Assessment of Indian Ocean longtail tuna (*Thunnus tonggol*) using data poor catch-based methods

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IOTC Secretariat

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Introduction

Assessing the status of the stocks of neritic tuna species in the Indian Ocean is fairly challenging due to the lack of available data. This includes limited information on stock structure, few standardised CPUE series and little biological information. Data poor stock assessments were conducted for Longtail tuna (*Thunnus tonggol*) in 2013 (Zhou and Sharma, 2013), 2014 (Zhou and Sharma, 2014) and 2015 (Martin and Sharma, 2015). This paper provides an update to these assessments based on the recent new catch information, using two methods to assess the status of *T. tonggol*: (i) Stock reduction analysis or Catch-MSY method (Kimura and Tagart 1982; Walters et. al. 2006; Martell and Froese 2012) and (ii) a posterior-focussed catch method, OCOM (Zhou et al., 2013).

Basic Biology

Longtail tuna (*Thunnus tonggol*) is an epipelagic species inhabiting tropical to temperate provinces of the Indo-Pacific, found almost exclusively in the neritic waters close to the shore, avoiding estuaries, turbid wasters and open ocean (Froese & Pauly 2015). It is one of the smallest species of the genus *Thunnus*, but relatively large compared with other neritic species with a maximum length of 145cm. Longtail tuna in the Indian Ocean is primarily caught by gillnet fleets operating in coastal waters with the highest reported catches from Iran, followed by Indonesia, India, Pakistan, Oman, Malaysia, Thailand and others (Geehan et al. 2016). Most research on Indian Ocean longtail tuna 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. These studies have provided varied estimates of growth, with von Bertalanffy *k* values ranging from 0.18 (Ghosh et al. 2010) – 1.5 (Itoh et al. 1999) with the majority of estimates somewhere in between. Some of these differences may be due to the different estimation techniques, due to regional differences in the maximum size of fish in the areas and due to differences in the size selectivity of the different fish sampling methods.

Fisheries and catch trends

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 vast majority of reported catches of longtail with a much smaller proportion caught by purse seine and line gear, with the majority of catches taken by coastal country fleets (Figure 1). Figure 2 shows the increase in total catches since 1950, highlighting a particularly rapid increase between 2004 and 2012, when catches reached a maximum of 175 459 t, followed by a decline to 146 751 by 2014 (Table 1). There have been a number of changes in the nominal catch series since the last assessments that took place in 2015, including an increase in the estimated catch for the years 2011 and 2012, and a reduction in the estimated catches in 2013. These changes are shown in Figure 3.

There is a relatively high uncertainty associated with the catch data for the neritic tunas due to the difficulties in differentiating amongst the different species resulting in highly aggregated reported data, often as 'seerfishes' or other groupings. Therefore the IOTC Secretariat uses various methods of estimating the disaggregated 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.

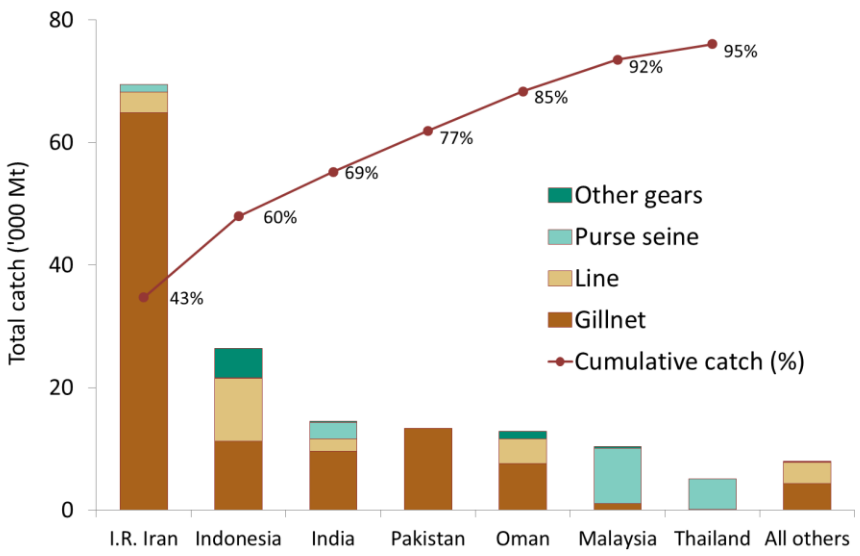

Figure 1. Average catches in the Indian Ocean over the period 2010-2014, by country. Countries are ordered from left to right, according to the level of catches of longtail reported. The red line indicates the (cumulative) proportion of catches of longtail for the countries concerned, over the total combined catches of this species reported from all countries and fisheries.

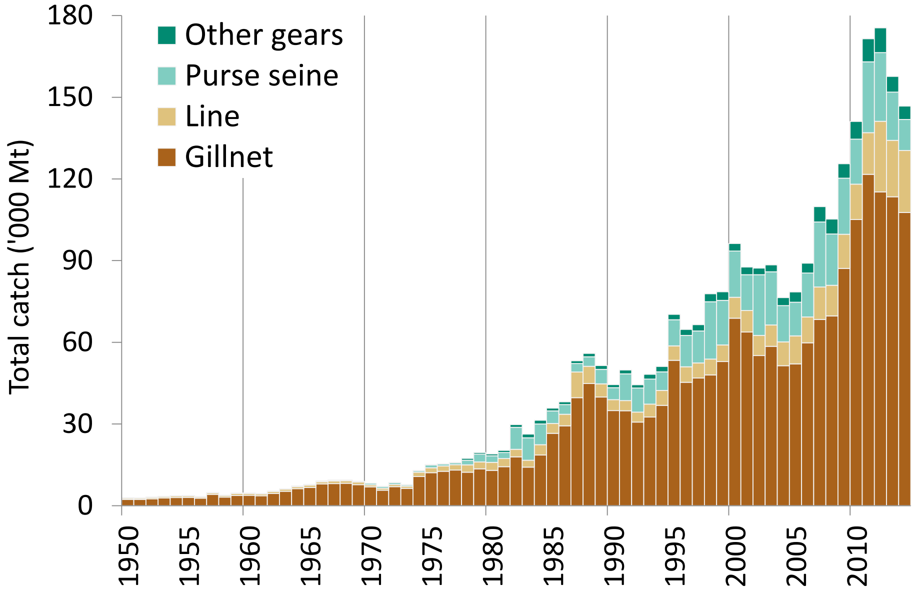

Figure 2. Annual catches of longtail tuna by gear as recorded in the IOTC Nominal Catch database (1950–2014)

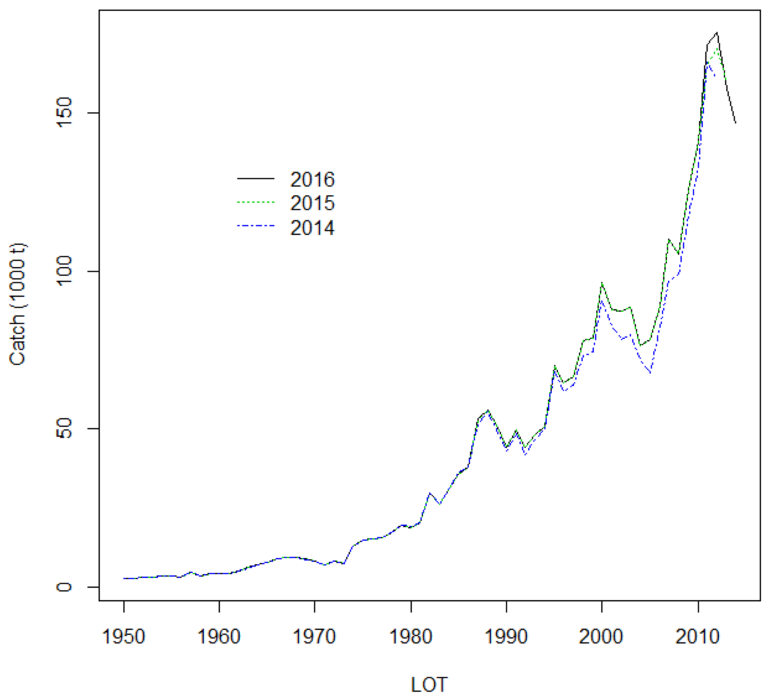

Figure 3. Revisions to IOTC nominal catch data for longtail tuna

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

Year	Catch (t)	Year	Catch (t)
1950	2,849	1982	29,811
1951	2,826	1983	26,264
1952	3,105	1984	31,392
1953	3,372	1985	35,850
1954	3,615	1986	38,147
1955	3,650	1987	53,221
1956	3,326	1988	55,950
1957	4,705	1989	51,474
1958	3,750	1990	44,448
1959	4,533	1991	49,813
1960	4,545	1992	44,413
1961	4,459	1993	48,238
1962	5,341	1994	51,112
1963	6,137	1995	70,252
1964	7,200	1996	64,759
1965	7,782	1997	66,500
1966	9,124	1998	77,807
1967	9,438	1999	78,556
1968	9,475	2000	96,315
1969	8,888	2001	87,671
1970	8,248	2002	87,260
1971	7,037	2003	88,443
1972	8,432	2004	76,392
1973	7,679	2005	78,498
1974	12,859	2006	89,081
1975	15,027	2007	109,851
1976	15,315	2008	105,260
1977	15,782	2009	125,601
1978	17,346	2010	141,115
1979	19,541	2011	171,496
1980	19,010	2012	175,459
1981	20,287	2013	157,656
		2014	146,751

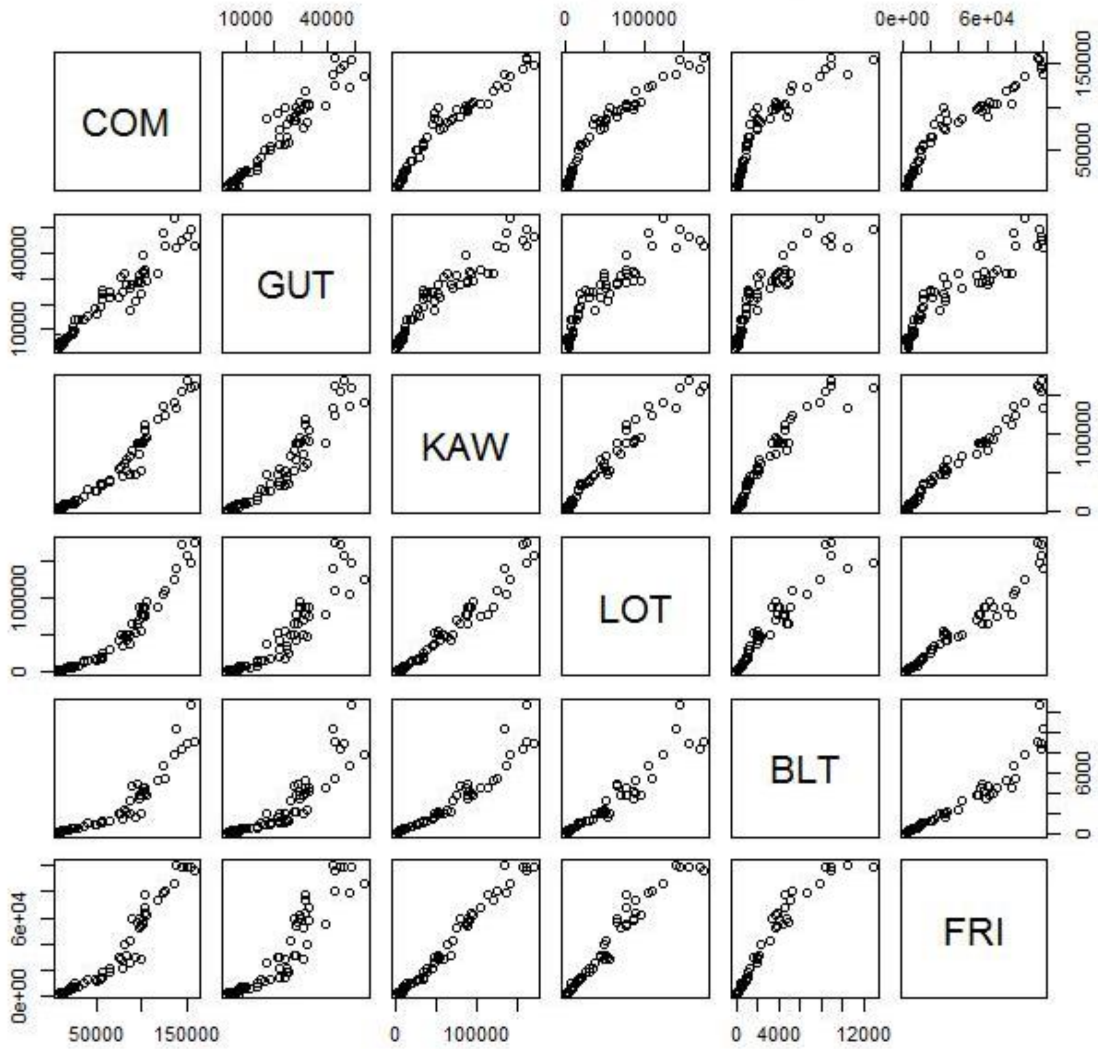

Figure 4. Correlations between catches of neritic tuna species over time

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, *T. tonggol* has a high level of resilience and so a range of 0.6 - 1.5 was used.

A reasonably wide prior range was also used for *K*, which ranged from the 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 where 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 at 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 at each given starting biomass level based on the assumptions that 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 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)*
Longtail – run 1	0.5 - 0.9	0.3 – 0.7	0.6 - 1.5	175 - 8773
Longtail – run 2			0.6 - 1.8	299 - 665

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

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

2) Optimised Catch Only Method (OCOM)

The Optimised Catch-Only Method was developed by Zhou *et al*. (2013) and 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–DATA13). 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 0.66 to 1.42.

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):

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

This was used to derive an alternate range for M, resulting in a set of estimated *r* values ranging from 0.49 to 0.94 ($0.38 \leq M \leq 0.82$) . 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 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 (OCOM method)

Initial *B/k*	Final *B/k*	*K (1000 t)*	*r*	
1	0.05 – 0.8	175 - 8773	0.66 – 1.42	5 equation average
	0.05 – 0.7		0.49 – 0.94	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 369 098 – 1 180 279 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 less probable tail of the distribution (i.e. 665 453 t, Figure 5) (Zhou et al., 2013) and the range for *r* was expanded to 1.2 multiplied by the maximum *r* (0.6 - 1.8). This resulted in slightly higher *r*, a more normal distribution of r and lower *K* estimates with little change in MSY (Figure 6). This was taken as the base model run and the results for this simulation are presented.

Figure 7 shows 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 biomass trajectory closely mirrors the catch curve with a slight increase in biomass in the early 2000s followed by a rapid decline (Figure 2). 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 which give a slightly higher average MSY, 142 407. The IOTC target and limit reference points for longtail tuna have not yet been defined, so the values applicable for all other IOTC species are used as in (Table 5). The KOBE matrix plot indicates that based on the Catch-MSY model results, longtail is overfished (B_{2014}/BMSY = 0.94) and is subject to overfishing (F_{2014}/FMSY = 1.07) (Figure 8).

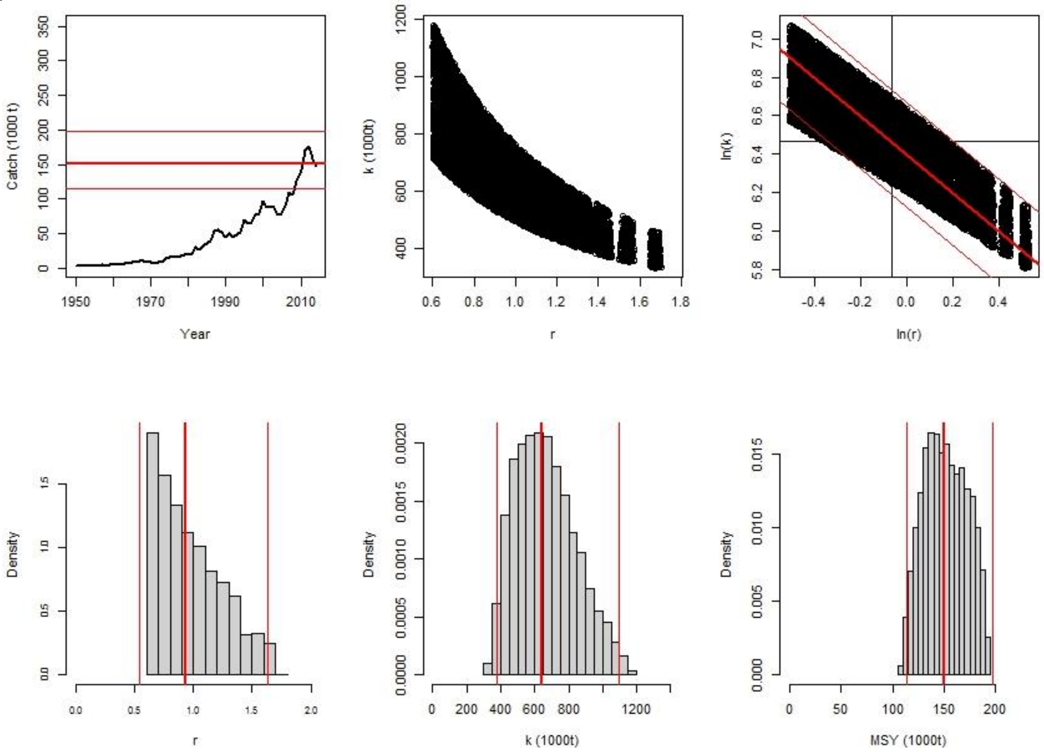

Figure 5. All feasible *r* and *K* combinations resulting from model simulations based on the original parameter constraints

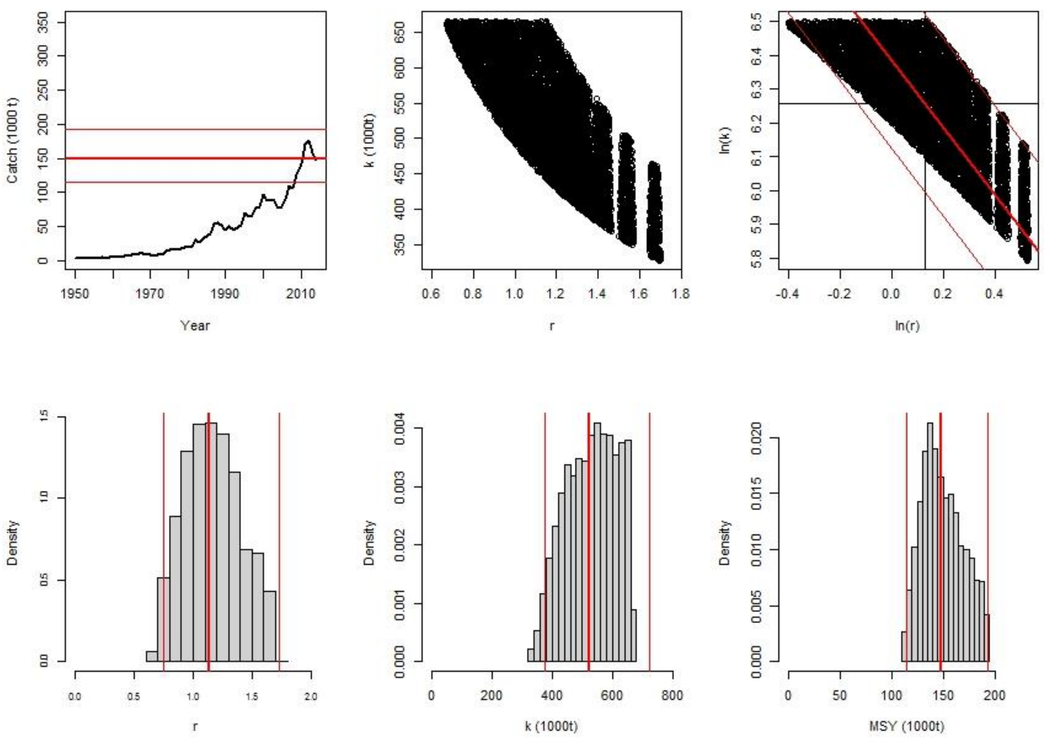

Figure 6. All feasible *r* and *K* combinations with further parameter constraints on max(K)

Table 5. IOTC reference points for *T. tonggol*

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

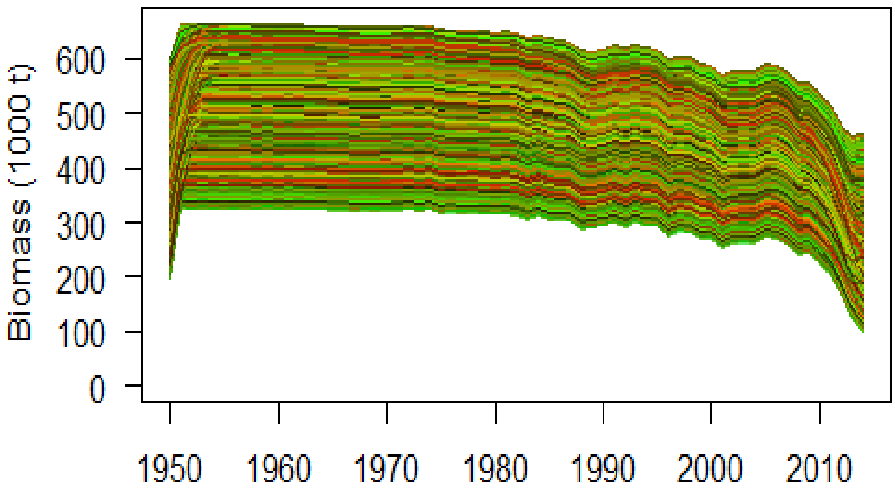

Figure 7. Simulated biomass trajectories based on the Catch-MSY method (Martell and Froese, 2012)

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

Quantile	K	r	Bmsy	MSY	Bend	Final D
0%	327 783	0.67	163 893	110 547	98 959	0.30
25%	520 576	0.91	260 288	129 282	211 163	0.41
50%	**573 570**	**1.03**	**286 785**	**140 016**	**268 643**	**0.47**
75%	622 100	1.13	311 050	156 219	334 380	0.54
100%	665 387	1.70	332 694	193 847	463 896	0.70

Table 7. Key management quantities from the Catch MSY assessment for Indian Ocean longtail tuna. Geometric means (and plausible ranges across all feasible model runs). n.a. = not available. Previous assessment results are provided for comparison.

Management Quantity	2014	2015	2016
Most recent catch estimate (year)	160 532 t (2012)	159 312 t (2013)	146 750 t (2014)
Mean catch – most recent 5 years[2]	135 036 t (2008 – 2012)	142 101 t (2009 – 2013)	158 495 t (2010 - 2014)
MSY (plausible range)	134 697	133 044	142 407 (110 547 to 193 847)
Data period used in assessment	1950 – 2012	1950 – 2013	1950 – 2014
F_{MSY} (plausible range)	n.a	0.41	0.41 (0.29 - 0.62)
B_{MSY} (plausible range)	232 437	261 900	280 620 (163 893 – 332 694)
$F_{current}/F_{MSY}$ (plausible range)	1.08[3]	1.23	1.07 (0.60 – 1.91)
$B_{current}/B_{MSY}$ (plausible range)	1.12	0.92	0.94 (0.60 – 1.40)
$SB_{current}/SB_{MSY}$ (80% CI)	n.a	n.a	n.a
$B_{current}/B_0$ (plausible range)	n.a	0.46	0.47 (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

[2] Data at time of assessment
[3] Arithmetic mean

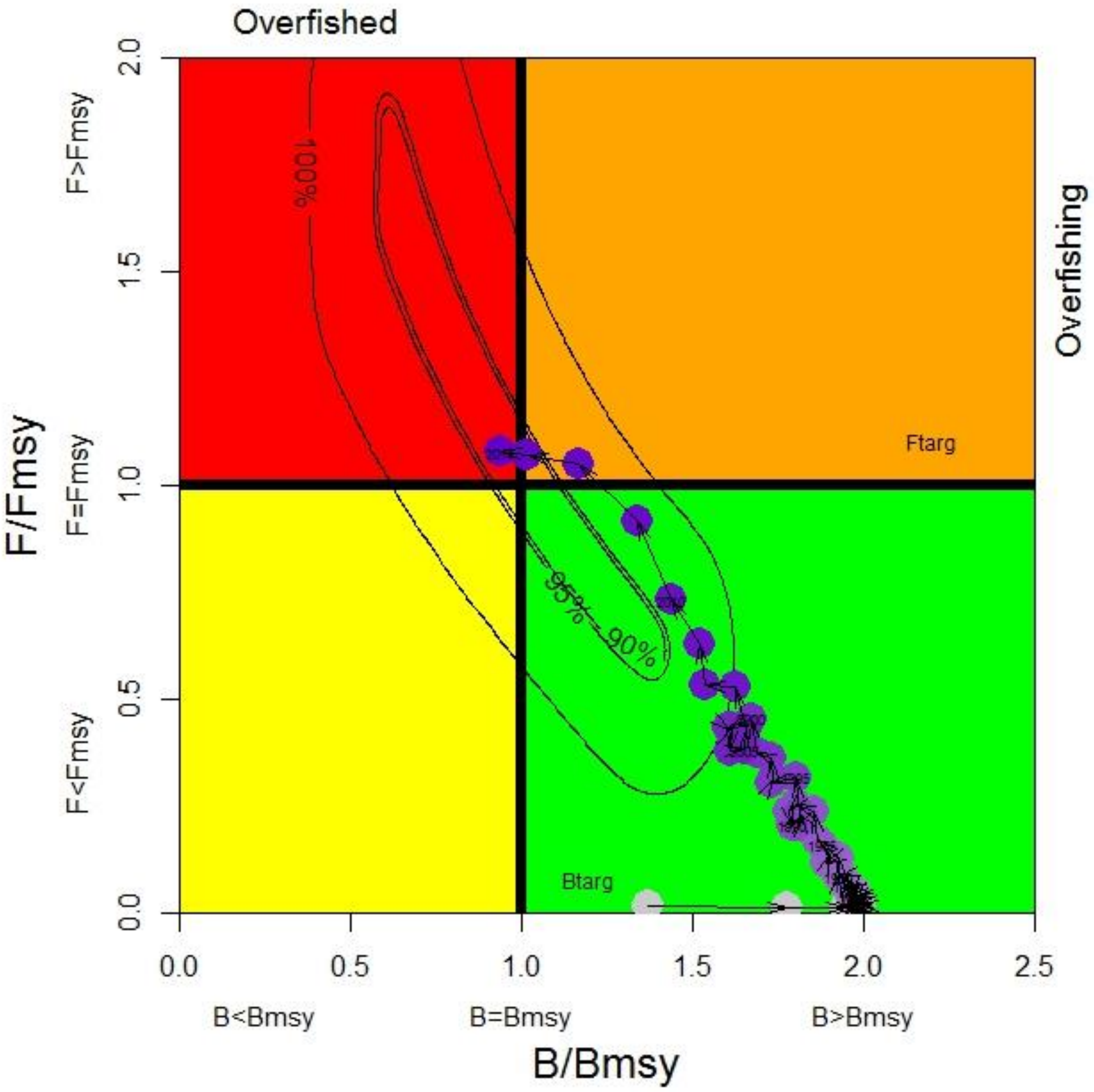

Figure 8. Catch-MSY Indian Ocean assessment Kobe plot for longtail tuna. The Kobe plot presents the trajectories for the range of plausible model options included in the formulation of the final management advice. The trajectory of the geometric mean of the plausible model options is also presented.

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.

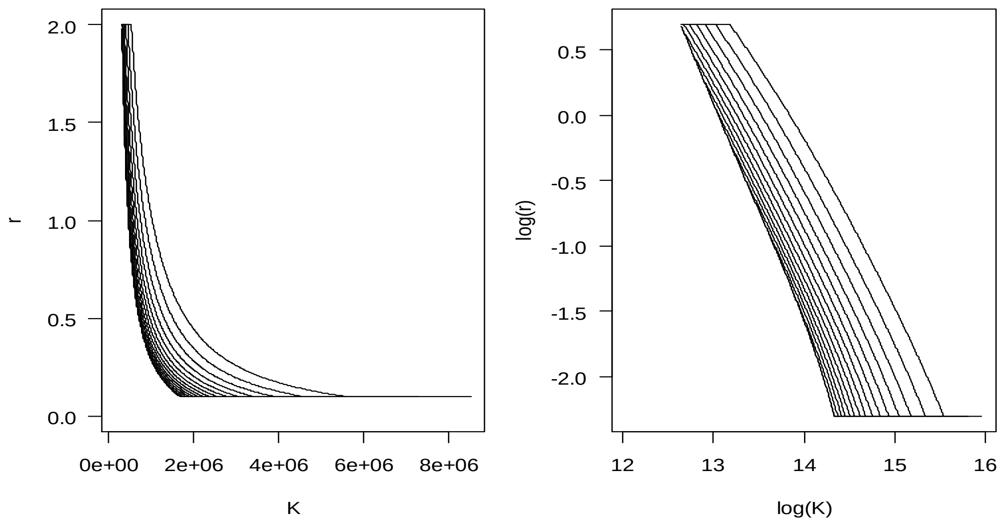

Figure 9. Initial plausible range of r and K values (non-informative priors)

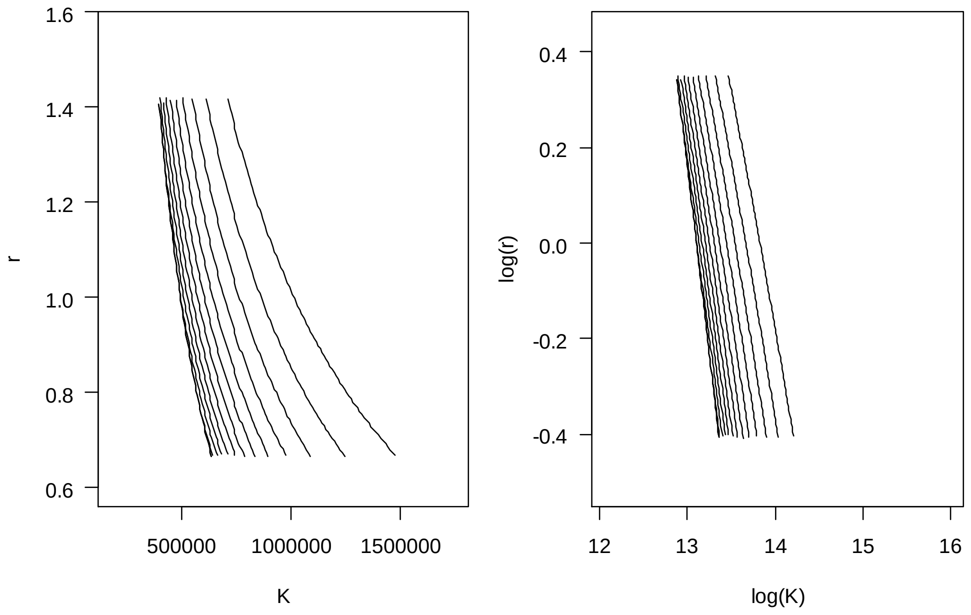

Figure 10. Plausible range of r and K with informative priors on r (0.66 – 1.42)

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 0.15.

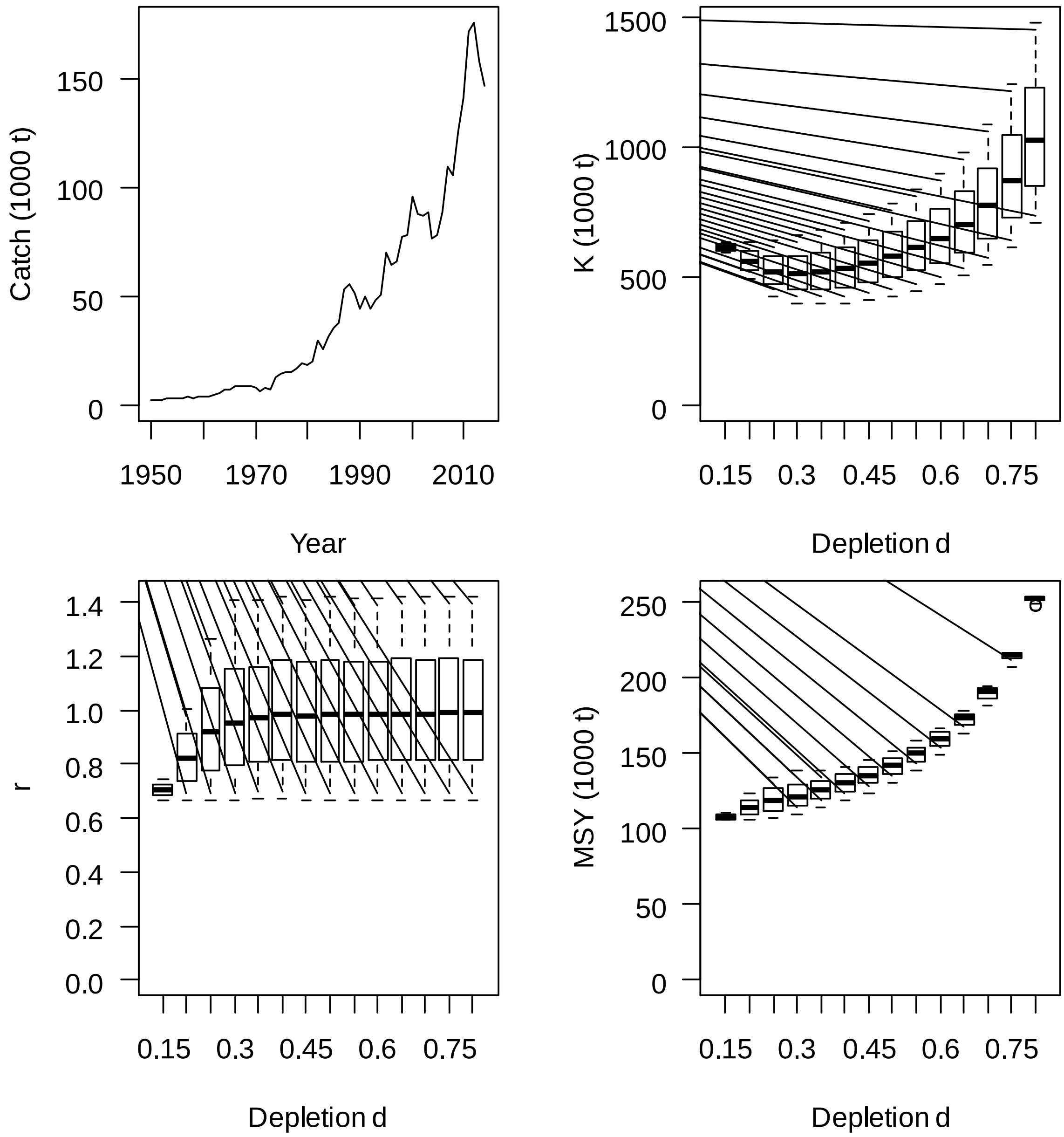

Figure 11. Longtail catch history, feasible carrying capacity, population growth rate and MSY at each assumed depletion level. There is no feasible solution when the depletion is assumed to be below 0.15.

Base case model results (for a maximum depletion level of 0.7) indicate that the biomass was approximately 590 000 t in 1950 and declined to approximately 295 000 t by 2014 (Figure 12). The estimated MSY associated with this projection is 140 000 t and ranges from approximately 105 000 t to 194 000 t based on the assumed maximum depletion level (Table 8).

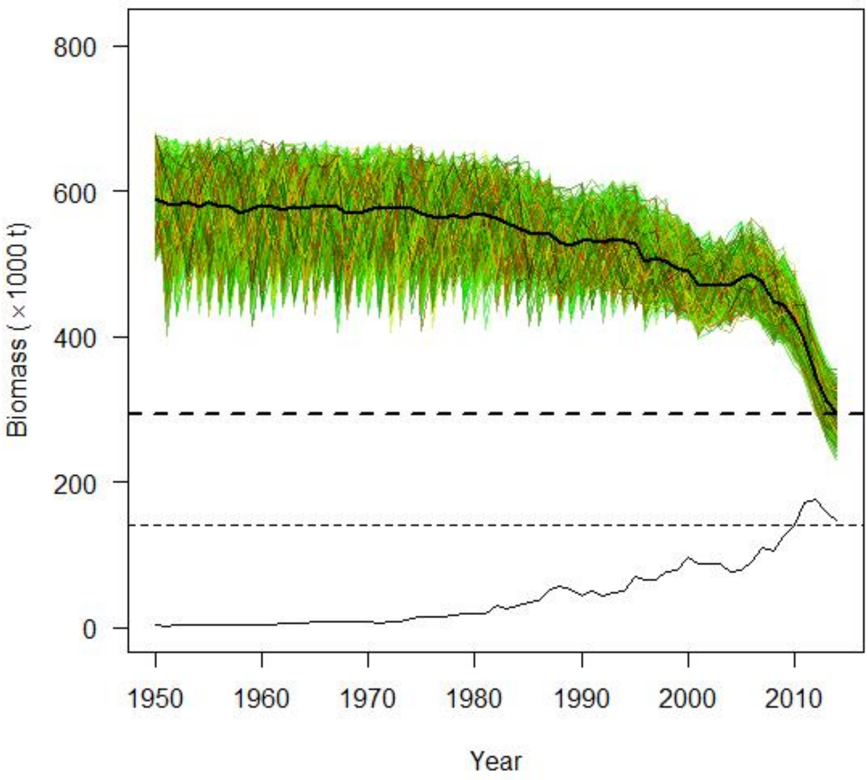

Figure 12. Longtail biomass trajectories from 500 simulations with upper depletion = 0.7.

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 most recent catch level (2014), and resulted in a further 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 remains just above MSY, resulting in a stock biomass also very close to the B_{MSY} level (Figure 14).

Table 8. OCOM key biological parameters for longtail under four assumed upper depletion levels[4]

Upper d	Quantile	K	r	MSY	B_{2014}	D
0.8	0%	393,428	0.66	105,604	264,338	0.41
0.8	25%	525,825	0.80	130,227	344,459	0.53
0.8	50%	624,807	0.96	149,305	366,743	0.56
0.8	75%	778,178	1.17	187,676	386,843	0.59
0.8	100%	1,480,023	1.42	253,479	467,942	0.71
0.7	0%	393,428	0.66	105,604	230,785	0.39
0.7	25%	505,612	0.79	126,609	279,545	0.47
0.7	**50%**	**586,824**	**0.96**	**140,326**	**294,785**	**0.50**
0.7	75%	681,080	1.16	162,667	309,541	0.52
0.7	100%	1,090,142	1.42	193,762	354,929	0.61
0.6	0%	393,428	0.66	105,604	194,849	0.35
0.6	25%	486,177	0.79	123,174	230,194	0.41
0.6	50%	559,860	0.95	134,208	240,138	0.43
0.6	75%	634,681	1.15	146,529	252,916	0.45
0.6	100%	896,116	1.42	166,522	301,276	0.53
0.5	0%	393,428	0.67	105,604	151,593	0.28
0.5	25%	471,167	0.78	119,894	188,430	0.35
0.5	50%	540,457	0.94	129,096	200,426	0.37
0.5	75%	610,284	1.14	136,699	212,974	0.39
0.5	100%	784,303	1.42	150,886	241,760	0.44

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 15) as well as a fixed future catch rate equal to the optimum rate for achieving the target biomass, i.e. MSY/ B_{MSY} (Figure 16). While both of these projections result in a biomass which rapidly stabilises 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. As the reported level of catches in 2014 (146 751 t) was similar to the estimated MSY (143 153 t), the outcome of these projections are fairly similar, with catches and predicted biomass close to the target levels over the short term, although biomass would be expected to decline gradually over the longer term while catches remain greater than MSY.

[4] 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.

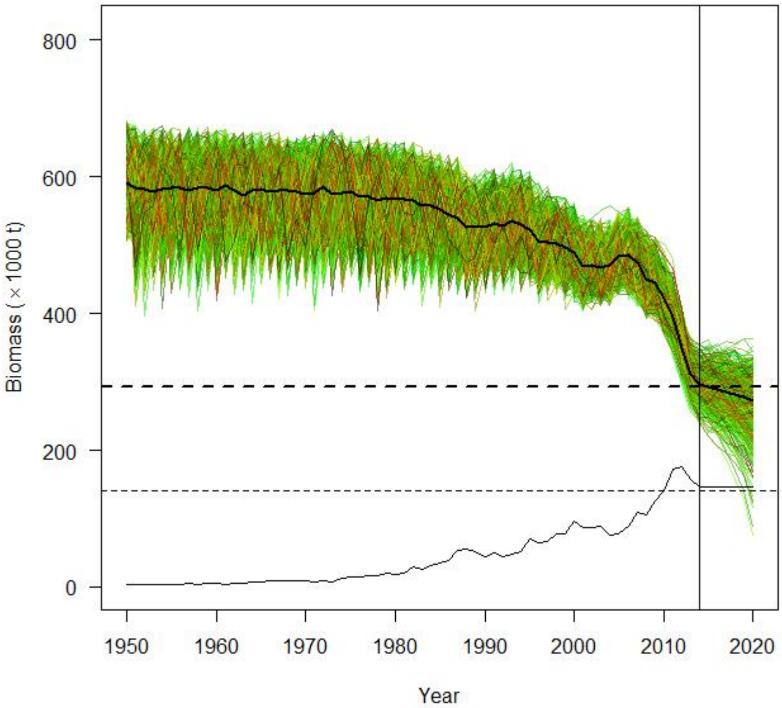

Figure 13. Projected longtail biomass trajectories under hypothetical annual catches equivalent to those of the final year (C_{2014}) until 2020. The vertical line is the last year for which catch data are available.

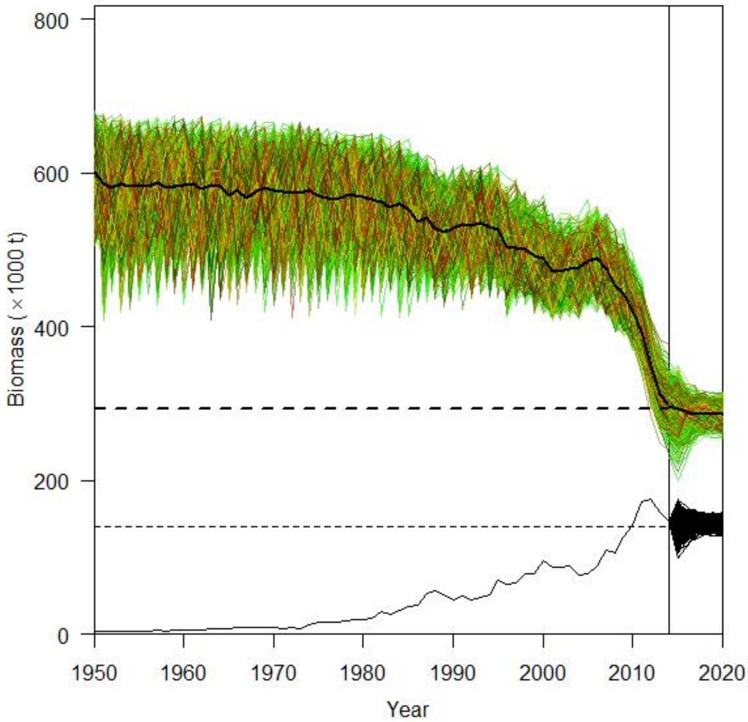

Figure 14. Projected longtail biomass trajectories under hypothetical annual catch rate (C_{2014}/B_{MSY}) at 2014 level until 2020. The vertical line is the last year for which catch data are available.

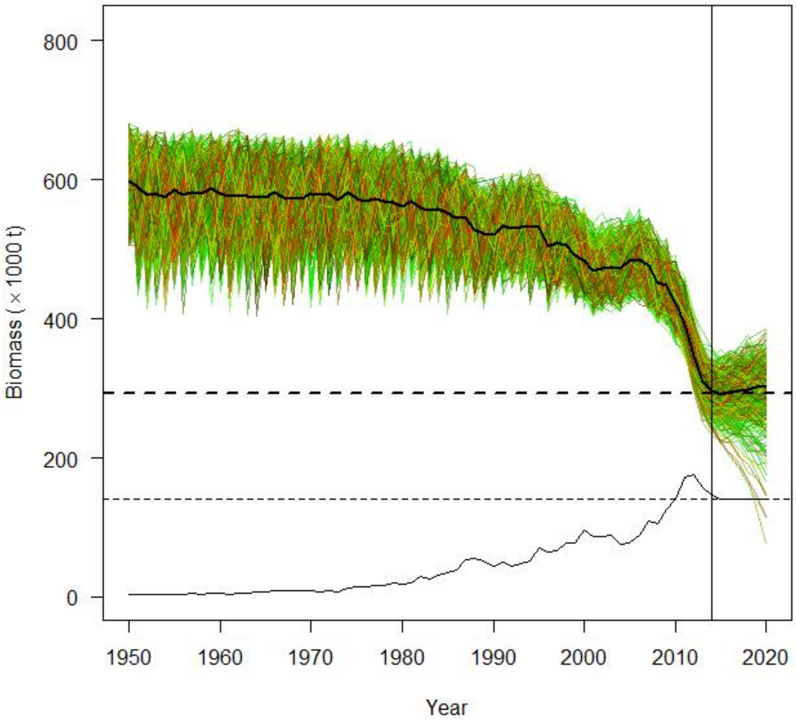

Figure 15. Projected longtail biomass trajectories under hypothetical future annual catch equivalent to MSY until 2020. The vertical line is the last year for which catch data are available.

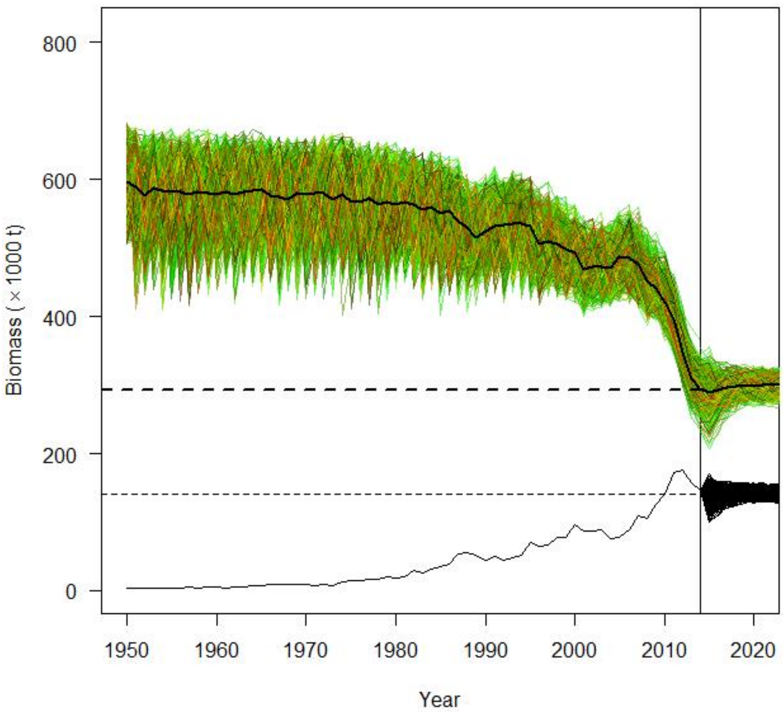

Figure 16. Projected longtail biomass trajectories under hypothetical annual catch rate at MSY level (MSY/B_{MSY}) until 2020. The vertical line is the last year for which catch data are available.

Management quantities based on geometric means and plausible are provided in Table 9. For the initial model run, the geometric mean MSY, 143 153 t, is slightly higher than the median, 140 326 t. The KOBE matrix plot based on the OCOM model results suggests that longtail is currently overfished (mean B_{2014}/B_{MSY} = 0.99) and subject to overfishing (mean F_{2014}/F_{MSY} = 1.03) (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.

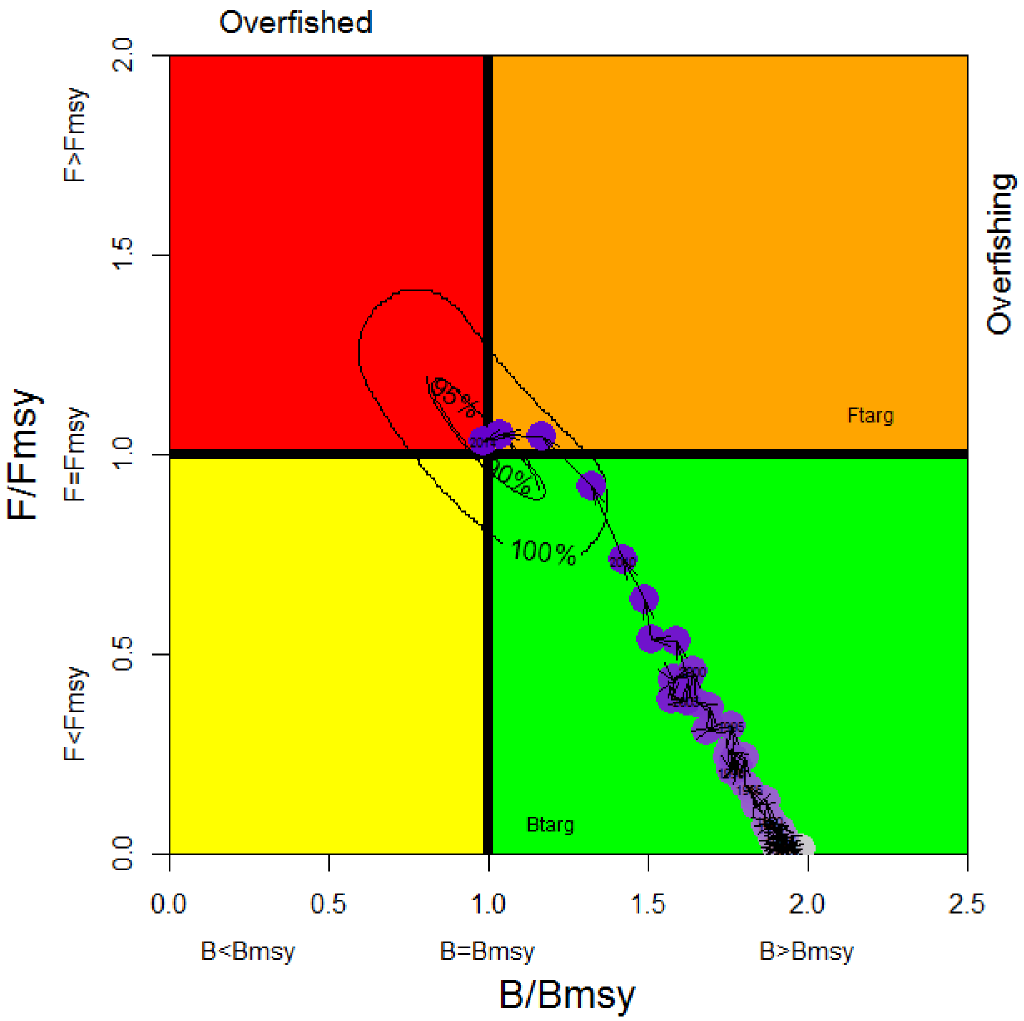

Figure 17. Longtail OCOM Indian Ocean assessment Kobe plot (all plausible model runs shown around 2014 estimate). Blue circles indicate the trajectory of the point estimates for the SB ratio and F ratio for each year 1950–2014. Target reference points are shown as B_{MSY} and F_{MSY}.

Table 9. Key management quantities from the OCOM assessment for Indian Ocean longtail tuna, using a base case with maximum depletion of 70%. Geometric means and plausible ranges in brackets. n.a. = not available. Previous assessment results are provided for comparison.

Management Quantity	2013	2014	2015	2016	2016 (alternative)
Most recent catch estimate	164 537	160 532	159 313 t	146 751 t	146 751 t
Mean catch over last 5 years[5]	121 062	135 036	142 457 t	158 495 t	158 495 t
MSY (plausible range)	123 840[6]	120 000[4]	137 687 t[7]	143 153 t[8] (105 604-193 762)	129 444 t (94 493 – 189353)
Data period used in assessment	1950 – 2011	1950 – 2012	1950 – 2013	1950 – 2014	1950 – 2014
F_{MSY} (plausible range)	0.49	0.39	0.39	0.39 (0.29 – 0.54)	0.29 (0.22 – 0.38)
B_{MSY} (plausible range)	198 105	254 359	287 920	297 689 (196 714 -545 071)	382 757 (256 801 – 695 025)
$F_{current}/F_{MSY}$ (plausible range)	1.04	1.19	1.11	1.03 (0.88-1.26)	1.18 (1.02 – 1.41)
$B_{current}/B_{MSY}$ (plausible range)	1.25	1.08	1.02	0.99 (0.78-1.19)	0.94 (0.76 – 1.12)
$SB_{current}/SB_{MSY}$ (80% CI)	n.a	n.a	n.a	n.a.	n.a.
$B_{current}/B_0$ (plausible range)	0.63	0.53	0.56	0.50 (0.39-0.60)	0.47 (0.34 – 0.76)
$SB_{current}/SB_0$ (80% CI)	n.a	n.a	n.a	n.a	n.a
$B_{current}/B_{0,\ F=0}$ (80% CI)	n.a	n.a	n.a	n.a	n.a
$SB_{current}/SB_{0,\ F=0}$ (80% CI)	n.a	n.a	n.a	n.a	n.a

[5] Data at time of assessment
[6] Median values shown
[7] median = 134 000
[8] median = 140 326

Discussion

Both the Catch-MSY and OCOM models provided relatively similar estimates of MSY, with a median MSY estimate of 140 000 t and mean estimates of 142 000 t and 143 000 t respectively (Table 10). These estimates are similar to, but higher than, previous assessment estimates (Table 7 and Table 9) (Zhou and Sharma, 2013; Zhou and Sharma, 2014; Martin and Sharma, 2015). Although reported catches decreased between 2012 and 2014 from 175 459 to 146 751 t, catches have remained well above (all current and previous estimates of) MSY since 2011.

Table 10. Key management quantities from the Catch-MSY and OCOM[9] assessments for Indian Ocean longtail tuna. 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)	146 751 t	146 751 t
Mean catch 2010–2014	158 495 t	158 495 t
MSY (plausible range)	142 407 t (110 547 - 193 847)	143 153 t (105 604 – 193 762)
Data period used in assessment	1950 – 2014	1950 – 2014
F_{MSY} (plausible range)	0.41 (0.29 - 0.62)	0.39 (0.29 – 0.54)
B_{MSY} (plausible range)	280 620 (163 893 – 332 694)	297 689 (196 714 -545 071)
F_{2014}/F_{MSY} (plausible range)	1.07 (0.60 – 1.91)	1.03 (0.88-1.26)
B_{2014}/B_{MSY} (plausible range)	0.94 (0.60 – 1.40)	0.99 (0.78-1.19)
SB_{2014}/SB_{MSY} (80% CI)	n.a	n.a.
B_{2014}/B_0 (plausible range)	0.47 (0.30 - 0.70)	0.50 (0.39-0.60)
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

Results suggest that the stock is still likely to be subject to overfishing with an F_{2014}/F_{MSY} ratio of 1.07 and 1.03 for the Catch-MSY and OCOM models respectively. This ratio is slightly lower than estimated in previous years, reflecting the drop in catches reported in the last two years, suggesting that fishing mortality has declined. Nevertheless, estimates of the B_{2014}/B_{MSY} ratio were also slightly lower than previous years, 0.94 and 0.99 for the Catch-MSY and OCOM models respectively. These stock status predictions correspond across the two models and the alternative model runs, suggesting that the stock is considered to be both '*overfished*' and '*subject to overfishing*'.

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

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

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

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