Stock status of Longtail tuna (*Thunnus tonggol*) in the Indian EEZ with conservation and management measure advisories.

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Introduction

Longtail tuna, *Thunnus tonggol*, one among the eight 'minor' or 'neritic' tunas found in tropical seas in the Indo-Pacific of late have become among the main market tunas in some regions leaving behind Albacore (*Thunnus alalunga*) and the big eye (*Thunnus obesus*) (Recio *et al*., 2022. Major fishing nations for longtail are Iran (42%), Indonesia (19%), Oman (12%) and Pakistan (11%), accounting for more than 80% of the total reported landings. Malaysia and India are the two other countries that contribute substantially to the landings of longtail tuna in the Indian Ocean (IOTC, 2021b).

Tunas form a major commercial resource in the India's EEZ with good catches being recorded along east and west coasts as well as the island territories. In 2014, an estimated 88,840t (IOTC-2015) of tunas were landed along the Indian coast. Neritic tunas constituted the bulk (65.2%) of the tuna landing in India with *Euthynnus affinis (41.8%)* being the dominant species followed by *T tonggol* (12.5%) (IOTC-2015). Andhra Pradesh, Tamil Nadu and Gujarat are the major states landing neritic tunas. The longtail tuna (*Thunnus tonggol*) is one of the six species of neritic tuna under IOTC management (Herrera, *et al*., 2009) and formed 12.5% of the total tuna and 17.81% of the neritic tuna landings with Gujarat and Maharashtra together contributing 94.3% of the longtail landing in India (IOTC-2015).

Studies on the population parameters and stock status of the tunas had largely been centered on the principal tunas like the skipjack (*Katsuwonus pelamis*), Yellowfin (*Thunnus albacares*) and the coastal tunas like the Kawakawa (*Euthynnus affinis*), Bullet tunas (*Auxis* spp). Recent information on the population parameters and stock assessment of the longtail tuna in India has been limited to the works by Ghosh *et al.*(2010), Abdussamad *et al.* (2012) and Vinod *et al.* (2017). However, except for Vinod *et al.* (2017), there had not been any exclusive study on the population dynamics and stock status of longtail tuna in its major ground in India *i.e.*, the north-west coast of India.

Pillai and Ganga (1985), while studying the overall fishery and biology of tunas in the Indian Seas, reported that the growth parameters of the species along Veraval Coast were:

L_∞=102.5 cm, K=1.05 year^{-1} and t_0=-0.0092 years. The natural mortality (M) was 1.31 year^{-1}, total mortality (Z) was 6.14 year^{-1} and fishing mortality (F) was 4.83 year^{-1} with the exploitation ratio estimated to be at 0.7. The fishery, population characteristics and yield estimates of coastal tunas *T. tonggol, E. affinis* and *A. thazard* at Veraval waters was studied during 2003–2006 by Ghosh *et al*. (2010). The study reported allometric growth, with VBGF growth equation as $L_t = 107.4\ [1 - e^{-0.18\ (t + 0.0729)}]$ for longtail tuna. The mortality parameters M, F and Z were 0.4, 0.72 and 1.12 year^{-1}, respectively with exploitation ratio of 0.64. The study also indicated overexploitation of longtail tuna along the Veraval coast. However, Abdussamad *et al*. (2012a) studied the fishery, biology and population characteristics of longtail tuna landed along the Indian coast during 2006-2010, stated growth pattern to be isometric with equation W=0.0147 $L^{3.01}$. The size at first maturity was reported to be 51.1 cm, with bimodal peak in recruitment. The growth parameters L_∞, K and $t_0$estimated for the species were123.5 cm, 0.51 year^{-1} and -0.0319 years respectively. Natural mortality (M) was estimated at 0.77with total mortality (Z) and fishing mortality (F) at 3.72 and 2.94 year^{-1}. Vinod*et al*. (2017) studied growth, age and mortality of *T. tonggol* exploited along the northwest coast of India with the data collected during 2004-2012, wherein length of fishes ranged between 22 and 86 cm and the weight between 150 and 6,250 gms. Growth parameters estimated for L_∞, K and $t_0$were 98.65 cm, 0.39 year^{-1} and -0.34 years, respectively. The natural mortality (M), fishing mortality (F) and total mortality (Z) were estimated as 0.49, 0.73 and 1.22 year^{-1}, respectively. The length weight relationship equation was W=0.0538 $L^{2.65}$, whereas M/K ratio was 1.8 and F/Z was 0.42.

There have been few studies on the population dynamics and stock assessment of longtail tuna elsewhere in the world. The recent ones being that by Kaymaran *et al*,(2013) for the Persian Gulf and Oman Sea, Ahmeda *et al*, (2016) for the Arabian Sea off Pakistan, Hassadee *et al* (2014) for Gulf of Thailand, Hassadee *et al* (2014), Andaman Sea, Griffith *et al*, (2010) for the Australian waters. A summary on the findings of all earlier studies is provided in the Table 1. A comprehensive assessment of the stock of longtail tuna in the Indian Ocean has not been made by IOTC so far, mainly owing to the paucity of standardized catch and effort data from all the sub regions. Basin scale assessment of the stock of the longtail tuna in the Indian Ocean have been limited to few assessments based on data poor methods as suggested by by Zhou and Sharma, (2013), Zhou and Sharma, (2014) and Martin and Sharma (2015). The IOTC-2016 recently updated the stock assessment of longtail using Catch-MSY (Kimura and Tagart 1982; Walters *et. al*. 2006; Martell and Froese 2012) and Optimised Catch Only

Methods (OCOM) (Zhou et al., 2013) methods. The results of the assessments indicated that the stock is being fished at MSY levels and higher catches could not be sustained and therefore advised adoption of a precautionary approach in management of the longtail resources. The earlier assessment of longtail tuna by IOTC in 2015, using the surplus production model (ASPIC) also indicated that the stock is being over fished and subject to overfishing.

Material and methods

Stock Assessment

Samples for the biological studies were drawn from gillnet landings at Veraval, Mangrol and Porbander landing centers on fortnightly during 2013 to 2016 basis following the multi-stage stratified random sampling design (Srinath *et al.*, 2005). Samples were transported to the Veraval Regional Center of CMFRI in preserved condition for further detailed analysis. The length-weight relationship of longtail tuna was estimated in standard form, $W= aFL^b$ as described in Le Cren (1951).

Estimation of Biological Reference Points

The biological reference points (BRPs) for longtail tuna off Gujarat were estimated using three methodologies: the Analytical Model (Yield per recruitment model by Thompson & Bell, 1934), biomass-based models (Schaefer (Schaefer, 1954) and CMSY (Froese *et al.*, 2017) models). Catch and effort data of longtail tuna collected by the Fisheries Resources Assessment Division of the Central Marine Fisheries Research Institute (CMFRI) (see Chapter 2) was used in the current assessment.

Per-recruit analyses

The Thompson and Bell bio-economic model (Thompson & Bell, 1934), using length-based data, was used to assess the impact of change in fishing mortality on yield, both in terms of biomass and economics. Relative yield-per-recruit (Y'/R) and biomass-per-recruit (B'/R) at different levels of fishing mortality were obtained from the estimated growth parameters and probabilities of capture by length (Pauly and Soriano, 1986). The estimates were made using FiSAT II (Knife-edge selection).

Surplus Production Model

The surplus production model of Schaefer (1954) was a second model used to estimate the status of the longtail tuna stock. The model is represented as:

$$\frac{dB_t}{dt} = rB_t\left(1 - \frac{B_t}{C}\right) - F_tB_t$$

where B_t is the biomass at time *t* (year), *r* is the intrinsic rate of increase of the stock, *C* is the carrying capacity, and F_t is the fishing mortality rate for age class t. The recursive expressions for calculating biomass and yield given by Prager (1994), based on the model parameters initial biomass B_0, carrying capacity, *C*, intrinsic growth rate *r*, and catchability coefficient *q* using time series data on catch and catch per unit effort, were followed in this study. The catch and catch per unit effort are the key input parameters in the surplus production models for the estimation of stock reference points. In situations of multi-species and multi-gear fishery, it is essential that we use the standardised catch per unit effort as input parameter. In this case, standardization of fishing effort was done following the weighted CPUE method (Kurup & Devaraj, 2000). The fishing mortality and biomass at MSY (F_{MSY} and B_{MSY}) were estimated as:

$$\text{MSY} = \frac{Kr}{4}; \quad B_{MSY} = \frac{K}{2}; \quad F_{MSY} = \frac{r}{2}; \quad f_{MSY} = \frac{r}{2\text{q}}$$

MSY was considered a limit reference point for the stock in the current assessment. MSY was estimated by the Schaefer model using a time series catch and standardised CPUE as input data. Fishing effort data were standardized before calculating catch per unit effort. Model fit was validated using significant impact (p<0.05) and R^2 values.

CMSY

CMSY is a Monte-Carlo method that estimates BRPs (MSY, F_{MSY}, and B_{MSY}) as well as relative stock size (B/B_{MSY}) and exploitation (F/F_{MSY}) from catch data and priors for resilience and stock status at the beginning and end of the time series. Analysis of the catch data of longtail tuna from 1985 to 2016 was done using CMSY method of Froese *et al.* (2017) using the version CMSY_O_7q.R in R software (version 3.4.1) to derive values for BRPs. The model is especially useful in estimation of stock of data-deficient fisheries as it uses an advanced Bayesian state-space implementation of the Schaefer surplus production model (BSM) fitted to catch and biomass or CPUE data. The main advantage of BSM over other implementations of surplus production model is the focus on informative priors and the ability to use short and/or incomplete data priors (Froese *et al.*, 2017). Thus, BSM methods were applied along with the CMSY using standardised catch per unit effort available for the period 2006-16 as the abundance information.

Preliminary analysis was done keeping the default prior values for initial, intermediate and final relative biomass values. The resilience (r) was kept as high following Froese & Pauly, (2018). Default values were maintained for the virgin biomass (k) and catchability coefficient (q). The analysis revealed that the catch data was reliable only from 1991 to 2016 as the catches steeply increased from 1991 onwards. The default prior relative biomass for initial, intermediate and final was medium, medium and low respectively. The initial prior relative biomass set by the default rules wasn't agreeable as the values were kept medium exploitation level while the fishery wasn't optimally exploited. Default values set for the intermediate was reasonable as the year 2012 witnessed high catches. The suggested final prior relative biomass was agreeable as the catches in the final year have fallen even below the average for 1990-2016 indicating very low biomass. Taking cues from the first analysis, the catch data for the period 1991 to 2016 was analysed in the final analysis choosing higher (0.5-09) initial prior relative biomass and lower (0.01-0.4) final prior relative biomass following Froese *et al.* (2017) while maintaining the default intermediate relative biomass.

Biological Reference Points using Analytical Model (Thompson & Bell)

Results revealed that the fishing mortality rate produced from the present effort level (2016) is producing an equilibrium yield of about 6,255 t and economic return of about 717 million rupees. The virgin stock biomass (12,921 t) and the spawning stock biomass (4,402 t) were at 51.55% and 18.54%, respectively. In theory, these results indicate that effort may be increased by 2.8 times of the present level to reach MSY, which would result in a yield of 6,640 t (Fig. 5.10). However, such an increase in fishing effort will decimate the virgin stock biomass (B_0) and virgin spawning stock biomass (SSB_0) to as low as 37.85% and 5.95% respectively which could be detrimental for the long-term sustainability of the resource. Moreover, the increase in yield would be marginal (451 t or 5%) and is not proportional to the required increase in effort. Similarly, the maximum economic yield (MEY) could be attained by increasing effort by 1.4 times to yield 727.6 million rupees. However, this will produce only a 1.5% increase (10.6 million rupees) from a 40% increase in effort and a reduction of the spawning stock biomass by 13%.

Considering the uncertainty involved in stock assessment models, with respect to fishery, growth, mortality and biological parametrers, it is advisable to adopt precautionary BRPs. For example, an SSB of 25% is essential to maintain a sufficient biomass of spawning stock, without which the stock might decline from inadequate recruitment. The results of the present study suggest reduction in fishing mortality by 40% to maintain the SSB level at 25% and ensure a virgin stock biomass of 50%. This decrease in fishing effort would decrease yield by about 12% (742t) and economic return by 9% (63 million rupees). However, this would ensure the presence of adequate SSB and biomass for recovery of stock and continued exploitation at sustainable levels.

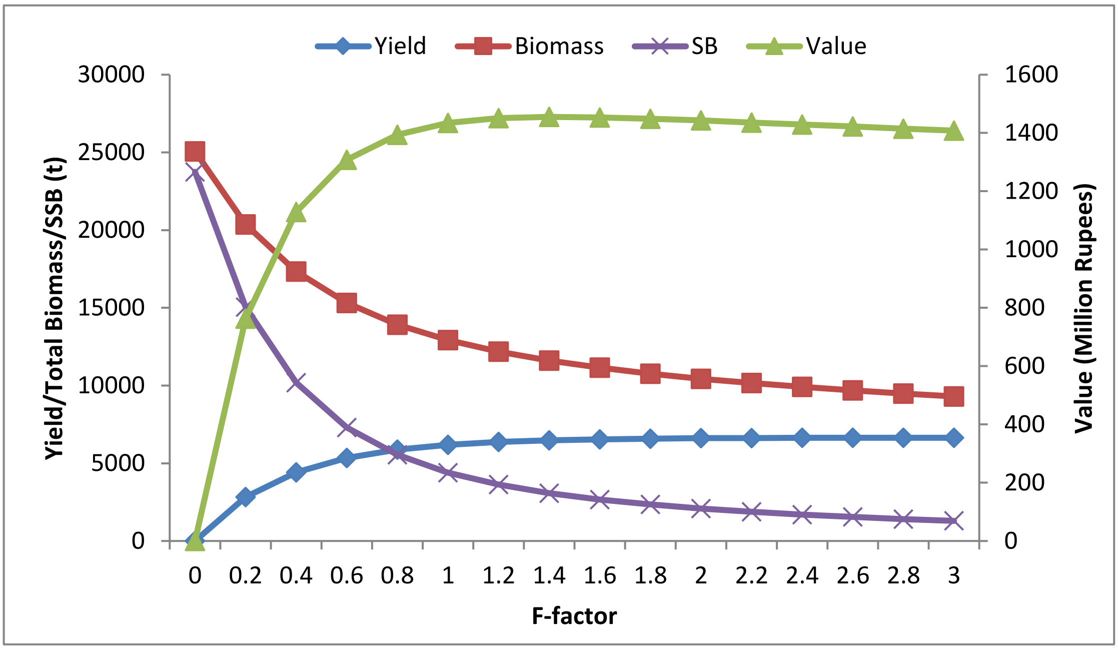

Figure 5.10: Results of the Thomson and Bell analysis of *T tonggol*

Biological Reference Points from Schaefer Model

The intrinsic growth rate (r) was estimated by the model to be 1.063, which can be considered a moderately fast growth rate. The fishing effort (in fishing hours) required to attain maximum sustainable yield (E_{MSY}) can be set as a limit for the exploitation and suggested as an input management measure (Fig. 5.11 & 5.12). The model estimated MSY as 7,703 t. F_{MSY} and B_{MSY} were estimated as 0.532 and 14484 t, respectively. The R^2 value between observed CPUE and model CPUE was 0.566 with a positive significant relationship ($P<0.05$) (Fig. 5.11).

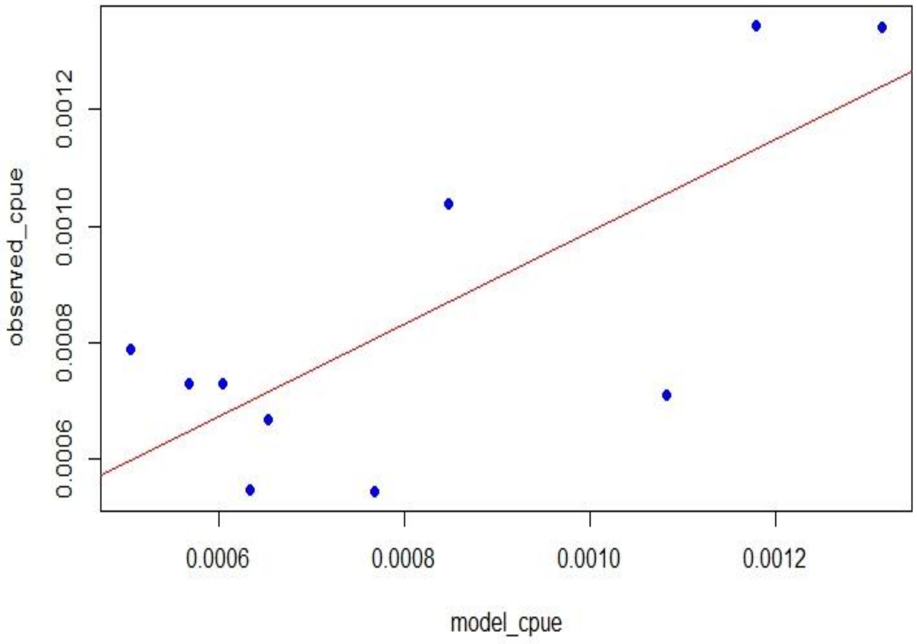

Figure 5.11: Schafer model fit: CPUE observed vs. CPUE model

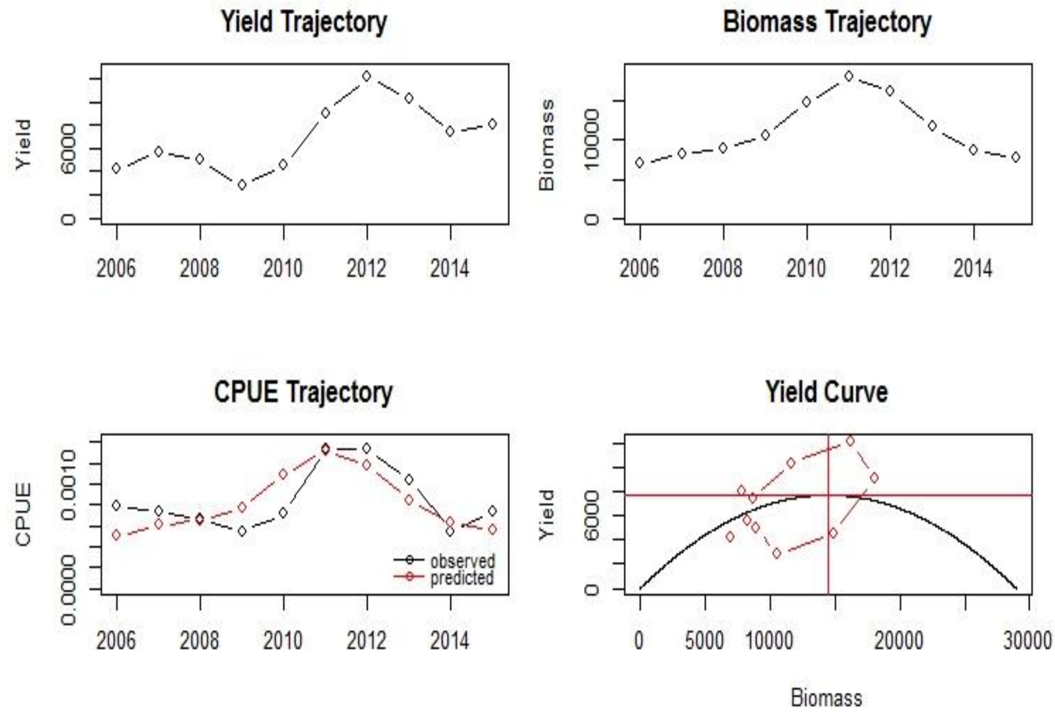

Figure 5.12: Output of Surplus production Schaefer model, i.e., time series yield trajectory, time series biomass trajectory, time series predicted and observed CPUE and yield curve

Biological Reference Points from CMSY

Estimated values of input parameters for the CMSY (and BSM) model as well as values for priors used are shown in Table 5.4. Fig. 5.13 explains the quality of the analysis. The panel A shows the time series of catches (black) and the three-year moving average (blue) with indication of highest and lowest catches. During the period (1991-2016), annual catches in Gujarat were 1,008 t (2003) gradual increased until 2012 (12,136 t), after which catches declined to X tons in 2016 (Fig. 5.13a). Fig. 5.13b shows the explored r-k values in log space and the r-k pairs found by CMSY model, compatible with the catches and the prior information. Fig. 5.13c shows the most probable r-k pairs and its approximate 95% confidence (blue cross) and the possible *r*-k pairs (black dots) found by the BSM model with the red cross indicating the 95% confidence limits. The estimated r-k pairs showed a decreasing trend although it was distributed up to the maximum *r* value. The optimum *r*-k values estimated by both the models were similar with both lying close to each other indicating better quality of the estimate. The estimated biomass trajectory in Fig. 5.14d indicates that the initial biomass prior value range (0.5-0.9) was reasonable as the catch in the initial years was much lower. Intermediate (0.5-0.9) and final (0.01-4.0) biomass priors have also been set reasonably by the default rules as the year 2012 witnessed sudden higher catches while the catch declined in the final year probably due to lower biomass. The trajectory of the biomass derived from CPUE data (red) followed the pattern of the biomass trajectory predicted by the CMSY. Similarly, the pattern of the exploitation rate predicted by the CMSY (blue) and that derived from the CPUE (red) were similar (Fig. 5.13e). The equilibrium catch curve from the CMSY model (Fig. 5.13f) indicated that the relative stock size from CMSY (blue) and BSM (red) did not closely align. This may be due to limited CPUE values, where many of the points fell below the equilibrium curve. This indicates sustainable exploitation and a growing stock biomass although in some years, the points fell outside the equilibrium curve, suggesting high exploitation and declining stock biomass.

The management quantities estimated using CMSY are shown in Table 5.5, while Fig. 5.14 shows the management quantities based on the BSM analysis. As the biomass information (CPUE) was available for the last ten years of the data series, the management quantities and graphical output based on the BSM assessment was regarded as the preferred results as they are generally more reliable than the CMSY estimates (Froese *et al*., 2017). The MSY values estimated by the CMSY and BSM methods differed by only 6%. Similarly, F, F_{MSY} and B_{MSY}

values estimated by both the methods differed by around 9%, 10% and 2%, respectively. The catches relative to the MSY (shaded area indicate the 95% confidence limits) may be seen at the upper right panel of Figure 5.14. Although the catches surpassed MSY from 2011 to 2015, they were below MSY in 2016. The total biomass fell below the sustainable limits (MSY) in the later part of the period under study. The exploitation rate slightly exceeded the biological sustainable limits from 2012 to 2015. The Kobe plot in the lower right corner of Figure 5.14 shows that the BRPs B/B_{MSY} and F/F_{MSY} have been exceeded since 2012, indicating the stock has been subjected to overfishing and has been overfished during this time. However, from 2015 the stock being has not been subjected to overfishing but is overfished.

Table 5.4: The prior values used and the key biological parameters estimated by CMSY method (Values in parenthesis indicate the 95% confidence limit)

Species and Area	*T tonggol*, Gujarat, India	
Data Period	1991-2016	
Abundance	CPUE	
Prior Initial Relative Biomass	0.5-0.9 expert	
Prior intermediate relative biomass	0.5 - 0.9 in year 2012 default	
Prior final relative biomass	0.01-0.4 default	
Prior range for r	0.6 - 1.5 expert	
prior range for k	7.01 - 70.1	
Prior range of q	6.3e-05 - 0.000199	
Results of CMSY Analysis		
	CMSY	**BSM (catch and CPUE)**
r (year^{-1})	1.19 (0.957-1.48)	1.24 (0.927-1.66)
k (t)	24 (17 - 34.4)	24.5 (20.6-29.1)
MSY (t year^{-1})	7210t (5.55 - 9.37)	7590t (6500-8880)
Relative Biomass in last year (t)	0.259 (0.0257 -0.395)	0.382 (0.28-0.474)
Exploitation (F/(r/2)in last year	1.16	0.742
q		7.8e-05 (5.69e-05-0.000107)
Catch 2016 (t)	4309	4309

Table 5.5: Results for management (based on BSM) from CMSY analysis (Values in parenthesis indicate the 95% confidence limit)

Reference Points	BSM estimates
F_{MSY} (year^{-1})	0.62 (CL=0.463-0.829)
MSY (t year^{-1})	7590t (6500– 8880)
B_{MSY} (t)	12300t (10300– 14500)
Biomass in last year (t)	9360t (2.5thperc=6850, 97.5 perc=11600)
Fishing mortality in last year	0.46 (2.5thperc=0.371,97.5perc=0.629)
F/F_{MSY}	0.742 (2.5thperc=0.599, 97.5perc=1.01)
B/B_{MSY}	0.764 (2.5thperc =0.559, 97.5perc=0.948)

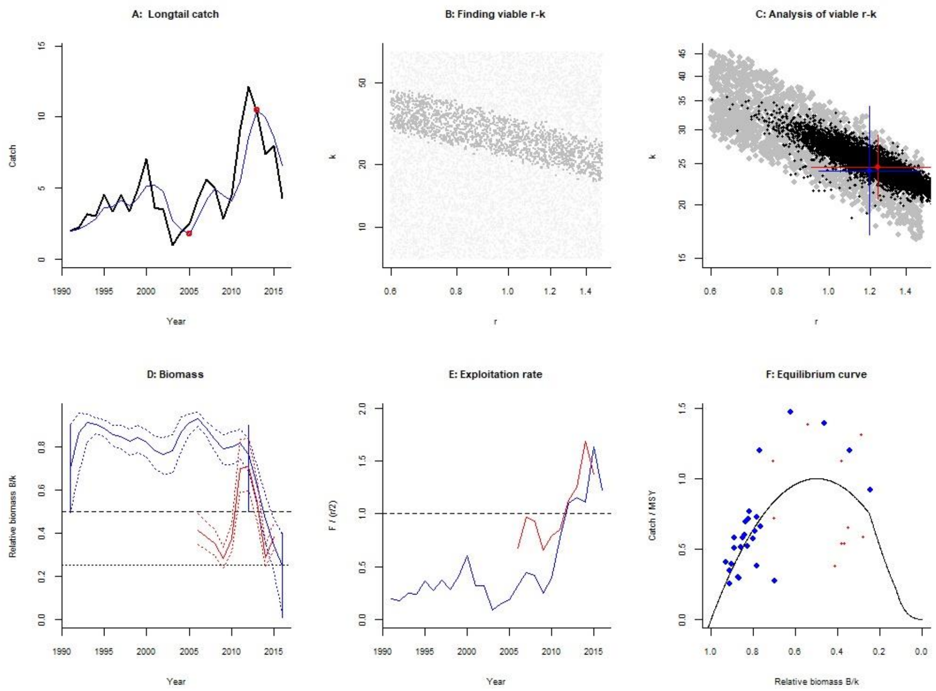

Figure 5.13: Graphical output of the CMSY Analysis for longtail tuna explaining the quality of the analysis. The panel A shows the time series of catches (black) and the three year moving average (blue) with indication of highest and lowest catches

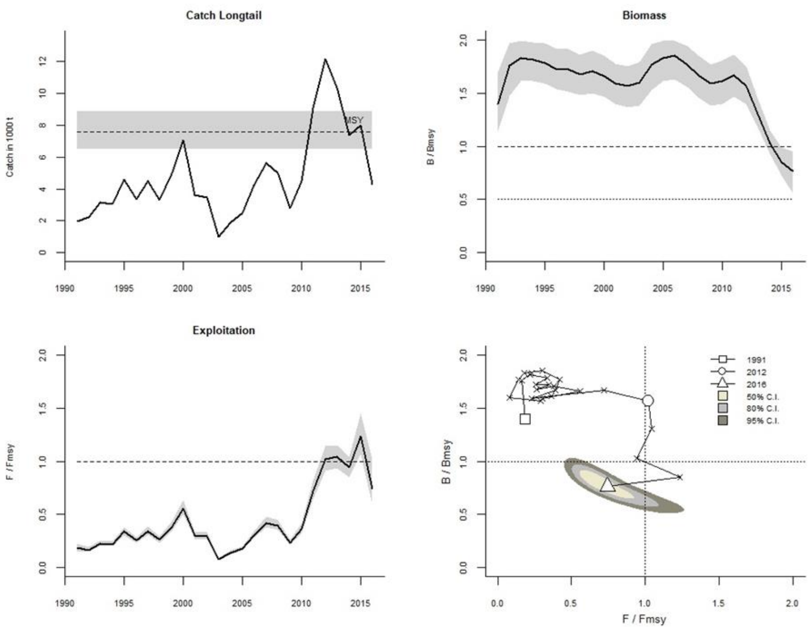

Figure 5.14: Graphical output of the CMSY for management purpose (based on BSM analysis)

Comparison of the Reference Points of T tonggol derived using the three models (Thompson& Bell, Schaefer and CMSY)

The MSY and F_{MSY} values estimated by the biomass-based models (CMSY, BSM and Schaefer) were comparable (Table 5.6). All the models predicted the F_{2016} to be less than F_{MSY}. The mean of MSY values by three biomass models was 7,481 t and that by all the four models was 7,271 t. The most recent catch of 4309 t in 2016 was lower than the mean catches for the 2014-2016 (6563t) and lower than MSY estimated by all models as well as the mean of all the four model values. The mean catch for the last 10 years (6914t) is also lower than the MSY values predicted by the biomass-based models as well as the mean of all the four models. Results from the three biomass-based models (Table 5.7) revealed that the stock is overfished but not subject to overfishing. Though the biomass-based models estimated the stock to be overfished, the fishery showed signs of improvement by way of reduction of fishing pressure in the later years. A summary of state of *T tonggol* fishery off Gujarat with colour code (as per ISSF, 2017) may be seen at Table 5.8.

Table 5.6: Reference points of longtail tuna from CMSY, Schaefer and Thompson & Bell Models

Management Quantity	CMSY Analysis		Holistic model (Schaefer)	Analytical model
	CMSY	BSM		

				(Thompson& Bell)
Most recent catch estimate (t) (2020)	4052	4052	4052	4052
Mean catch (t) (2007-16)	6914	6914	6914	6914
Mean catch (t) (2014-16)	6563	6563	6563	6563
Data period used in the assessment	1991-2016	1991-2016	1991-2016	2012-2016
r	1.19	1.34	1.063	-
k	27500	23800	28967	-
F	0.584	0.64	0.43	1.21
Biomass (t)	6260	9360	7677	12922
MSY (t)	7150	7590	7703	6640
F_{MSY}	0.596	0.67	0.532	2.17
B_{MSY} (t)	12100	11900	14484	9487
F_{2016}/F_{MSY}	0.98	0.742	0.82	0.56
B_{2016}/B_{MSY}	0.517	0.764	0.53	1.36
B_{2016}/B_0	-	-	-	0.56
SB_{2016}/SB_{MSY}	-	-	-	1.5
SB_{2016}/SB_0	-	-	-	0.2

Table 5.7: Performance of the *T tonggol* fishery in Gujarat as per CMSY, and BSM [Symbols- ★ , ●, and ■ indicates status as per CMSY, BSM, and Schaefer models respectively]

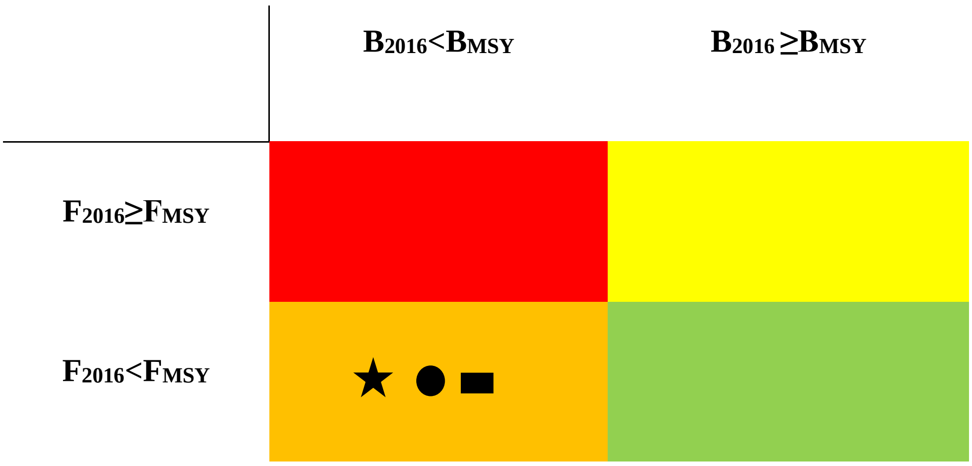

Table 5.8: Summary of state of *T tonggol* fishery off Gujarat with colour code (as per ISSF, 2017)

Stock Abundance	CMSY	Biomass is below B_{MSY} but moving towards the safer limits	
	BSM	Biomass is below B_{MSY} but moving towards the safer limits	
	Schaefer	Biomass is below B_{MSY} but moving towards the safer limits	
	Thompson & Bell	Biomass is much higher than the B_{MSY}	
	Thompson & Bell	Spawning biomass is at or above SSB_{MSY}	
Fishing Mortality	CMSY	F is below F_{MSY}	
	BSM	F is below F_{MSY}	
	Schaefer	F is below F_{MSY}	
	Thompson & Bell	F is below F_{MSY}	
Environment		Gillnet is the major gear targeting the LOT in the region. Sensitive species constituted only 0.12% of the catch and low value bycatch (LVB) formed 5.58% of non-tuna fishes caught. There aren't any discard, except the legally protected species (Turtle and Dolphin). These were released back live whenever encountered in live condition.	

5.4 Discussion

Stock Assessment

Stock assessment of longtail tuna has previously been undertaken on a few occasions in India, which was mainly carried out following analytical methods. James *et al.* (1993) estimated MSY for longtail tuna as 3,069 t when the average landing of the species was around 1,900 t. Standing and spawning stock biomass was estimated by Abdussamad *et al.* (2012a) and reported existence of a healthy spawning biomass (nearly 67% of virgin biomass) in the northwest region. However, the present study revealed that the estimated 2016 spawning biomass had declined to 19% of the virgin biomass. Estimates of the spawning biomass of longtail tuna in the region are scant preventing a comparison of the results from the present study. The longtail tuna fishery in Gujarat witnessed its historic high catch in the year 2013 (12,136 t) with an average landing of 9,386 t during the five years (2011-15). The average catch during 2011-15 was 130% of the average (4,105 t) of the preceding five-year period (2005-2010). Evidently, there has been an increase in fishing effort, above sustainable levels. Though there is scope for increasing the yield at sustainable level by additional effort, it is not advisable as it will lead to a sharp reduction in the standing stock and a further reduction to spawning stock biomass with very marginal gain in economic terms. In order to maintain a healthy spawning biomass i.e. 25% of the virgin biomass; considered being optimum for the surplus production; the fishing effort has to be reduced by 40%.

It is advisable to use both analytical and biomass dynamic approaches wherever data is available to have a comparison of the results (Hoggarth *et al*., 2005) and hence, estimation of stock using two biomass dynamic model (Schaefer and CMSY) was also made. Assessment of the longtail tuna stock in India at national or regional level has not been attempted using holistic models like the Schaefer's model, although the model has been widely used in the assessment of different fisheries in India, such as the ring seine fishery along Kerala coast (Balan & Sathianandan, 2007), threadfin bream fishery (Sathianandan and Jayasankar, 2009, Najmudeen *et al.*, 2014 and Sreekanth *et al.*, 2015), and the North Atlantic Ocean swordfish *Xiphias gladius* stocks (Prager, 2002). Similarly, CMSY has not been used so far in assessment of any of the resources of India. The MSY, F, F_{MSY} and B_{MSY} values estimated by the CMSY, BSM and Schaefer methods were comparable with little variation indicating the reliability of the estimates.

The latest assessment of the stock of longtail tuna in the Indian Ocean region was conducted by the IOTC (IOTC, 2017d) using Catch-MSY, Optimised Catch Only Methods (OCOM) and Stock Reduction Aanalsys (SRA) methods. The models all suggested that the stock is subject to overfishing, while the CMSY and OCOM models also suggesting the stock is overfished. An assessment using ASPIC (A stock-Production model Incorporating Covariates) with standardised CPUE data from drifting gillnet fisheries in Oman (Al-Kiyumi *et al*., 2014) projected longtail tuna in the northwest Indian Ocean entered an overfishing state in 2013. This was thought to be due to a shift in fishing by the distant water gillnet fleet to the shelf areas of the region owing to the expansion of piracy off Somalia to central Indian Ocean during 2008-2013. Nishida & Iwasaki (2015) also assessed the stock of longtail tuna in the

Indian Ocean in 2013 using ASPIC, but with limited CPUE data, and concluded it was overfished and subject to overfishing.

The stock of longtail tuna in the northern Arabian Sea off the northwest coast of India is in a relatively good state with the catches in 2020 and the average catch in the last three years remaining below the MSY estimates produced by all the models in the present study. However, longtail tuna catches increased steeply from 2011 onwards and the average catch during the last six years remained nearly 43% higher than the average landing in 20 years preceding 2011. The introduction of a fleet of larger multi-day gillnetters since 2008 (Polara *et al*., 2014) and expansion of the fleet and the area of operation in the subsequent years have led to this increase in landings of longtail tuna in Gujarat. Exploitation of the stock above MSY levels in 2012 and 2013 may have reduced the biomass to low levels, which may have hindered subsequent recruitment, and thus, lower catches in 2016. However, it showed signs of relief with the catches of longtail tuna in 2017 showing an increase over 2016.

Increasing the catch of longtail tuna by way of further spatial expansion of the current fishing area is limited. Longtail tuna is a neritic species and at present, the fishing effort is expended all through the shelf areas of Gujarat. However, diversifying the effort to areas beyond the shelf (beyond the 200 m depth contour) limited to the EEZ of the country to target the oceanic tunas like the skipjack and yellowfin could be attempted as these resources are not fully exploited at present as per national assessments. The fourty percent excess effort estimated by the analytical method can be diverted exclusively to the oceanic areas to harness the resources therein at sustainable levels. New crafts *in lieu* of the older vessels may be made resource specific with efficient preservation facilities onboard (e.g., refrigeration) in order to increase profits as well as to reduce the wastage of fish due to spoilage. However, a wider continental shelf poses additional challenge for oceanic tuna fisheries in the state by affecting the economics of operation. Maintaining high quality fish product is another challenge with the kind of preservation techniques (use of ice) in vogue in the extant crafts. However, these issues may be overcome by introducing larger collector vessels equipped to efficiently store the catch while providing provisions and fuel to fishing vessels to allow them to make fewer trips back to port for unloading and refuelling. Compliance of the management and conservation measures imposed at national and international levels of fisheries management (e.g., IOTC) is a further consideration.

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