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Stock assessment of Indian Ocean skipjack tuna using biomass dynamics model: with focus on the impact of catch uncertainty

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Summary

In this paper we presented a stock assessment for Indian Ocean skipjack tuna using biomass dynamic model. The estimated parameters include MSY (maximum sustainable yield), F_{MSY} (fishing mortality at MSY), q (catchability coefficient), K (carrying capacity) and B1/K (Initial biomass over carrying capacity). The estimated median MSY based on Logistic production model was 758 (1000 tons) and based on Fox production model was 1,110 (1000 tons), respectively. The results also showed that catch bias had influences on the assessment results. When the bias of nominal catch was adjusted by 20%, 15%, 10%, 5% (i.e. the historical catch was underestimated), the assessment results were significant differences. Overall, it is difficult to determine the stock status due to the high uncertainties in the derived management quantities. Therefore, this assessment still needs to be improved by covering more uncertainty sources.

1 Introduction

The Indian Ocean skipjack tuna (*Katsuwonus pelamis*, SKJ) fishery is one of the largest tuna fisheries in the world. Recently, stock assessment of skipjack tuna in the Indian Ocean was mainly conducted based on integrated model (Stock Synthesis) (Sharma, *et. al.,* 2014). The 2014 assessment estimated that the stock was in the green zone of the Kobe plot (i.e. neither overfished nor overfishing). No stock assessment was carried out for skipjack tuna since 2014. Using the most recent fishery data (up to 2016), this paper describes a stock assessment for the Indian Ocean SKJ using a biomass dynamic model. Several model scenarios were considered, with the focus of understanding the impact of catch uncertainty on assessment results.

2 Material and Methods

2.1 Data

For this assessment, Indian Ocean skipjack tuna was assumed to be subject to 4 fisheries, i.e., Purse seine fishery of free-school (PSFS), Purse seine fishery of associated-school (PSLS), Pole-and-line and small seine fisheries (BB), and Other fishery (OTHER). The data sets compiled for the current assessment were fishery-specific catch and standardized CPUE indices, provided by the IOTC Secretariat for 19th WPTT.

The Indian Ocean skipjack tuna catch history is shown in **Figure 1**. The catch data available up to 2016 showed that the SKJ catch increased quickly from the 1980s to a peak in 2006, and has been declining quickly from 2007 to 2012, with a steep increase in 2013. For 2013-2016, the catch was relatively stable. The standardized CPUE series used in the current assessment (PSLS and Maldive PL) is shown in **Figures 2-4**. Because the current assessment model can only run fitting when the catch and CPUE series have the same length, we uses the time period of **2004-2015** for both the catch and CPUE data.

2.2 Model

The stock was assessed using biomass dynamic model, which was a computer program (ASPIC) developed to estimate parameters of non-equilibrium surplus production model (Prager, 1992). It includes two types of surplus production models: Logistic and Fox models. Both the Logistic and Fox models were considered in this study. The basic form of Logistic production model can be described as follows:

$$\frac{dB}{dt} = rB(B_\infty - B) \quad \text{(Schaefer, 1954)} \qquad (1)$$

The basic form of Fox production model can be described as follows:

$$\frac{dB}{dt} = rB(\ln B_{\infty} - \ln B) \quad \text{(Fox, 1970)} \tag{2}$$

where B is the population biomass, t is time, $B_{\infty}$is the carrying capacity, r is the intrinsic rate of population increase. And in the biomass dynamic model the stock next year (B_{t+1}) is

$$B_{t+1} = B_t + P_t - C_t \tag{3}$$

where B_t is the sum of the current biomass, C_t is catch, P_t is plus the surplus production.The output parameters include:B_1/K (ratio of initial biomass over carrying capacity), *MSY* (maximum sustainable yield), q (catchability coefficient), K (carrying capacity), and E_{MSY} (optimum fishing effort). Bootstrap was used to quantify the uncertainty associated with these estimates. An R package was used for plotting, examining goodness of fit, estimating uncertainties, and deriving management quantities (Kell e*t al*., 2007).

2.3 Catch uncertainty and scenario design

Because of a variety of fishing gears and fishing fleet structures, statistical bias in the historical nominal catches (under-reported or over-reported) are believed to be existed for skipjack. For example, catches may not be fully reported by some fleets. Therefore, in this study, we also investigate the impact of the catch error on stock assessment results, i.e, by increasing or decreasing the original catch data with a fixed percentage. A total of 7 scenarios were designed for skipjack (**Table 1**).

3 Results and discussion

3.1 Outputs from ASPIC

The summary and results of ASPIC runs are shown in **Table 2**. The results of three scenarios showed some differences. We compared the model results with the base case. Run 2 used the nominal catch data and EU_PS standardized CPUE data from 2004 to 2016. The results showed that there were significant differences in MSY and the current biomass. Run 3 used the nominal catch data and Maldives_PL standardized CPUE data from 2004 to 2015, the result showed that there were significant differences, and the Fox model failed to converge. This is probably the CPUE time series is short, the spatial area may not represent the Indian Ocean, and the indices may not be representative of the overall abundance due to the effort being concentrated on FADs in recent years.

Patterns in the residuals from the fits to the CPUE may indicate biased estimates of parameters, reference points and stock trends. Therefore when fitting a model, the residuals should be checked to identify violations of the assumptions. Initially, the residuals of a fit should be distributed normally and a similar way in the entire time series. The residuals estimated for the two runs are shown in **Figure 5**. And the estimated differences between observed and predicted indices of abundance are shown in **Figure 6.** From **Figures 5 and 6**, it is showed that the residuals from both the logistic and Fox models are relatively distributed.

3.2 Uncertainty estimates

We ran 500 bootstrappings to quantify the uncertainties assocated with the estimates produced by the model. The bootstrapped estimates of stock trend are shown in **Figures 7-8**. The variation of bootstrapped distributions was wide. In addition, differences between bootstrapped results and original fits were checked, noting that the orginal estimates and bootstrapped median were very similar.

The distribution of stock status from bootstrapping was displayed in a Kobe plot in **Figure 9**. The median stock trajectories from the 500 boostrapping for the stock status were plotted in a Kobe plot in **Figure 10**. It was found that current relative biomass is more precisely estimated with the Fox model.

3.3 Impact of catch error on the stock assessment

The summary of model specifications and results are shown in **Table 3**. By comparing the fishing mortality between the 6 sensativity models and the base model, it was found that the fishing mortalities of all models were in the same trend. The fishing mortality increased gradually from 2004 to 2006, followed by a steep increase in 2012. However, under different assumptions, the fishing mortality estimates were also different.

The spawning stock biomass (SSB) of all models had similar trends, and in contrast to the fishing mortality trends, the SSB has been declining since 2004, although there was a short-term increase in 2013. Through the comparison of the results of the base model and the sensitivity analysis models, it can be seen that the results from Fox model was more sensitive to the catch error.

When the bias of nominal catch was assumed to be 20%, 15%, 10%, 5% (i.e. the historical catch was underestimated), the assessment results were basically consistent (Logistic production model). When the bias of nominal catch was assumed to be -20%, -15%, -10%, -5%, the results were similar. Therefore, uncertainty in catch reporting may have significant impacts on assessment results from Fox production model. However, this assessment still needs to be improved to cover more range of uncertainty sources.

4 Acknowledgements

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5 References

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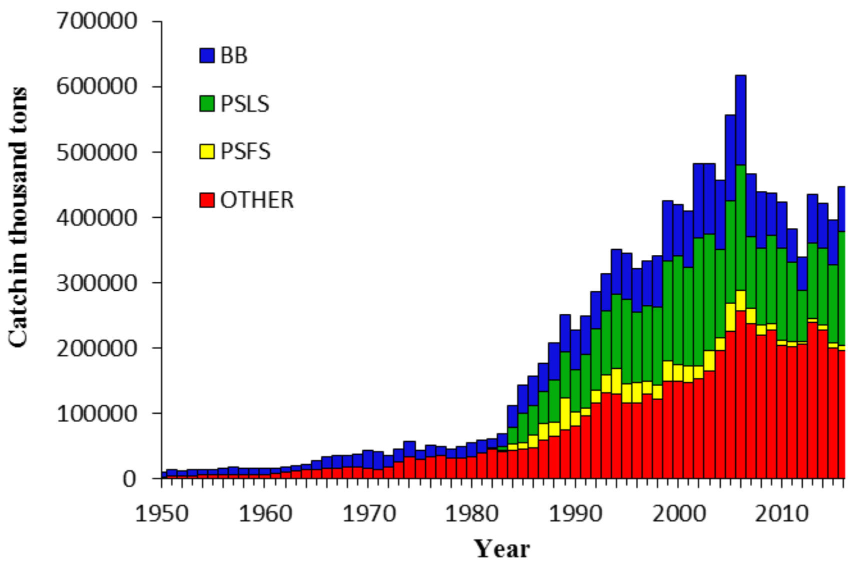


Fig. 1 Trend of skipjack tuna catch in the Indian Ocean by fishery

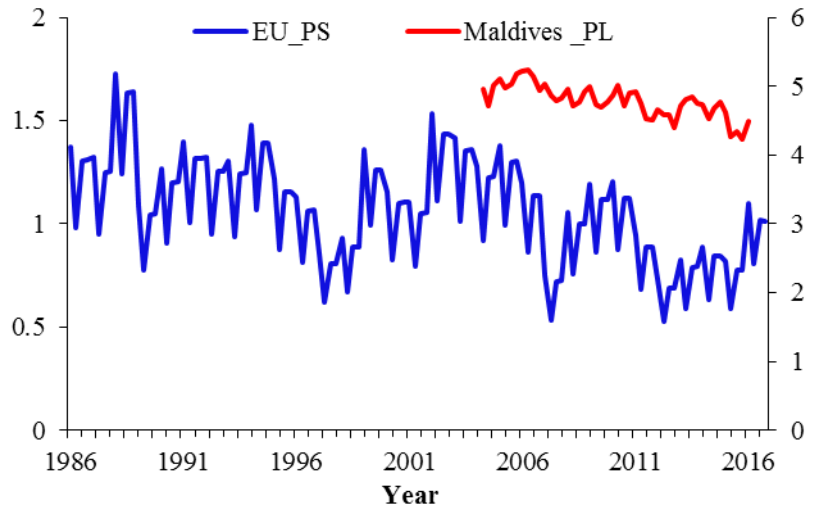


Fig. 2 CPUE series for Indian Ocean SKJ (EU PSLS and Maldives PL)

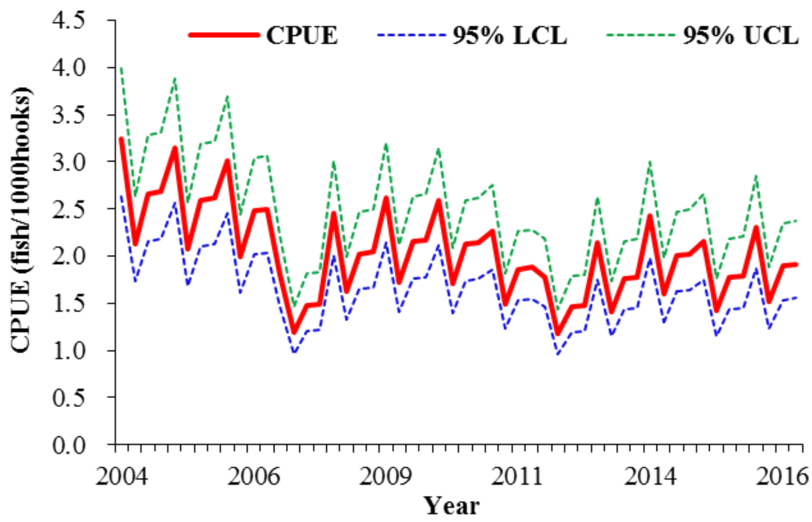


Fig. 3 CPUE series used in current assessment (EU PSLS).

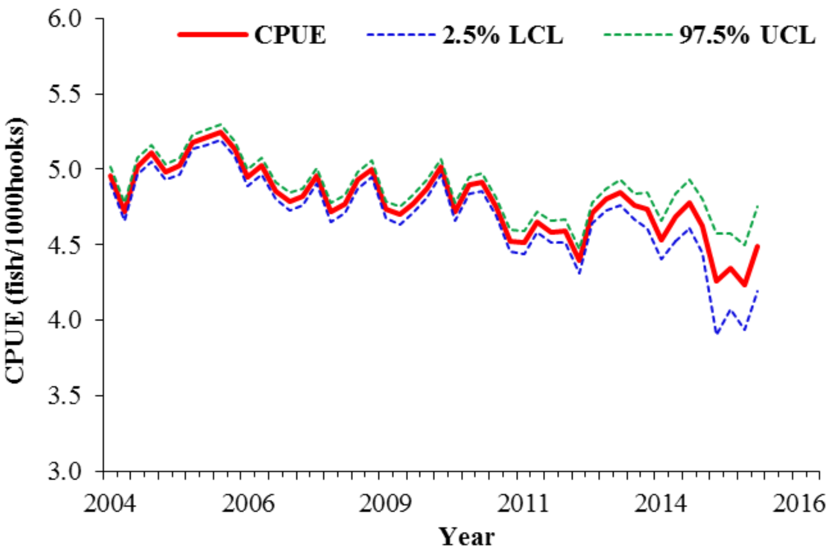
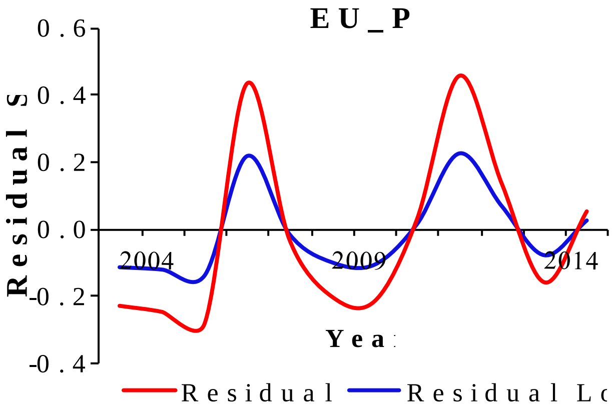


Fig. 4 CPUE series used in current assessment (Maldives PL).



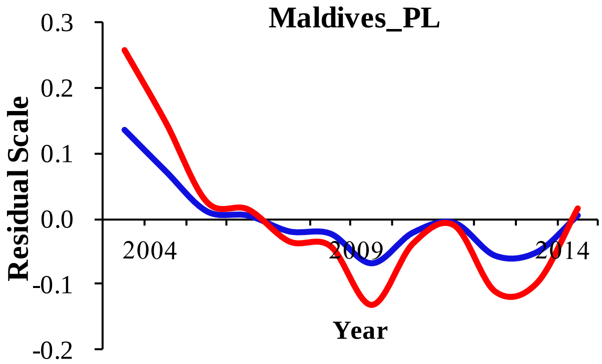


Fig. 5 Residuals derived from fitting with Logistic and Fox production models

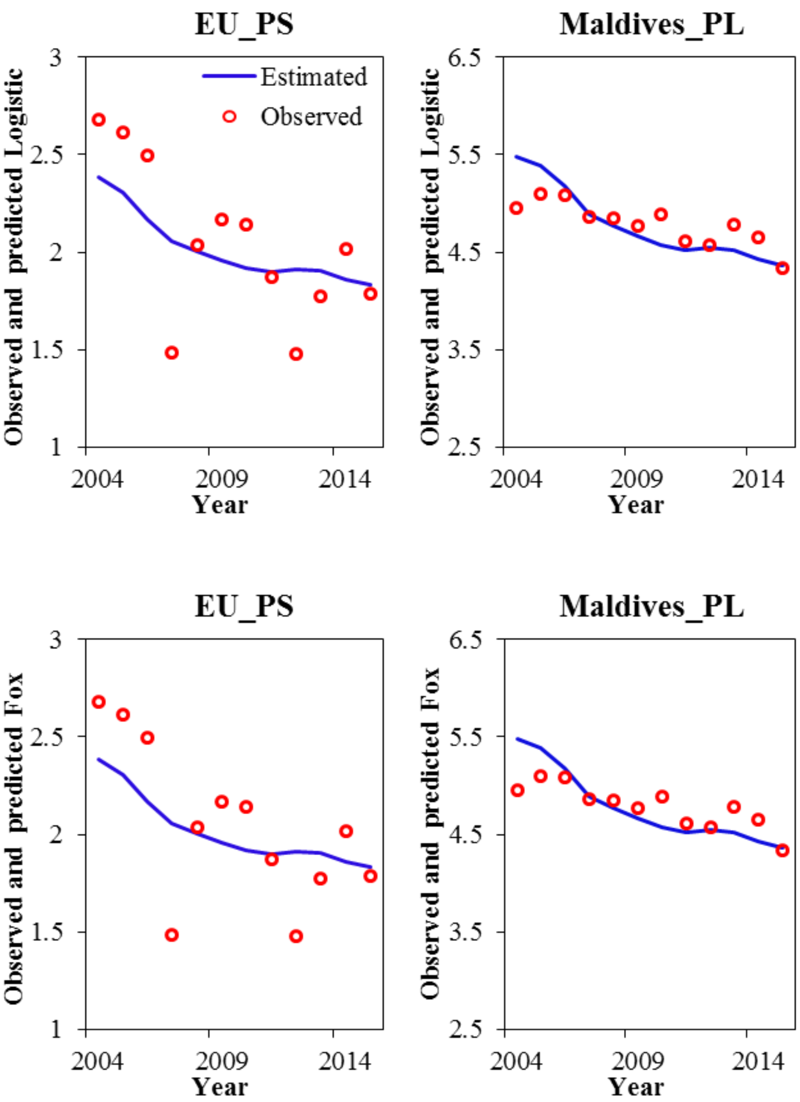


Fig. 6 Model predicted and observed abundance indices

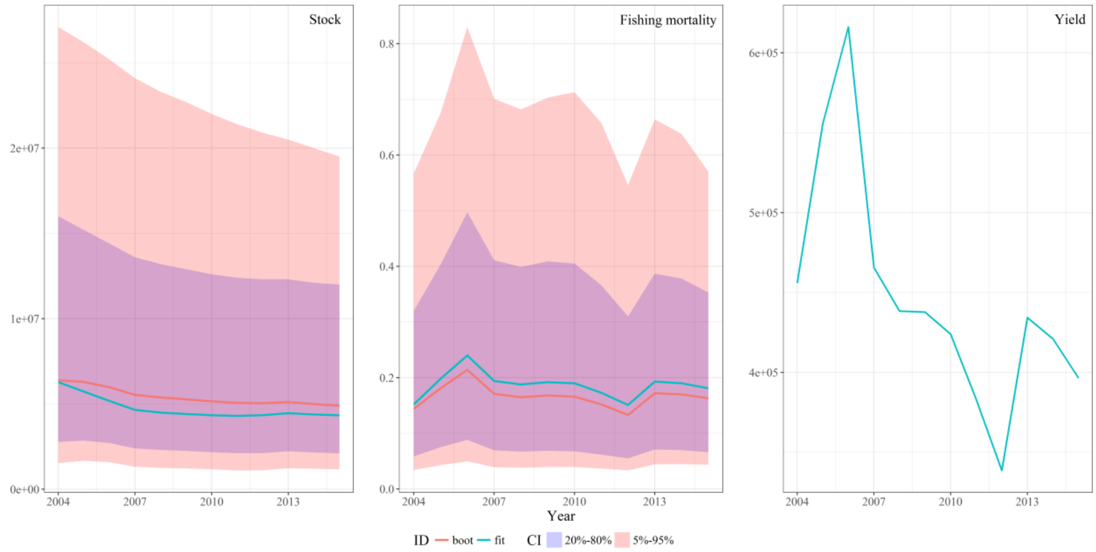


Fig. 7 Bootstrap results (Logistic)

Fig. 8 Bootstrap results (Fox)

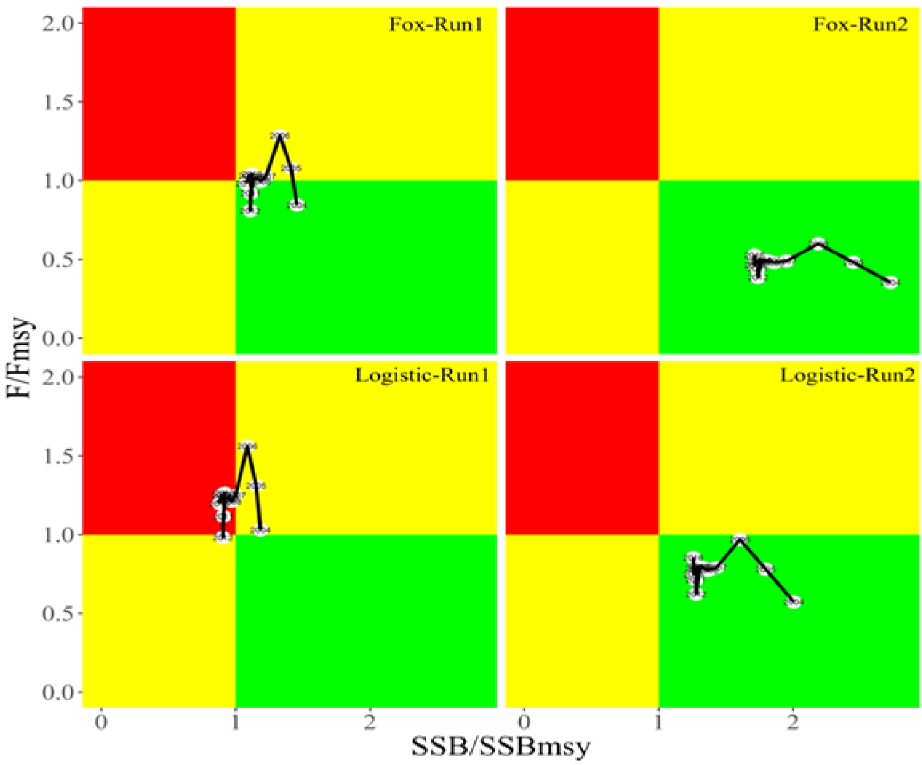


Fig. 9 Kobe plots for the skipjack tuna assessment

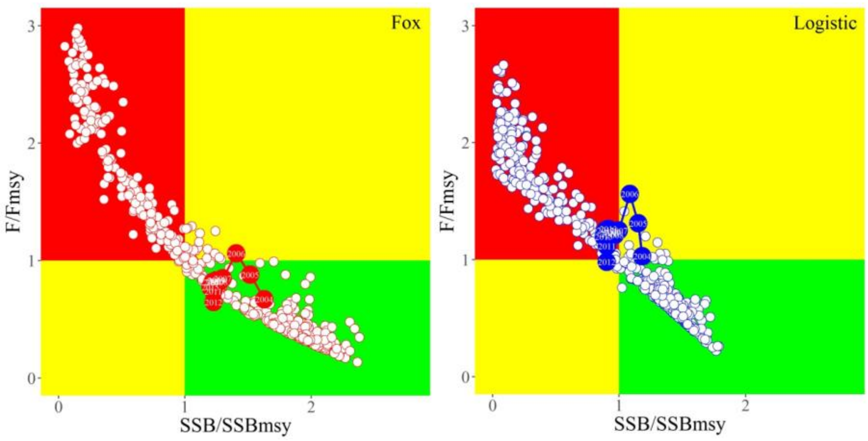


Fig. 10 Relative biomass and fishing mortality trajectories (median from bootstrap) and bootstrapped stock status for the two models run.

Table 1. Base case model and sensitivity models for skipjack tuna

Scenario No	Model	Time period	Adjust level for catch
1*	Fox Logistic	2004-2015	-
2	Fox Logistic	2004-2015	20%
3	Fox Logistic	2004-2015	10%
4	Fox Logistic	2004-2015	5%
5	Fox Logistic	2004-2015	-5%
6	Fox Logistic	2004-2015	-10%
7	Fox Logistic	2004-2015	-20%

"*" means base case.

"Adjust level for catch" means increase or decrease from the nominal catch level by fishery and year.

Table 2. Summary results of ASPIC runs

Run No.	Years	Model	CPUE		B1/K
			EU_PS	Maldives_PL	
1 (Base)	2004-2015	Fox	2004-2015	2004-2015	Fix(0.75)
		Logistic			
2	2004-2016	Fox	2004-2016	~	Fix(0.75)
		Logistic			
3	2004-2015	Fox	~	2004-2015	Fix(0.75)
		Logistic			

Run No.	*Model*	*MSY*	$TB_{current}$	TB_{MSY}	TB_{ratio}	$F_{current}$	F_{MSY}	F_{ratio}
1*	Fox	1.11E+06	5.23E+06	4.90E+06	1.068	0.151	0.154	0.983
	Logistic	7.58E+05	4.75E+06	5.46E+06	0.869	0.166	0.139	1.196
2	Fox	7.36E+05	2.39E+06	1.42E+06	1.679	0.186	0.352	0.528
	Logistic	4.22E+05	2.17E+06	1.76E+06	1.229	0.204	0.239	0.855
3	Fox	-	-	-	-	-	-	-
	Logistic	4.25E+05	3.64E+06	2.14E+06	1.701	0.11	0.212	0.519

"*" means base case.

"-" means the results not available.

Table 3. Summary of management quantities and related parameters for Indian Ocean skipjack

Scenario No	Model	*MSY*	F_{MSY}	B_{MSY}	*k*	*r*
	Fox	1.11E+06	0.153611	4.89E+06	9.79E+06	0.307223
1*	Logistic	7.58E+05	0.138796	5.46E+06	1.09E+07	0.277592
	Fox	1.33E+06	0.152549	5.91E+06	1.18E+07	0.305098
2	Logistic	9.08E+05	0.139496	6.51E+06	1.30E+07	0.278992
	Fox	1.23E+06	0.134984	6.19E+06	1.24E+07	0.269968
3	Logistic	9.34E+05	0.140363	6.65E+06	1.33E+07	0.280726
	Fox	1.16E+06	0.150591	5.24E+06	1.05E+07	0.301181
4	Logistic	7.95E+05	0.139379	5.70E+06	1.14E+07	0.278757
	Fox	1.06E+06	0.135843	5.29E+06	1.06E+07	0.271686
5	Logistic	7.19E+05	0.135843	5.29E+06	1.06E+07	0.271686
	Fox	1.00E+06	0.157146	4.33E+06	8.66E+06	0.314292
6	Logistic	6.82E+05	0.139379	4.89E+06	9.78E+06	0.278757
	Fox	8.83E+05	0.151697	3.95E+06	7.91E+06	0.303393
7	Logistic	6.06E+05	0.139613	4.34E+06	8.68E+06	0.279226

"*" means base case