Assessment of Indian Ocean longtail tuna (*Thunnus tonggol*) using data-limited methods

21st June 2017

IOTC Secretariat

IOTC, PO Box 1011, Le Chantier Mall, Victoria, Seychelles.[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 lack of available data. This includes limited information on stock structure, few standardised CPUE series and little biological information. Data poor stock assessments have been conducted annually for Longtail tuna (*Thunnus tonggol*) since 2013 (Zhou and Sharma, 2013; Zhou and Sharma, 2014; Martin and Sharma, 2015; Martin and Robinson, 2016). This paper provides an update to these assessments based on the most recent catch information report to the IOTC, using two methods to assess the status of *T. tonggol*: (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). A further method, stochastic SRA, was also used to explore the potential for the inclusion of size data in the assessment.

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 the majority of estimates of von Bertalanffy k values ranging from 0.18 (Ghosh et al. 2010) – 0.55 (Yesaki, 1989) with some more extreme values; 1.5 (Itoh et al. 1999). 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 (IOTC, 2015).

Fisheries and catch trends

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 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, namely I.R.Iran, Indonesia, Pakistan, India and Oman (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 170,359 t. This has since been followed by a decline to the current estimated total catches of 132,723 t in 2015 (Table 1). There has been very little change in the nominal catch series since the last assessments (Figure 3).

There is a relatively high uncertainty associated with the catch data for 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 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.

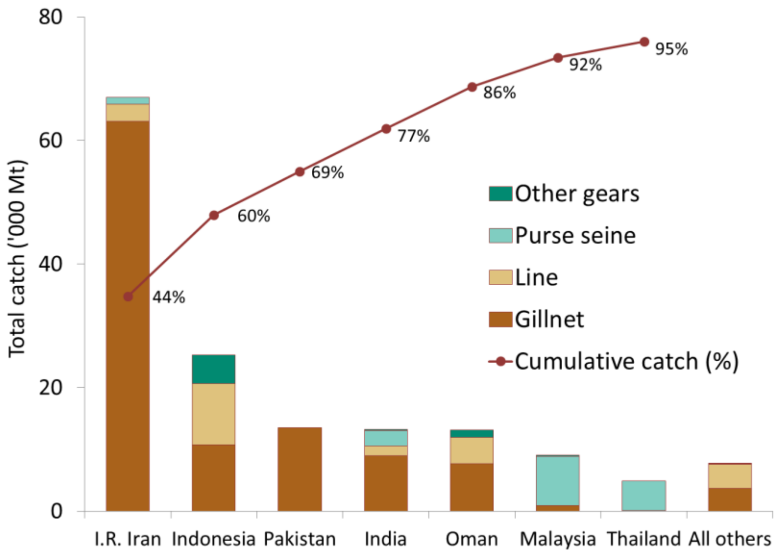

Figure 1. Average catches in the Indian Ocean over the period 2012-2015, by country. The red line indicates the (cumulative) proportion of catches of longtail by country.

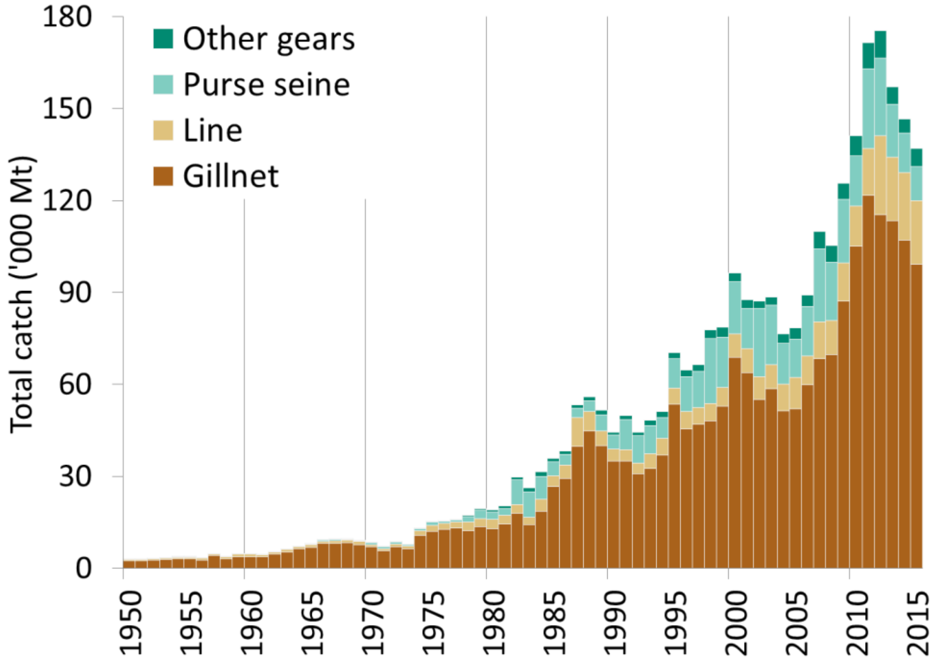

Figure 2. **Annual catches of longtail tuna by gear, 1950 – 2015 (IOTC database)**

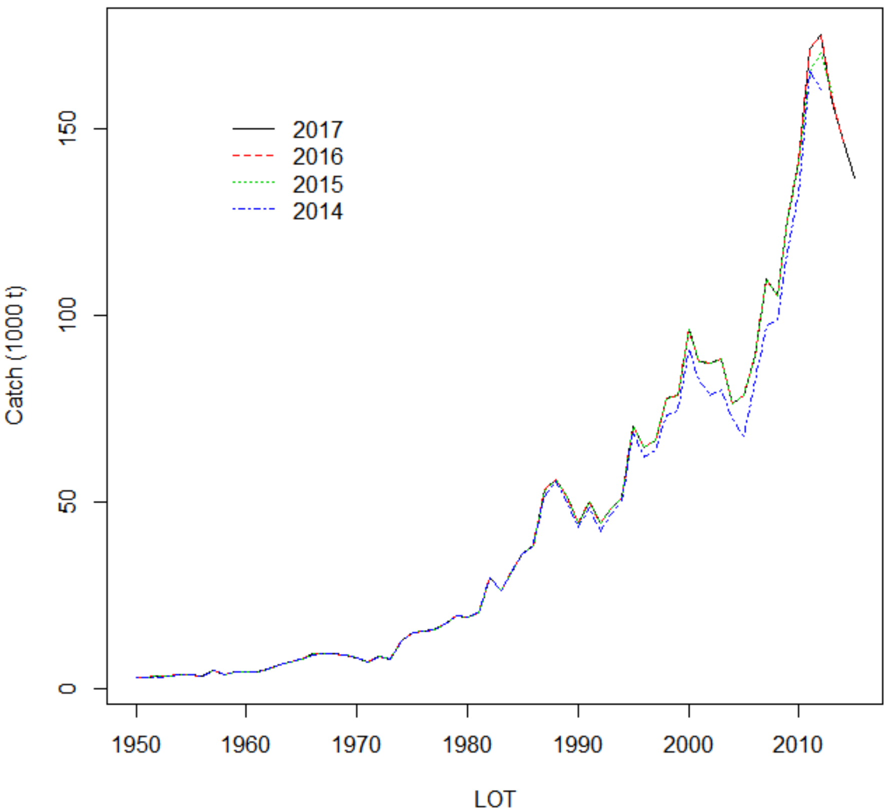

Figure 3. Revisions to IOTC nominal catch data for longtail tuna (datasets available from 2014 – 2017)

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

Year	Catch (t)	Year	Catch (t)
1950	2,848	1983	26,264
1951	2,824	1984	31,392
1952	3,103	1985	35,850
1953	3,371	1986	38,147
1954	3,613	1987	53,221
1955	3,649	1988	55,950
1956	3,325	1989	51,474
1957	4,704	1990	44,448
1958	3,749	1991	49,813
1959	4,531	1992	44,413
1960	4,543	1993	48,238
1961	4,458	1994	51,112
1962	5,340	1995	70,252
1963	6,135	1996	64,759
1964	7,199	1997	66,500
1965	7,781	1998	77,806
1966	9,123	1999	78,555
1967	9,437	2000	96,315
1968	9,474	2001	87,671
1969	8,886	2002	87,260
1970	8,248	2003	88,443
1971	7,037	2004	76,392
1972	8,432	2005	78,498
1973	7,679	2006	89,081
1974	12,859	2007	109,851
1975	15,027	2008	105,260
1976	15,315	2009	125,601
1977	15,782	2010	141,115
1978	17,346	2011	171,496
1979	19,541	2012	175,459
1980	19,010	2013	157,093
1981	20,287	2014	146,567
1982	29,811	2015	136,849

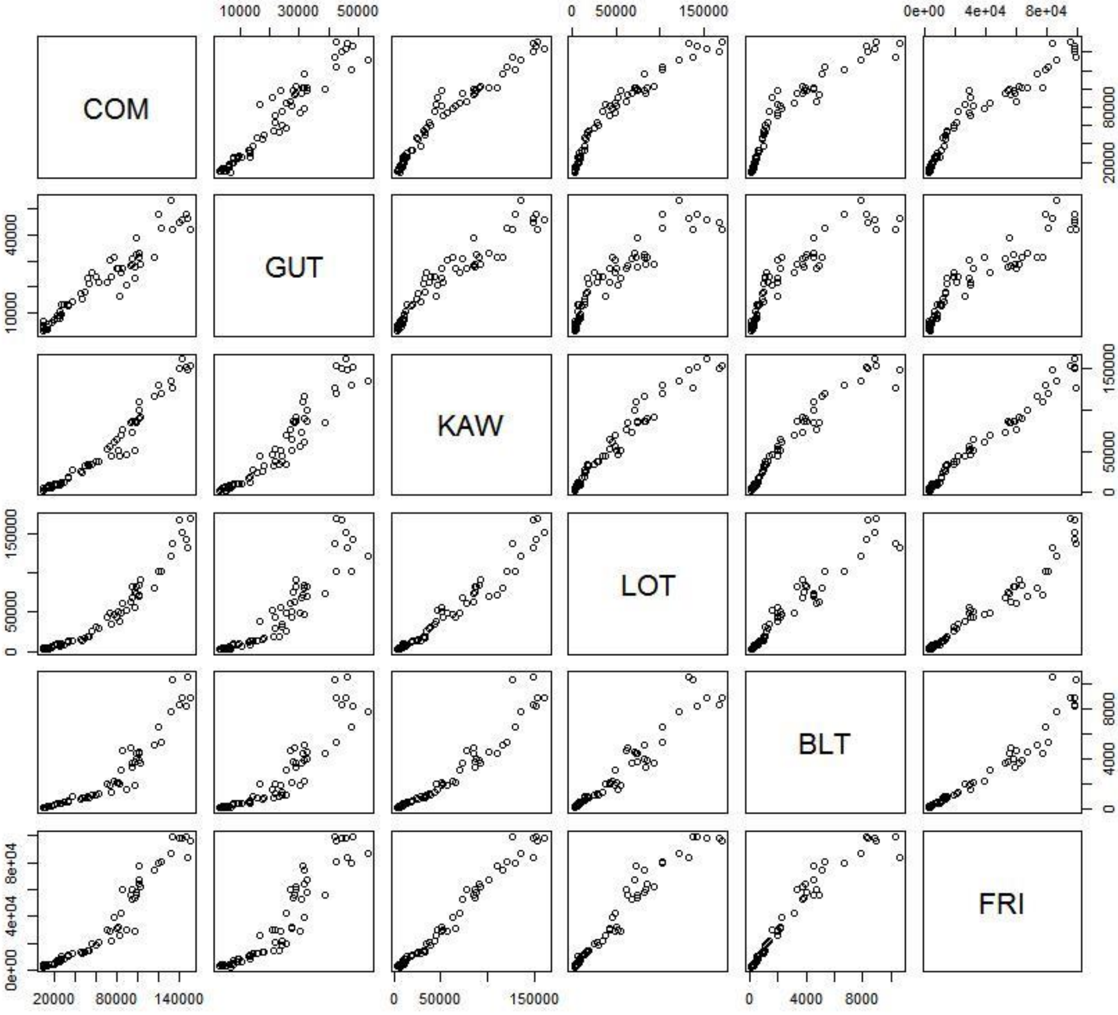

Figure 4. Correlations between catches of neritic tuna species (1950 – 2015)

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.

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

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

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. 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 than 1000 pairs are found.

The most probable r-k pair were determined using the method described by Ferose 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) 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 $|B_{2015} - DK|$ where B_{2015} 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_{2015} 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 0.56 to 1.39. While depletion levels were originally set ranging from 0.05 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; 0.5, 0.6 and 0.7.

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

While B_{MSY} and F_{MSY} were calculated from the equations $\quad B_{MSY} = \frac{K}{2}$ and

$$F_{MSY} = -ln\left[1 - \left[\frac{MSY}{(Bmsy + MSY)}\right]\right]$$

The range of r and K values were further reduced by selecting only those combinations corresponding to the 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

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

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 depletion level was set at $D = 0.7$.

3) Stochastic SRA method

The C-MSY and OCOM methods used the Schafer surplus-production model which imposes strong assumptions on the productivity of the stock. Although the estimate of MSY is generally robust with both methods, estimates of other management quantities are sensitive to the assumed level of stock depletion. Below we tentatively considered the stochastic stock reduction analysis approach (Stochastic SRA) by Walters et al. (2004), as implemented in the Data Limited Methods toolkit (Carruthers et al. 2014), as an attempt to overcome some of these limitations. This approach uses an age-structured model with parameters sourced from available information. It also incorporates time series of age-frequency data (converted from the length frequencies) to constrain feasible biomass trajectories, without making explicit assumptions about the level of stock depletion.

The stochastic SRA uses historical catches to estimate recruitment rates that can support those catches, also consistent with the age frequency data (Walters et al. 2004). It uses Monte Carlo simulations to provide distributions for feasible stock size over time under alternative hypotheses about unfished recruitment rates and about variability around assumed stock–recruitment relationships (Walters et al. 2004). The use of an age structure model utilized the information on life history parameters of the species; the inclusion of the age frequencies accounts for potential recruitment variabilities. Estimation of reference points such as unfished biomass (B0) or target biomass (BMSY) are estimated from the population model.

The model is implemented in the Stochastic_SRA function of the R package DLMtools (see Carruthers et.al. 2014 for the full description of the model). The model is age-structured with a maximum age of 12, and includes population processes such as recruitment, aging, natural- and fishing mortality. Most model parameters (e.g. growth, maturity, and natural mortality, etc.) varied as random variables across simulations, and were sampled from a uniform distribution with the lower and upper bounds detailed in Table 3. The parameter values are based on available information on life history parameters of longtail (IOTC Secretariat 2015, 2016). The Beverton-Holt stock recruitment relationship was assumed with a steepness parameter ranging from 0.3 to 0.9. Further stochasticity was introduced by allowing for both annual variability and time-varying trend for a number of parameters (Figure 5). For example, natural maturity was assumed to have an annual standard deviation ranging 0-0.1, and also vary between -5% and 5% from year to year. The population is assumed to reside in two areas: a fished area and a protected area (not subject to fishing). We further assumed that the fraction of the unfished biomass in the protected area ranges from 0.05 to 0.2, and the fish has an annual probability between 0.85 and 0.98 of remaining within the fished area (see Table 3).

The model was run from 1950 to 2015 with parameters sampled from the specified distribution, and only parameters that generate feasible population trajectories were retained. A population trajectory is considered to be feasible if it supports the known historical catches and if the difference between the expected age frequencies and observed length frequencies is below a pre-defined threshold value. The age frequencies are converted from the length frequency samples available at the IOTC Secretariat, 1985-2015. The numbers of fish in each age were determined by applying an age-length key to the length composition. The age-length key was derived by assuming an equilibrium population age-length structure based on an assumed natural mortality of 0.6, the average length-at-age from the longtail growth parameters and the standard deviation of length-at-age (CV 0.1). The converted age frequency has very few fish older than (Figure 6).

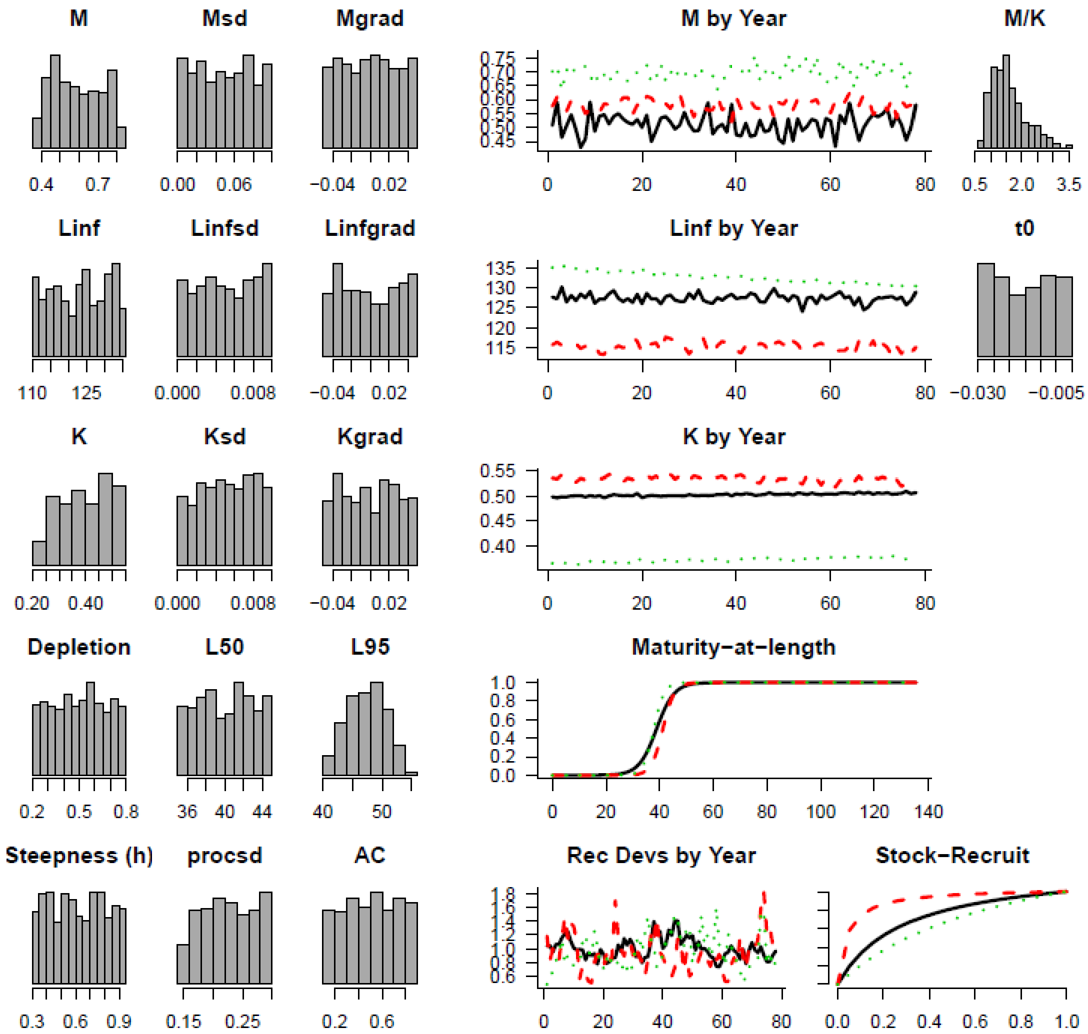

Figure 5: Distributions of input parameters used in the stochastic SRA analysis.

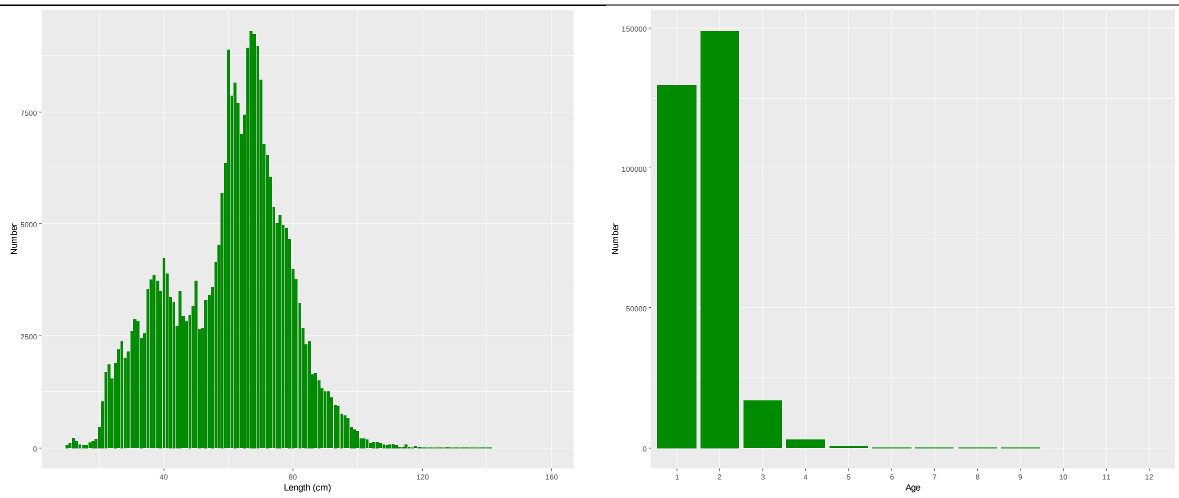

Figure 6: The aggregated length frequency of longtail (left), 1985-2015 from IOTC database and the converted age frequency (right).

Table 3: Parameters used for the stochastic stock reduction analysis of longtail. The parameters are sourced from IOTC Secretariat (2015, 2016).

Parameter	Value	Definition
maxage	12	The maximum age of individuals that is simulated
R0	1000	The magnitude of unfished recruitment (arbitrary scale-less)
M	0.38 – 0.82	Natural mortality rate
Msd	0–0.1	Inter-annual variability in natural mortality rate expressed as a coefficient of variation
Mgrad	(-0.05 – 0.05)	Mean temporal trend in natural mortality rate, expressed as a percentage change in M per year (uniform distribution)
h	0.3 – 0.95	Steepness of the stock recruit relationship (uniform distribution)
SRrel	1	Beverton-Holt SR relationship
Linf	110 – 135.4	Maximum length (uniform distribution)
K	0.23 – 0.55	von B. growth parameter k (uniform distribution)
t0	(-0.03– 0)	von B. theoretical age at length zero (uniform distribution)
Ksd	0 – 0.01	Inter-annual variability in growth parameter k (uniform distribution)
Kgrad	(-0.05 – 0.05)	Mean temporal trend in growth parameter k, expressed as a percentage change in k per year (uniform distribution)
Linfsd	0 – 0.01	Inter-annual variability in maximum length - uniform distribution
Linfgrad	(-0.05 – 0.05)	Mean temporal trend in maximum length, expressed as a percentage change in Linf per year (uniform distribution)
a	0.00002	Length-weight parameter alpha (uniform distribution)
b	2.83	Length-weight parameter beta (uniform distribution)
D	0.10–0.8	Current level of stock depletion (Bcurrent/Bunfished) (uniform distribution)
L50	35 – 45	Length-at- 50 percent maturity (uniform distribution)
L50_95	5 – 10	Length increment from 50 percent to 95 percent maturity
Perr	0.15–0.3	Process error, the CV of lognormal recruitment deviations (uniform distribution)
AC	0.1 – 0.9	Autocorrelation in recruitment deviations (uniform distribution)

Frac_area_1	0.05 – 0.2	The fraction of the unfished biomass in stock 1 (uniform distribution)
Prob_staying	0.85 –0.98	The probability of invividuals in area 1 remaining in area 1 over the course of one year (uniform distribution)

Results

C-MSY method

Figure 7 shows the results of the CMSY assessment for longtail. Table 4 provides a summary of the distributions of the key biological parameters across all feasible runs at all starting depletion levels. 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 a 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 331 000 – 709 279. 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. The biomass trajectory closely mirrors the catch curve with a slight increase in biomass in the early 2000s followed by a rapid decline.

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 8 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 Bmsy, and the lower left graph shows exploitation rate F relative to Fmsy. The lower-right panel shows the development of relative stock size (B/Bmsy) over relative exploitation (F/Fmsy).

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). Management quantities (estimated means and 95% confidence ranges) are provided in Table 7, which shows an average MSY of 144 000 t. The KOBE matrix plot indicates that based on the Catch-MSY model results, longtail is overfished (B2015/BMSY=0.94) and is subject to overfishing (F2015/FMSY = 1.00).

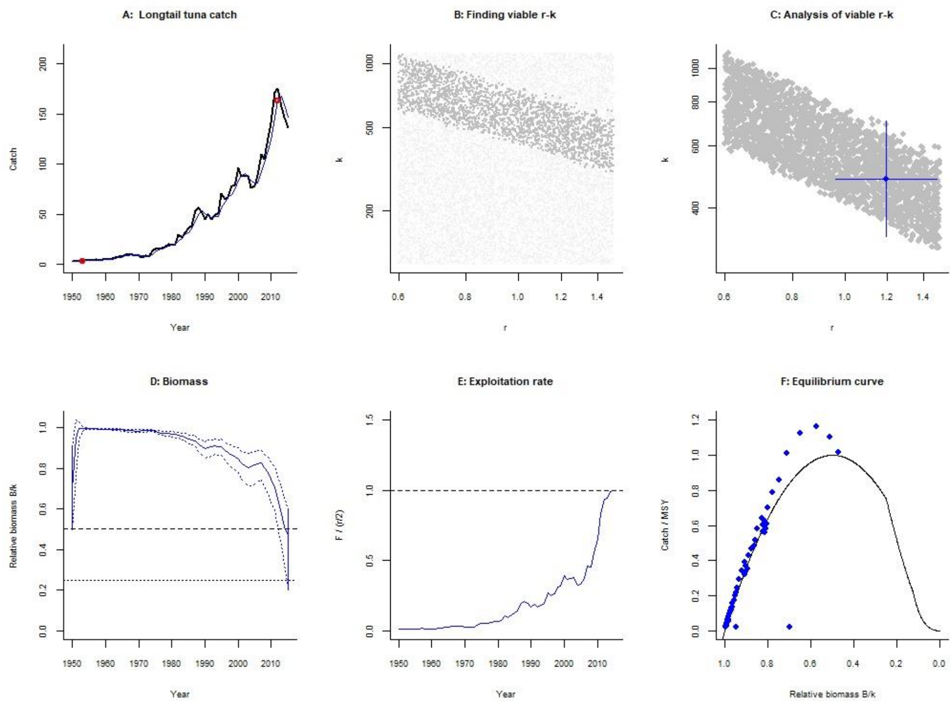

Figure 7. Results of CMSY analyses for longtail.

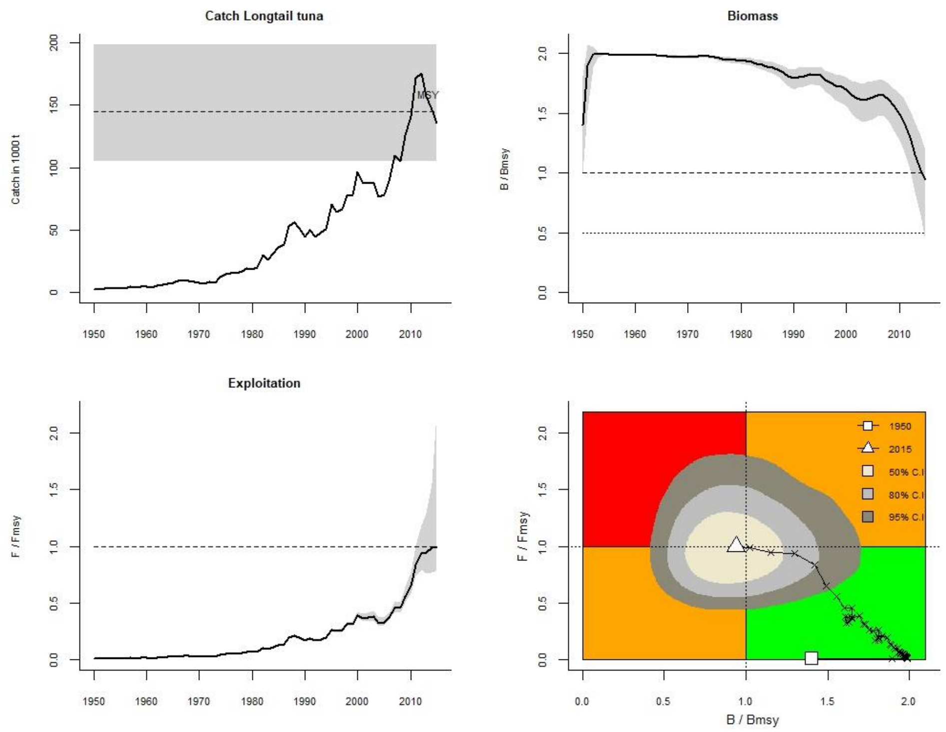

Figure 8. Graphical output of the CMSY analysis of longtail for management purposes.

Table 4: Key biological parameters (mean and 95% confidence intervals) from the C-MSY assessment assuming final depletion levels (0.2–0.6).

	K	r	Bmsy	Msy	Depletion
Estimate	484 (331 – 709)	1.2 (0.96 – 1.48)	242 (166 – 354)	144 (105 –198)	0.47 (0.22 – 0.60)

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}

Table 6. 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	2017
Most recent catch estimate (year)	160 532 t (2012)	159 312 t (2013)	146 750 t (2014)	136 849 t (2015)
Mean catch – most recent 5 years[4]	135 036 t (2008 – 2012)	142 101 t (2009 – 2013)	158 495 t (2010 – 2014)	157 493 t (2011 – 2015)
MSY (plausible range)	134 697	133 044	142 407	144 000 (105 000 –198 000)
Data period used in assessment	1950 – 2012	1950 – 2013	1950 – 2014	1950 – 2015
F_{MSY} (plausible range)	n.a	0.41	0.41	0.60 (0.48 - 0.74)
B_{MSY} (plausible range)	232 437	261 900	280 620	242 000 (166 000 – 354 000)
$F_{current}/F_{MSY}$ (plausible range)	1.08[5]	1.23	1.07	1.00 (0.79 – 2.19)
$B_{current}/B_{MSY}$ (plausible range)	1.12	0.92	0.94	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	0.46	0.47	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

[4] Data at time of assessment
[5] Arithmetic mean

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.

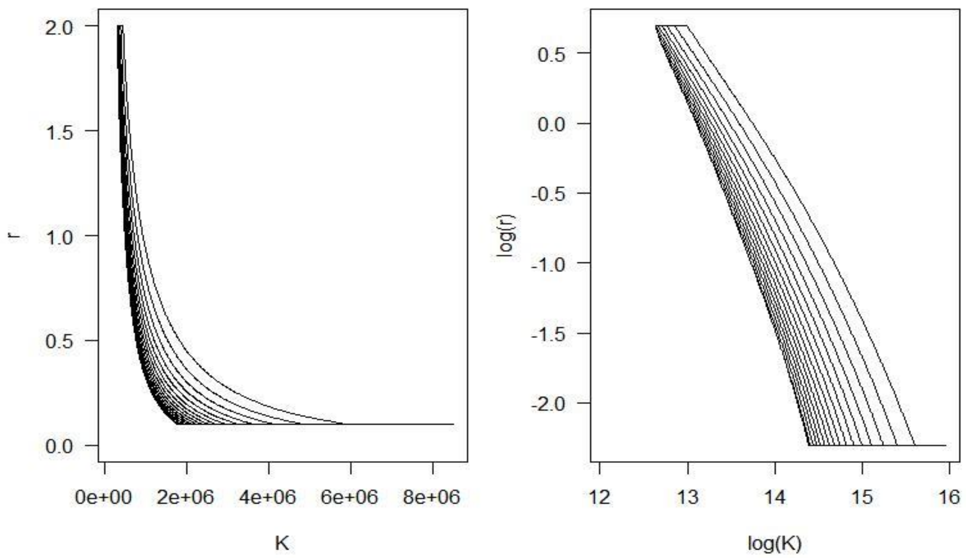

Figure 9. Initial plausible range of r and K values

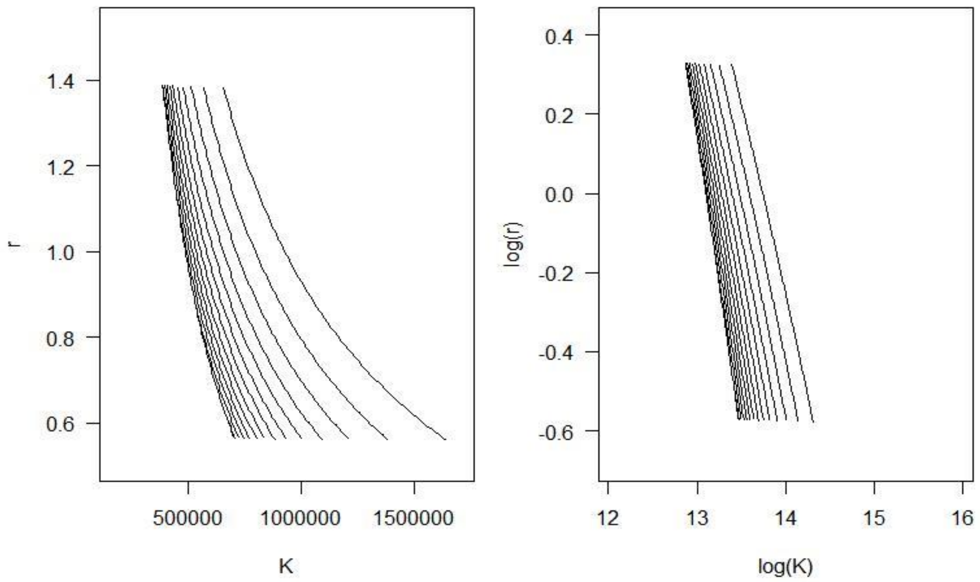

Figure 10. Plausible range of r and K with informative priors on r (0.56 – 1.39)

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.

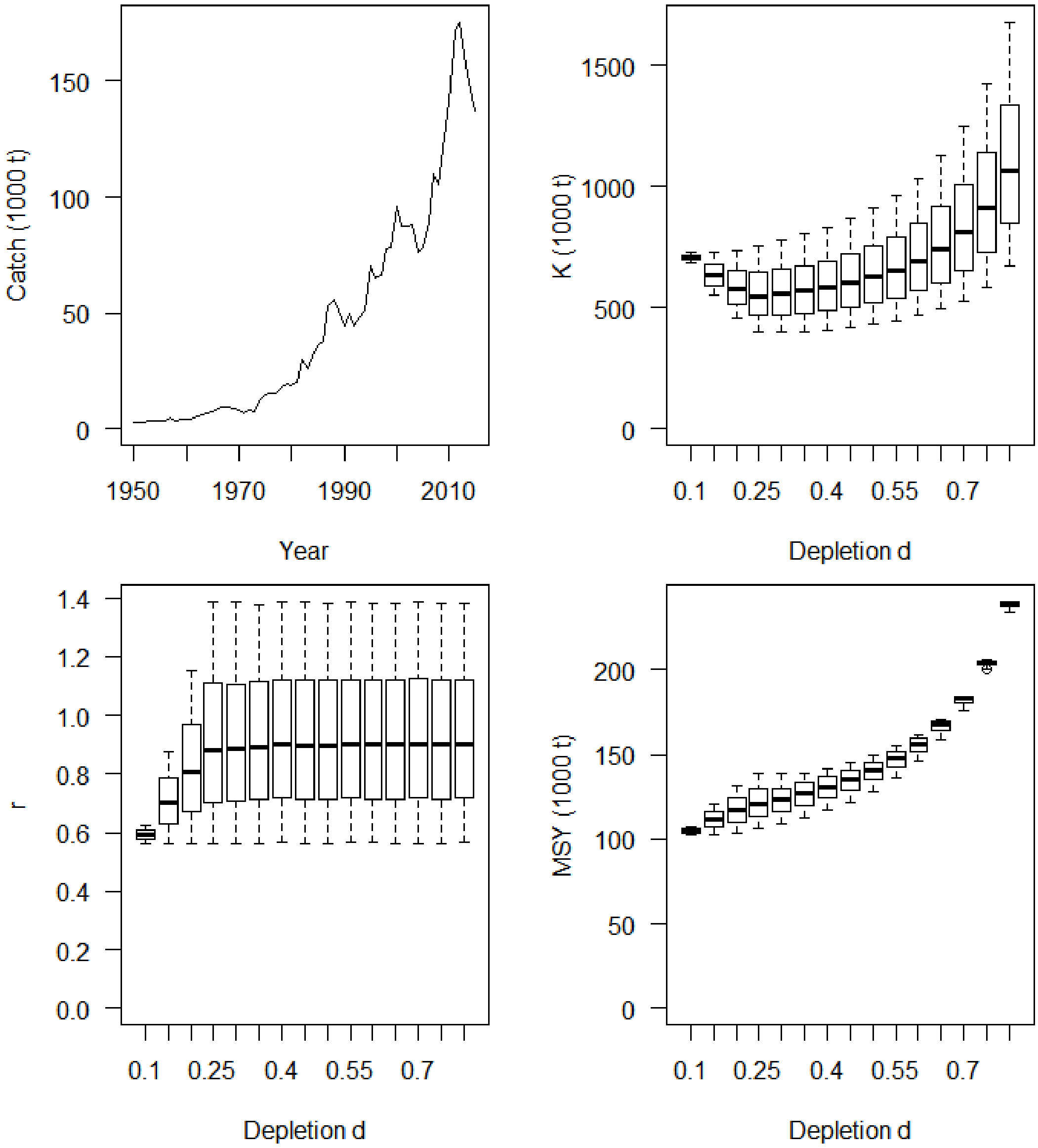

Figure 11. Longtail catch history, feasible carrying capacity, population growth rate and MSY at each assumed depletion level. There is no feasible solution when the depletion is assumed to be below 0.1.

Base case model results (for a maximum depletion level of 0.7) indicate that the biomass was approximately 630 000 t in 1950 and declined to approximately 300 000 t by 2015 (Figure 12). The estimated MSY associated with this projection is 138 000 t and ranges from approximately 100 000 t to 180 000 t based on the assumed maximum depletion level (Table 7).

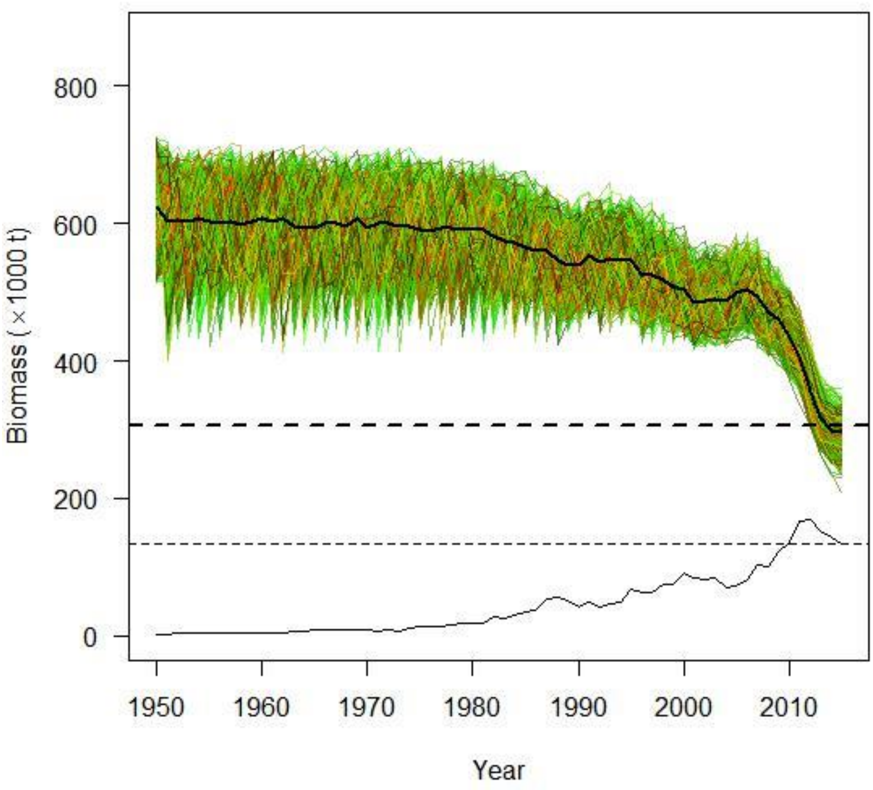

Figure 12. Longtail biomass trajectories from 500 simulations with upper depletion = 0.7.

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 (2015) (Figure 13). 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_{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. This projection predicts that the catch remains close to MSY, resulting in a stock biomass also very close to the B_{MSY} level (Figure 14).

Table 7. OCOM key biological parameters for longtail under four assumed upper depletion levels[6]

Upper d	Quantile	K	r	MSY	B_{2015}	D
0.8	0%	399,645	0.56	103,026	295,733	0.42
0.8	25%	551,149	0.70	128,329	354,257	0.52
0.8	50%	673,122	0.88	144,538	375,700	0.55
0.8	75%	826,927	1.10	178,830	399,222	0.58
0.8	100%	1,677,813	1.39	240,248	475,186	0.68
0.7	0%	399,645	0.56	103,026	214,567	0.34
0.7	25%	529,963	0.70	125,055	284,536	0.45
0.7	**50%**	**629,723**	**0.87**	**138,021**	**303,439**	**0.48**
0.7	75%	748,263	1.10	156,313	319,588	0.50
0.7	100%	1,245,555	1.39	183,977	370,313	0.59
0.6	0%	399,645	0.56	103,026	174,052	0.28
0.6	25%	509,591	0.70	121,903	227,176	0.37
0.6	50%	605,517	0.86	133,081	247,532	0.41
0.6	75%	713,881	1.09	143,747	264,580	0.43
0.6	100%	1,031,927	1.39	161,455	319,256	0.52
0.5	0%	399,645	0.56	103,026	102,532	0.17
0.5	25%	497,745	0.69	118,542	184,572	0.31
0.5	50%	591,442	0.85	128,264	201,467	0.34
0.5	75%	691,842	1.08	136,078	219,135	0.37
0.5	100%	910,276	1.39	149,380	269,552	0.45

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/ BMSY (Figure 16). While both of these projections result in a biomass which rapidly stabilises at the corresponding BMSY 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 2015 (136 8493 t) was similar to the estimated MSY (139 710 t), the outcome of these projections are fairly similar, with catches and predicted biomass close to the target levels over the short term.

[6] NB While K, R and MSY are derived from the optimisation model, B_{2015} 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.

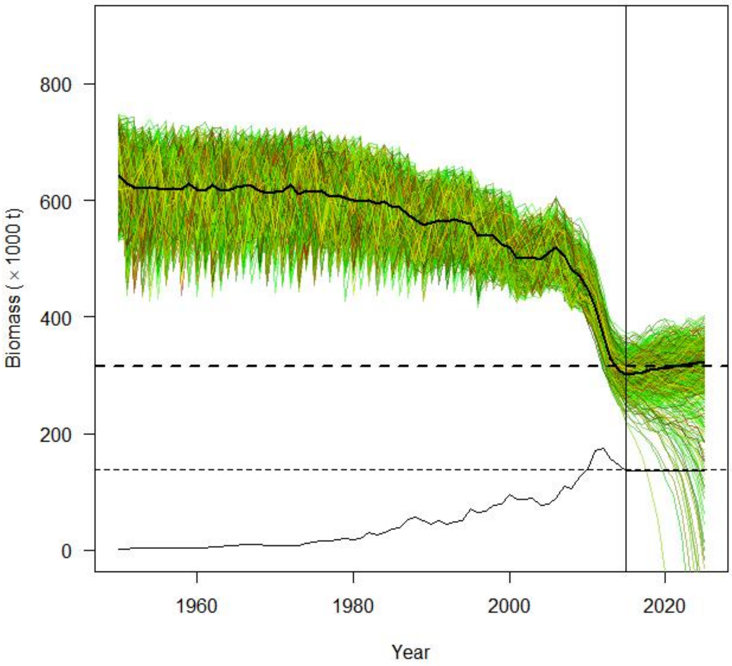

Figure 13. Projected longtail biomass trajectories under hypothetical annual catches equivalent to those of the final year (C_{2015}) until 2020. The vertical line is the last year for which catch data are available.

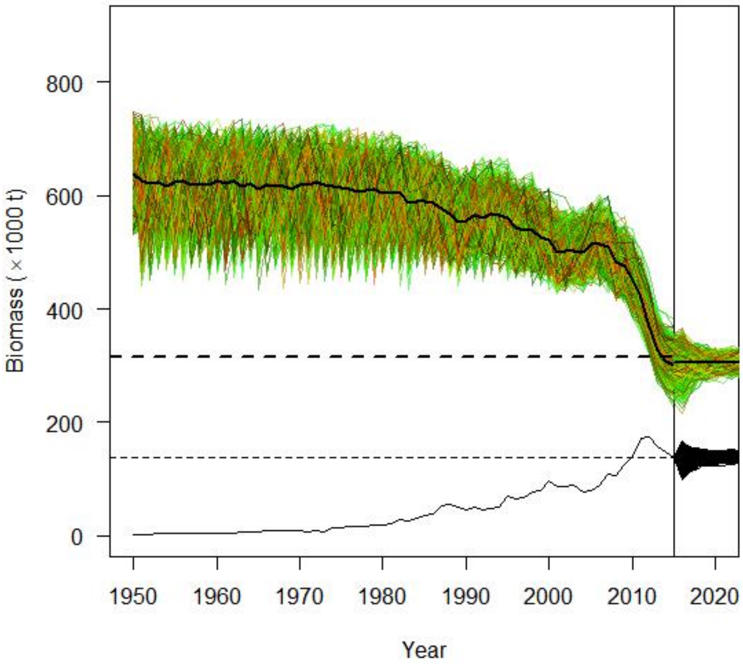

Figure 14. Projected longtail biomass trajectories under hypothetical annual catch rate (C_{2015}/B_{2015}) until 2020. The vertical line is the last year for which catch data are available.

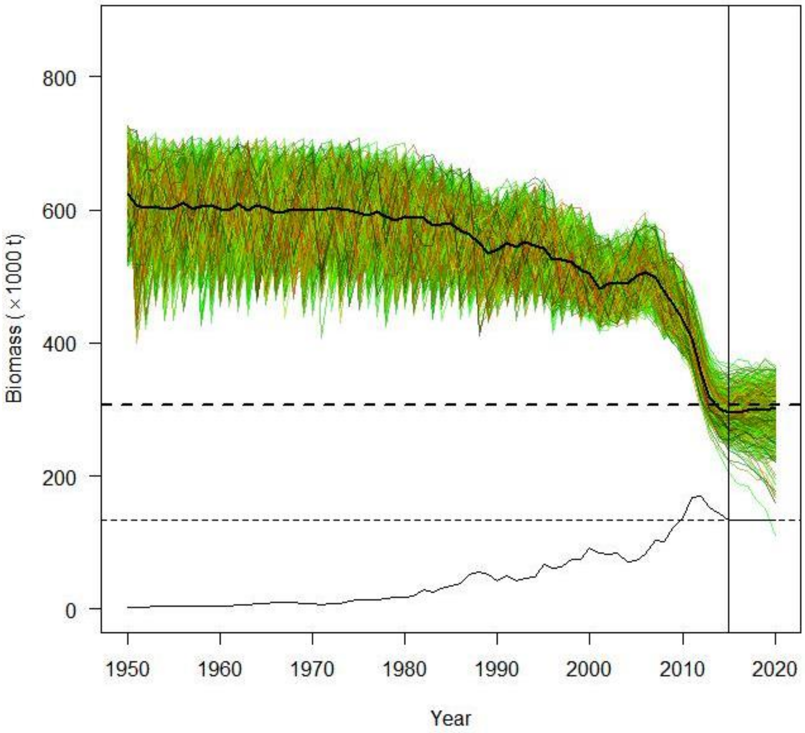

Figure 15. Projected longtail biomass trajectories under hypothetical future annual catch equivalent to MSY until 2020. The vertical line is the last year for which catch data are available.

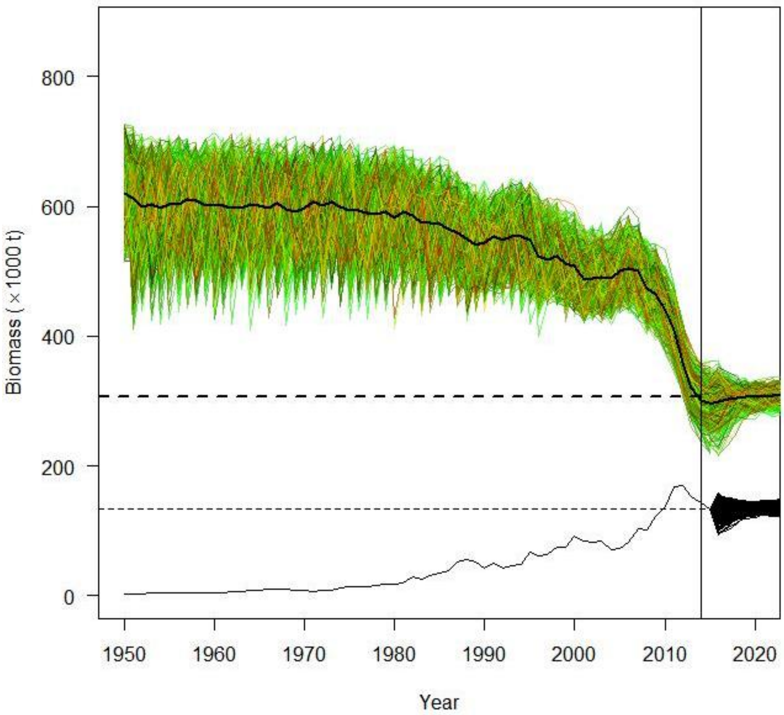

Figure 16. Projected longtail biomass trajectories under hypothetical annual catch rate at MSY level (MSY/B_{MSY}) until 2020. The vertical line is the last year for which catch data are available.

Management quantities based on geometric means and plausible ranges are provided in Table 8. The KOBE matrix plot based on the OCOM model results suggests that longtail is currently overfished (mean B_{2015}/B_{MSY} = 0.94) and subject to overfishing (mean F_{2015}/F_{MSY} = 1.04) (Figure 17).

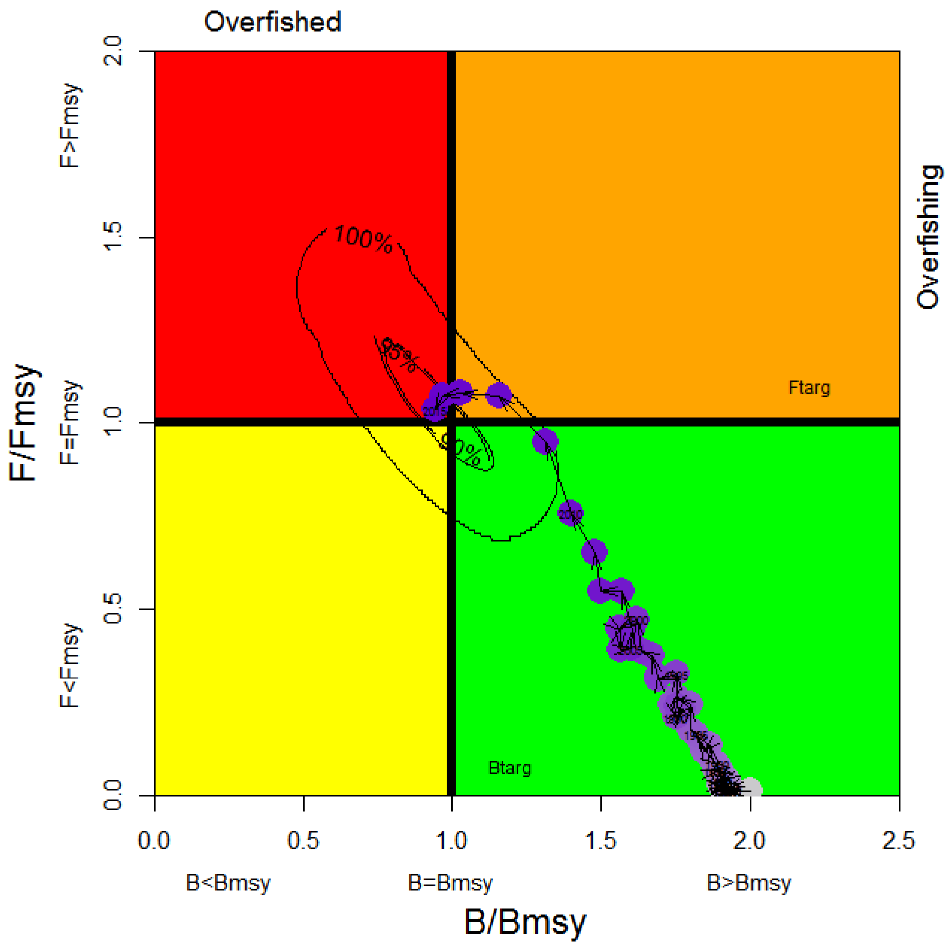

Figure 17. Longtail OCOM Indian Ocean assessment Kobe plot (all plausible model runs shown around 2015 estimate). Blue circles indicate the trajectory of the point estimates for the SB ratio and F ratio for each year 1950–2015. Target reference points are shown as B_{MSY} and F_{MSY}.

Table 8. 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	2017
Most recent catch estimate	164 537	160 532	159 313 t	146 751 t	136 849 t (2015)
Mean catch over last 5 years[7]	121 062	135 036	142 457 t	158 495 t	157 493 t (2011 – 2015)
MSY (plausible range)	123 840[8]	120 000[4]	137 687 t[9]	143 153 t[10]	139 710 t[11] (103 025 – 183 977)
Data period used in assessment	1950 – 2011	1950 – 2012	1950 – 2013	1950 – 2014	1950 – 2015
F_{MSY} (plausible range)	0.49	0.39	0.39	0.39	0.43 (0.28 – 0.69)
B_{MSY} (plausible range)	198 105	254 359	287 920	297 689	318 940 (199 822 –622 778)
$F_{current}/F_{MSY}$ (plausible range)	1.04	1.19	1.11	1.03	1.04 (0.84 – 1.46)
$B_{current}/B_{MSY}$ (plausible range)	1.25	1.08	1.02	0.99	0.94 (0.67 – 1.16)
$SB_{current}/SB_{MSY}$ (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	0.48 (0.34 – 0.59)
$SB_{current}/SB_0$ (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

[7] Based on the available data at time of assessment
[8] Median values shown
[9] median = 134 000
[10] median = 140 326
[11] median = 138,021

Stochastic SRA

Results from the Stochastic SRA are shown in Figure 18 and Figure 19. Three hundred simulations were carried out, and a small number of samples were excluded as they have resulted in a stock status in the final year less than 10% of the unexploited level. Estimated selectivity reaches the maximum at age 2. Estimates of recruitment deviations appear very noisy and show a strong pulse in 1988, corroborating a strong year class of one-year old in the observed age frequency. The predicted age distributions are dominated by one and two years olds, but older fish are also evident.

Estimates of management quantities are shown in Table 10. The average MSY is estimated to be 130 240 t, slightly lower than the current catch. Spawning biomass in 2015 is estimated to be 2% higher than Bmsy. These estimates are reasonably close to the C-MSY method. However the estimate of current fishing pressure appears too high (F2015/FMSY = 3.27), and has very large uncertainty (Figure 20). The reason is not clear. Kolody et al. (2011) found that Fmsy may not be estimated well for short lived species possibly due to unusual stock dynamics, and suggested using catch / MSY as a proxy for F/Fmsy. The catch in 2015 is estimated to be about 4% higher than MSY, but is well within the plausible range of MSY estimates.

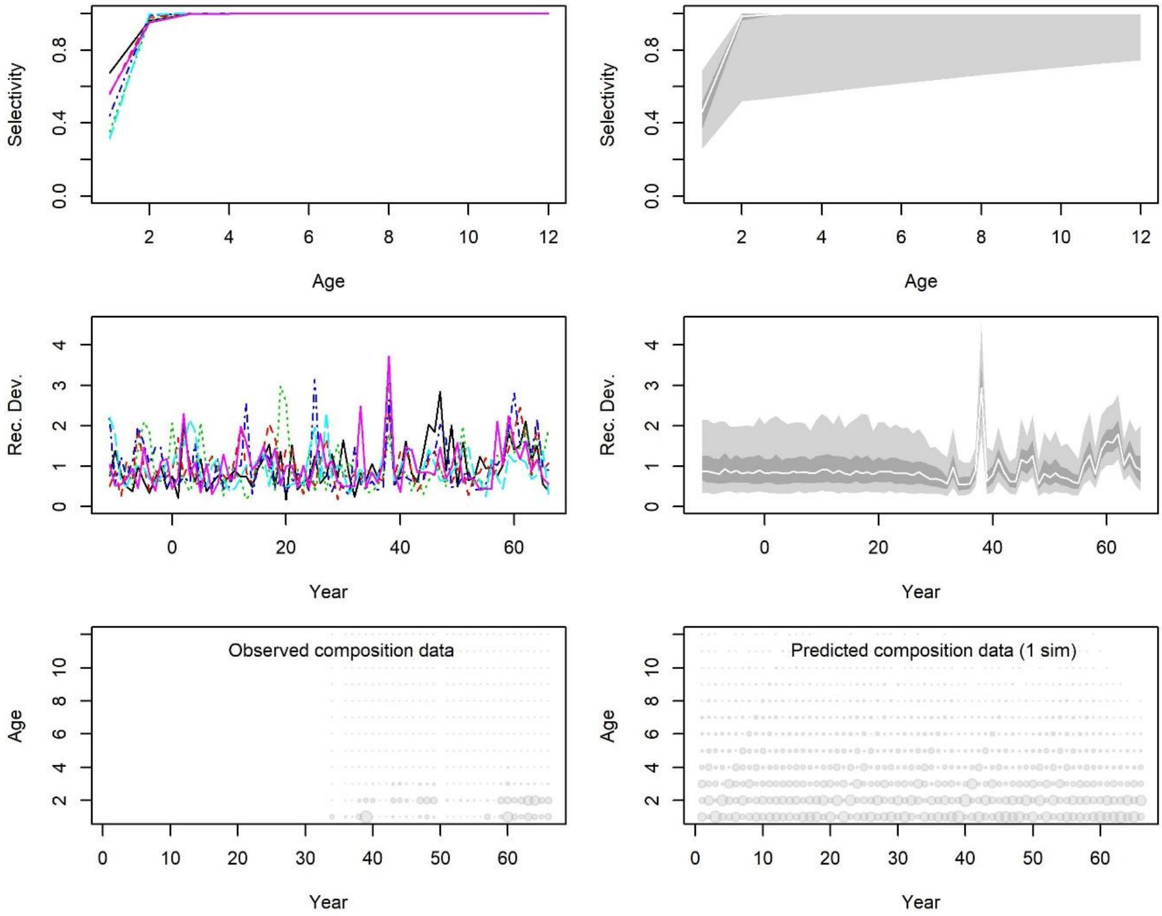

Figure 18: Estimates of age-based selectivity (1st row) and annual recruitment deviation (2nd row) from Stochastic SRA. The left panel shows realisations from 3 samples, and the right panel shows the median and 90% quantile. The third row shows the observed (left) and predicted (right) age frequencies.

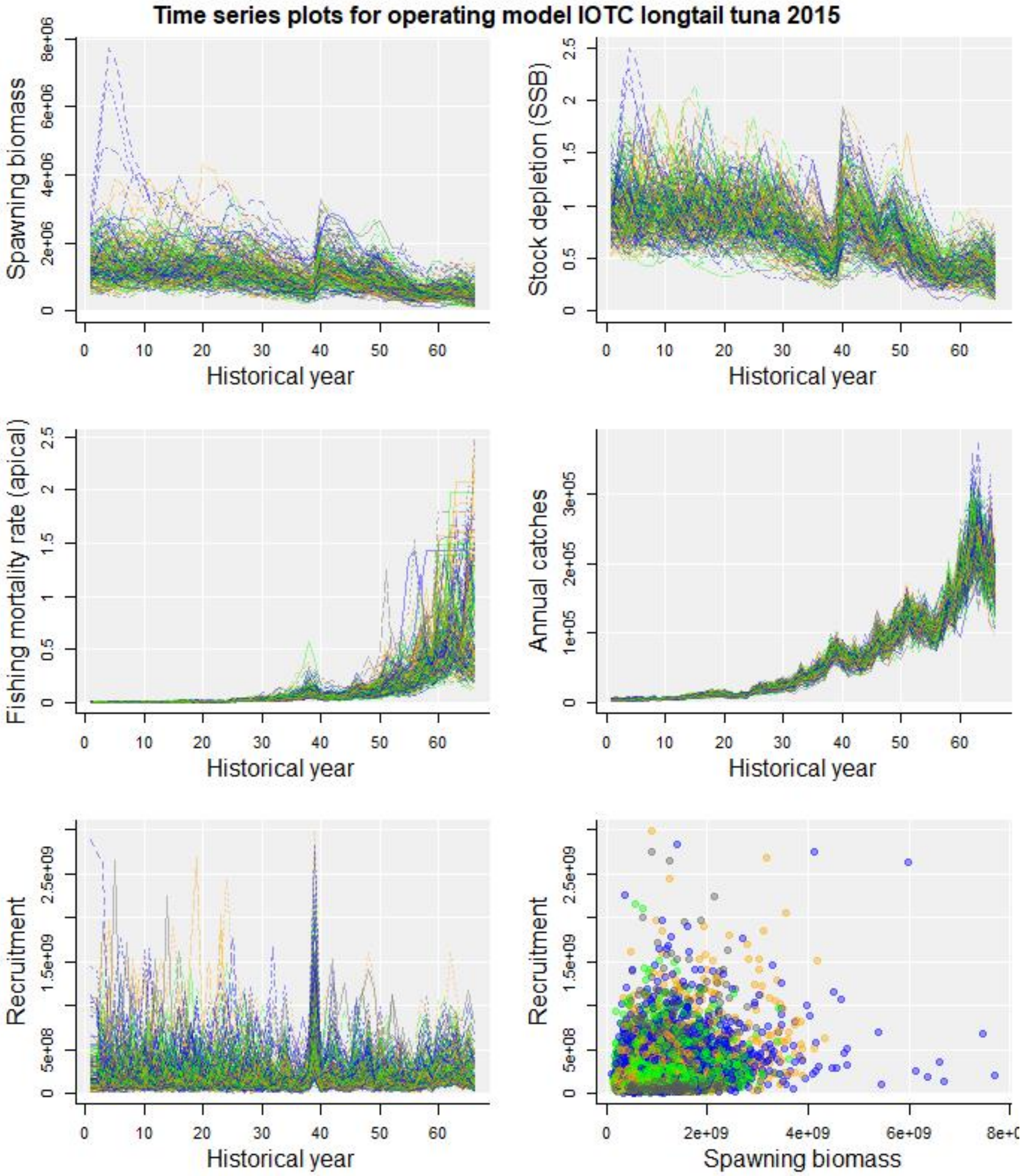

Figure 19: Predictions from the Stochastic SRA including feasible spawning biomass trajectories, depletion, fishing mortality, and annual recruitment estimates.

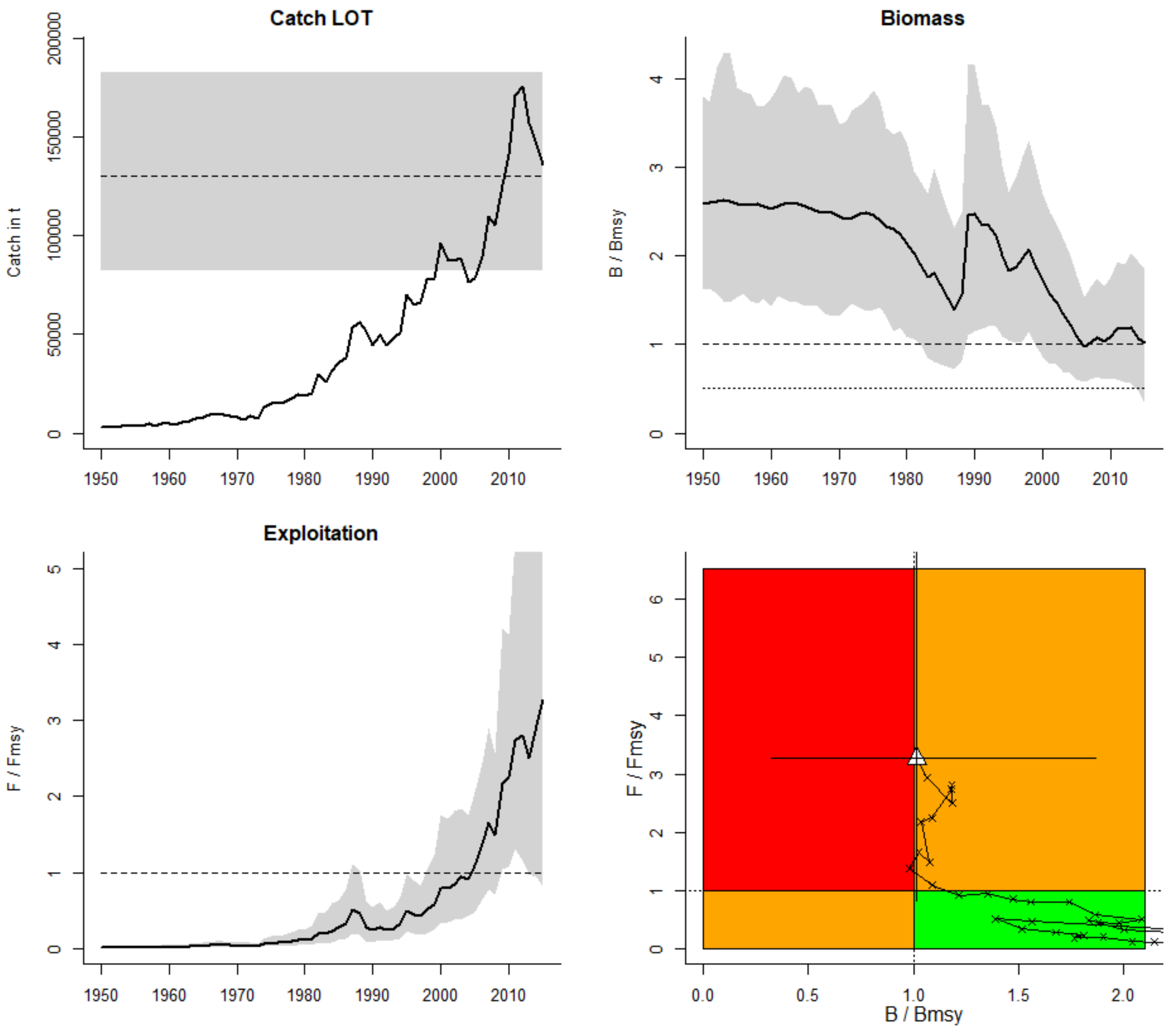

Figure 20: Management quantities of stochastic SRA.

Table 9: **Management quantities from the Stochastic SRA for Indian Ocean longtail tuna, means and 95% confidence interval.**

Management Quantity	**2017**
MSY (95% CI)	130 240 t (75 974 – 190 475)
Data period used in assessment	1950 – 2015
F_{MSY} (95% CI)	0.25 (0.10 – 0.40)
B_{MSY} (95% CI)	561 691 t (308 737– 822 471)
$F_{current}/F_{MSY}$ (95% CI)	3.27 (0.82 – 6.69)
$C_{current}$/MSY (95% CI)	1.04 (0.71 – 1.79)
$SB_{current}/SB_{MSY}$ (95% CI)	1.02 (0.32 – 1.86)
$SB_{current}/SB_0$ (95% CI)	0.39 (0.12 – 0.60)

Discussion

All three models, C-MSY, OCOM and stochastic SRA, provided relatively similar estimates of MSY, with mean estimates of approx. 144 000 t, 140 000 t and 130 000 t respectively, with the highest estimate produced by the C-MSY method (Table 10). The estimates produced by the C-MSY and OCOM methods are also similar to previous assessment estimates (Table 6 and Table 8) (Zhou and Sharma, 2013; Zhou and Sharma, 2014; Martin and Sharma, 2015). Reported catches decreased between 2012 and 2015 from 175 459 to 136 856 t, and so the current catch is below the C-MSY and OCOM estimates of MSY, but remains above the stochastic SRA estimate.

Table 10. Key management quantities from the Catch-MSY and OCOM[12] assessments for Indian Ocean longtail tuna. Geometric means are provided (with plausible ranges across all feasible model runs). n.a. = not available.

Management Quantity	C-MSY	OCOM	Stochastic SRA
Most recent catch estimate (2015)	136 849 t	136 849 t	136 849 t
Mean catch 2011–2015	157 493 t	157 493 t	157 493 t
MSY	144 000 (105 000 – 198 000)	139 710 t (103 025 – 183 977)	130 240 (75 974 – 190 475)
Data period used in assessment	1950 – 2015	1950 – 2015	1950 – 2015
F_{MSY}	0.60 (0.48 - 0.74)	0.43 (0.28 – 0.69)	0.25 (0.10 – 0.40)
B_{MSY}	242 000 (166 000 – 354 000)	318 940 (199 822 –622 778)	561 691 (308 737–822 471)
$Catch_{2015}/MSY$	–	–	1.04 (0.71 – 1.79)
F_{2015}/F_{MSY}	1.00 (0.79 – 2.19)	1.04 (0.84 – 1.46)	3.27 (0.82 – 6.69)
B_{2015}/B_{MSY}	0.94 (0.43 – 1.19)	0.94 (0.67 – 1.16)	–
SB_{2015}/SB_{MSY}	–.	–	1.02 (0.32 – 1.86)
B_{2015}/B_0	0.47 (0.22 - 0.60)	0.48 (0.34 – 0.59)	–
SB_{2015}/SB_0	–	–	0.39 (0.12 – 0.60)
$B_{2015}/B_{0,\ F=0}$	–	–	–

Results suggest that the stock is still likely to be subject to overfishing with all models producing a F_{2015}/F_{MSY} ratio above 1.00. This ratio has been decreasing over the last few years, reflecting the recent decline in catches (Table 6 and Table 8). Nevertheless, estimates of the B_{2015}/B_{MSY} ratio have remained similar, given that the average catches over the last 5 years (157 000 t) have been higher than all estimates of MSY. These stock status predictions across the three models suggest that the stock is considered to be '*subject to overfishing'* and the C-MSY and OCOM models suggest it is also '*overfished*' while the stochastic SRA suggests it is *'not overfished*'.

[12] 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 are based primarily on the catch data and an underlying Schaefer model, an alternative assessment method using different data and alternative assumptions were used to explore the status of the stock further. The Stochastic SRA attempted in this report used a more realistic population dynamic model, utilizing available life-history parameters of the species and fishery data beyond catch series. Therefore it may represent an improvement over the catch-MSY method which is based on a simpler model and uses catch data only. However, estimates of management quantities using this approach currently are highly uncertain, therefore may not be useful for providing management advice. The model relies on information on key population parameters such as growth, maturity, and growth, most of which are highly variable, as the estimates were based on a number of independent studies that have taken place in particular regions for particular time periods. The model included age frequencies (converted from length frequencies) to estimate variability of annual recruitment and to condition feasible population estimates, therefore requires these data to be representative of the age/size structure of the population. The length data in the IOTC database for longtail were known to be highly incomplete: the data were available only for selected fisheries, total numbers of samples vary across all years, are also well below the minimum sampling standard recommended by the IOTC Secretariat.

References

Charnov, E.R., Gislason, H., & Pope, J.P. 2013. Evolutionary assembly rules for fish life histories. Fish and Fisheries. 14: 213-224.

Carruthers, T.R., Punt, A.E., and Walters, C.J. et al. (2014). Evaluating methods for setting catch limits in data-limited fisheries. Fisheries Research 153, 48–68.

Froese, R. & Pauly, D., 2015. Fish Base.

Froese, R., Demirel, N., Caro, G., Kleisner, K.M. and Winker, H., 2016. Estimating fisheries reference points from catch and resilience. Fish and Fisheries, 18 (3). pp. 506-526. DOI 10.1111/faf.12190.

Gislason, H., Daan, N., Rice, J.C. and Pope, J.G. (2010). Size, growth, temperature, and the natural mortality of marine fish. Fish and Fisheries 11, 149–158.

Ghosh, S., Pillai, N.G.K. & Dhokia, H.K., 2010. Fishery, population characteristics and yield estimates of coastal tunas at Veraval. *Indian Journal of Fisheries*, 57(2), pp.7–13.

Hoenig, J.M. 1983. Empirical use of longevity data to estimate mortality rates. Fishery Bulletin 82: 898–903.

IOTC Secretariat, 2015. Population parameters: Longtail tuna (*Thunnus tonggol*). Working Party Paper, IOTC-2015-WPNT05-DATA13.

Itoh, T., Yuki, Y. & Tsuji, S., 1999. Spawning possibility and growth of longtail tuna, Thunnus tonggol, in the water around Japan. *Bulletin of the National Research Institute of Far Seas Fisheries*, 0(36), pp.47–53.

Jensen, A.L. 1996. Beverton and Holt life history invariants result from optimal tradeoff of reproduction and survival. Can. J. fish. Aquat. Sci. 53, 820-822.

Kimura, D.K., and Tagart, J.V. 1982. Stock reduction analysis, another solution to the catch equations. Can. J. Fish. Aquat. Sci. **39**: 1467–1472.

Kolody, D., M. Herrera and J. Million. 2011. 1950-2009 Indian Ocean Skipjack Tuna Stock Assessment (Stock Synthesis). IOTC-2011-WPTT-14(Rev1).

IOTC Secretariat, 2016. Longtail tuna supporting information for the 6th Session of the IOTC Working Party on Neritic Tunas. 2016.

Martell, S. and Froese, R. 2012. A simple method for estimating MSY from catch and resilience. Fish and Fisheries. 14: 504–514.

Martin, S. and Sharma, R. 2015. Assessment of Indian Ocean longtail tuna (*Thunnus tonggol*) using data poor catch-based methods. IOTC-2015-WPNT05-22.

Martin, S. and Robinson, J. 2016. Assessment of Indian Ocean longtail tuna (*Thunnus tonggol*) using data poor catch-based methods. IOTC-2016-WPNT06-17_Rev_1.

Pauly, D. 1980. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. J. Cons. Int. Explor. Mer: 175-192.

Geehan, J., Pierre, L., and Fiorellato, F. 2016. Review of the Statistical Data Available for Bycatch Species. *IOTC-2016-WPNT06-07.*

Walters, C. Martell, S., and Korman, J. 2006. A stochastic approach to stock reduction analysis. Can. J. Fish. Aquat. Sci. 63: 212-223.

Schaefer, M.B. 1954. Some aspects of the dynamics of populations important to the management of commercial marine fisheries. Bulletin, Inter-American Tropical Tuna Commission 1:27-56.

Then, A. Y., Hoenig, J. M., Hall, N. G., and Hewitt, D. A. 2014. Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species. – ICES Journal of Marine Science, doi: 10.1093/icesjms/fsu136.

Yesaki, M., 1989. Estimates of age and growth of kawakawa (*Euthynnus affinis*), longtail tuna (Thunnus tonggol) and frigate tuna (Auxis thazard) from the Gulf of Thailand based on length data. IPTP-89-GEN-17 -AUG_1, Indo-Pacif, p.Development Management Programme.

Zhou S.J., Yin S.W., James T.T., Anthony D.M.S., and Michael F. (2012) Linking fishing mortality reference points to life history traits: an empirical study. Canadian Journal of Fisheries and Aquatic Science 69, 1292-1301. doi:10.1139/F2012-060.

Zhou, S., Pascoe, S., Dowling, N., Haddon, M., Klaer, N., Larcombe, J., Smith, A.D.M., Thebaud, O., and Vieira, S. 2013. Quantitatively defining biological and economic reference points in data poor and data limited fisheries. Final Report on FRDC Project 2010/044. Canberra, Australia.

Zhou, S., Chen, Z., Dichmont, C.M., Ellis, A.N., Haddon, M., Punt, A.E., Smith, A.D.M., Smith, D.C., and Ye, Y. 2016. Catch-based methods for data-poor fisheries. Report to FAO. CSIRO, Brisbane, Australia.

Zhou, S. and Sharma, R. 2013. Stock assessment of two neritic tuna species in Indian Ocean: kawakawa and longtail tuna using catch based stock reduction methods. IOTC Working Party Paper. IOTC–2013–WPNT03–25.

Zhou, S. and Sharma, R. 2014. Stock assessment of neritic tuna species in Indian Ocean: kawakawa, longtail and narrow-barred Spanish mackerel using catch based stock reduction methods. IOTC Working Party Paper. IOTC–2014–WPNT04–25.