. 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.

Management Quantity	**2014**	**2015**	**2016**	**2017**
Most recent catch estimate (year)	143 333 t (2012)	153 341 t (2013)	154 723 t (2014)	154 177 t (2015)
Mean catch – most recent 5 years [6]	137 116 t (2008 – 2012)	145 817 t (2009 – 2013)	148 610 t (2010 – 2014)	151 502 t (2011 – 2015)
MSY (plausible range)	124 367 t[7]	127 731 t[8]	131 053 t	130 720 t (95 598 – 180 164)
Data period used in assessment	1950 - 2012	1950 - 2013	1950 - 2014	1950 – 2015
F_{MSY} (plausible range)	0.42	0.33	0.34	0.35 (0.18 – 0.7)
B_{MSY} (plausible range)	240 940	320 664	326 217	370 974 (186 702 – 881 633)
$F_{current}/F_{MSY}$ (plausible range)	1.10	1.21	1.21	1.28 (1.03 – 1.69)
$B_{current}/B_{MSY}$ (plausible range)	1.03	0.96	0.95	0.89 (0.63 – 1.15)
$SB_{current}/SB_{MSY}$ (80% CI)	-	-	-	-
$B_{current}/B_0$ (plausible range)	0.51	0.53	0.52	0.44 (0.31 – 0.57)
$SB_{current}/SB_0$ (80% CI)	-	-	-	-
$B_{current}/B_{0,\ F=0}$ (80% CI)	-	-	-	-
$SB_{current}/SB_{0,\ F=0}$ (80% CI)	-	-	-	-

[6] Data at time of assessment
[7] median
[8] 125 299 (median)

Discussion

The assessment results for the two methods provided fairly similar estimates of maximum sustainable yield; the C-MSY model estimated the geometric mean MSY at 138 000 t while the OCOM model estimated it at ~131 000 t (Table 8). These findings were similar to the 2016 assessment results which estimated MSY at 141 000 t and 131 000 t for the Catch-MSY and OCOM methods respectively. Both model estimates suggest that current catch levels (152 000 t average over the last five years) are above the maximum sustainable yield.

Table 8. Key management quantities from the Catch-MSY and OCOM[9] assessments for narrow-barred Spanish mackerel. Geometric means are provided (with plausible ranges across all feasible model runs).

Management Quantity	C-MSY	OCOM
Most recent catch estimate (2015)	154 177 t	154 177 t
Mean catch 2011–2015	151 502 t	151 502 t
MSY (plausible range)	138 000 (104 000 to 183 000)	130 720 t (95 598 – 180 164)
Data period used in assessment	1950 – 2015	1950 – 2015
F_{MSY} (plausible range)	0.60 (0.48 - 0.74)	0.35 (0.18 – 0.7)
B_{MSY} (plausible range)	232 000 (161 000 – 333 000)	370 974 (186 702 – 881 633)
F_{2015}/F_{MSY} (plausible range)	1.19 (0.94 – 2.59)	1.28 (1.03 – 1.69)
B_{2015}/B_{MSY} (plausible range)	0.94 (0.43 – 1.19)	0.89 (0.63 – 1.15)
SB_{2015}/SB_{MSY} (80% CI)	-	-
B_{2015}/B_0 (plausible range)	0.47 (0.22 - 0.60)	0.44 (0.31 – 0.57)
SB_{2015}/SB_0 (80% CI)	-	-
$B_{2015}/B_{0,\ F=0}$ (80% CI)	-	-
$SB_{2015}/SB_{0,\ F=0}$ (80% CI)	-	-

Estimates of current stock status were also lower than those derived from the 2016 assessments. In 2016, the predicted biomass relative to optimum levels ($B_{current}/B_{MSY}$) was 1.02 for Catch-MSY and 0.95 for OCOM, while in 2017 the ratios were somewhat lower at 0.94 and 0.89 respectively (Table 8). In terms of fishing mortality relative to optimum levels ($F_{current}/F_{MSY}$), the ratios in 2016 were 1.06 for Catch-MSY and 1.21 for OCOM, whereas the current assessment update suggests an increase to 1.19 and 1.28. While there are substantial uncertainties that are described throughout this paper, based on the weight-of-evidence currently available, these results suggest that the stock is considered to be both *'overfished'* and '*subject to overfishing'*. Catches have remained consistently above both model estimates of MSY since 2011, with only one year (2012) of catches higher than current (2015) levels. Nevertheless, there are substantial uncertainties that are described throughout this paper and further work to collate the available size frequency data, derive improved estimates of growth parameters and develop indices of abundance are needed to improve understanding of the stock status.

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

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