Working paper for

18th Working Party on Ecosystems and Bycatch (WPEB18)

Indian Ocean Tuna Commission (IOTC)

Virtual
5-9 Sep 2022

A preliminary stock assessment of scalloped hammerhead shark (*Sphyrna lewini*) in the Indian Ocean

Document #: IOTC–2022–WPEB18–XX

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Summary

*The study conducted a demographic analysis and preliminary stock assessment to status by Leslie matrix and CMSY method for the Indian Ocean scalloped hammerhead shark (Sphyrna lewini). Monte Carlo simulation was used to integrate uncertainty of biological information and key parameters. The results indicated that scalloped hammerhead shark productivity was low, with the intrinsic rate of increase r is from 0.12 to 0.23*yr^{-1}*, and the most uncertainty is inconclusive fecundity where the litter size is from 13 - 41 pups per year. The results are sensitive to the final depletion level, and all scenarios reveal that the average of the last three-year catch is lower than MSY; however, the stock status is overfished. Given the high uncertainty in the catch series and high amounts of misidentified catch, future assessments need to consider more date-limited methods based on the different sources of data and improve the reconstruction of catch series.*

1 Input Data

The nominal catch of Scalloped Hammerhead Shark (refer to SPL) collected by IOTC for 1986-2020 was selected in this study. The age and growth of SPL have not been intensively investigated in the Indian ocean; however, their growth curve can be found in the Northwestern Pacific Ocean where asymptotic length (L_{oo}) = 319.72 cm total length (TL), growth coefficient (K) = 0.25, and age at zero length (t_0) = - 0.41yr (Chen, 1999). The maximum age for Atlantic Ocean scalloped hammerheads is estimated to be over 30 years. In the northern Gulf of Mexico females are believed to mature at about 15 years. To consider the uncertainty of mature age and one year gestation period, we assumed a discrete uniform distribution of U (14, 18) for the first delivery age. As Smith (1997) we also assumed a uniform distribution of U (15-31) for litter size per one-year reproductive cycle. The sex ratio at birth was assumed to be 1:1 as suggested by Marie(2019).

2 Methods

2.1 Demographic analysis

An age-structured matrix population model (Caswell 2001) was used to investigate the demography of the IO SPL:

$$N_{\mathrm{t}+1} = \mathbf{M}N_{\mathrm{t}} \tag{1}$$

where N_{t} is the vector with numbers at each age in year t. The matrix **M** is a Leslie population projection matrix:

$$\mathbf{M} = \begin{bmatrix} f_0 & f_1 & f_2 & \cdots & f_{\mathrm{x}} \\ s_0 & 0 & 0 & 0 & 0 \\ 0 & s_1 & 0 & 0 & 0 \\ 0 & 0 & \cdots & 0 & 0 \\ 0 & 0 & 0 & s_{\mathrm{x}-1} & 0 \end{bmatrix} \tag{2}$$

where the s_{x} element is the annual natural survivorship term for age x. The f_{x} elements represent the age-specific per-capita fecundity rates. A birth-pulse population and a post-breeding census were assumed (Caswell, 2001). Accordingly, the first age class (age 0) is represented by the new born pups and the fecundity (f_{x}) terms include the probability that a pregnant female survives and delivers the pups at the end of the year ($f_{\mathrm{x}} = s_{\mathrm{x}}\mathrm{M}_{\mathrm{x}}$, in which M_{x} is the average number of female pups per female).The M_{x} terms were calculated as the product of the number of pups per female and the female sex ratio of the litters, which was then divided by the length of the reproductive cycle in years.

According to matrix algebra, $AN_t = \lambda N_t$, where λ is called the eigenvalue of matrix A. Therefore, biologically λ is the finite rate of population increase and r ($= \ln \lambda$) is defined as the intrinsic rate of population increase (Brewster-Geisz and Miller, 2000). The value of λ is determined by finding the dominant eigenvalue of A by using matrix algebra (Simpfendorfer, 2005). The underlying assumption of the matrix model (Equation 1) is that the population will grow exponentially and reach a stable age distribution with equilibrium (Caswell 2001).

2.2 Survival rate and natural mortality

Age-specific survival rate (S_t) is defined as:

$$S_{\mathrm{t}} = \mathrm{e}^{-Mt} \tag{3}$$

where M_t is the (instantaneous) natural morality. Thus, the estimate of survival rate is dependent on natural mortality. As natural mortality is often difficult to be estimated and is the main source of uncertainty in quantifying population dynamics. We considered five empirical methods to calculate M based on life-history information: (1) Hoenig's (1983) method, i.e., $\ln(\mathrm{M}) = 1.46 - 1.01\ln(t_{max})$; (2) Hewett and Hoenig's (2005) method, i.e., $\mathrm{M} = 4.22/t_{max}$; and (3) Peterson and Wroblewski's (1984) method, i.e., $\mathrm{M}_t = 1.92W_t^{-0.25}$ which estimates M based on its relationship with growth and weight parameters.

Triangular distribution (probability density functions, *pdf*) was assumed for annual survival at age. The triangular distribution can be used to represent the uncertainty in life-history parameters before stochastic demographic analysis is conducted. This distribution is particularly convenient because it allows a lower and upper bound for the parameter and the assignment of a most likely value between this range(Aires-da-Silva and Gallucci, 2007).

For each age, the lowest and highest estimates of survival rates derived from the above 4,000 M estimates were taken as the bounds, and the mean value was assumed as the most likely value in the triangular distributions. The probability density functions calculated was used as the survival rates in this demographic analysis.

2.3 Scenarios of demographic analysis

The key output of the demographic analysis is the intrinsic rate of population increase (r). The uncertainty of r arises from the uncertainties in the life-history parameters. In this study, two scenarios were developed to investigate the impacts of uncertainty about survivorship on the estimates of r. In this study, 10,000 Monte Carlo simulations were run by sampling from the generated life-history parameters and hence maturity-at-age, fecundity-at-age, maximum age, and age-at-maturity Distributions for four demographic parameters, i.e., the intrinsic rate of population increase (r), net reproductive rate (R_0), generation time (G), and population doubling time (t_{x2}) were estimated based on the methods and definitions in Aires-da-Silva and Gallucci (2007).

2.4 CMYS Method

Most DLMs can be generally divided into three categories as follow: (1) Catch only methods (data-poor methods) which only rely on the catch time series; (2) Abundance-based methods (data-moderate methods) which additionally require relative abundance index. (3) length/age-based methods which fix the model with historical catch and length-frequency data without abundance. Given the lack of length-frequency data and representative abundance index data, The Commission recognized to use of data-poor, catch-based methods for SPL stock assessment. Thus, we chose a catch-only model, CMSY (Froese et al., 2017), as the probe in this study.

We used demographic analysis conduct an informative prior distribution for intrinsic rate of increase r. Besides, we also assumed a uniform distribution of U[0.05, 0.5] for parameter r as the non-informative prior. For the carrying capacity K, we used the 95% confidence interval of the prior information as the bounds of r (r_{low} and r_{high})and highest catch (Max_{catch})to generate a prior of K with uniform distribution.

$$K_{low} = \frac{Max_{catch}}{r_{high}}, K_{high} = \frac{4Max_{catch}}{r_{low}}$$

We assumed the almost unfished condition at the beginning of the assessment, where B_{sta}/B_0 followed a uniform distribution of U[0.2, 0.6]. For the last year in the assessment, we used the CMSY rule based on the ratio of catch in last year to the highest year. Given the ratio is lower than 0.7, we assumed a uniform distribution of U[0.01, 0.4] for B_{last}/B_0

and an alternative distribution of U[0.2, 0.6]. A total of eight scenarios were considered in our CMYS model (Table3).

3.Results

Table 3 showed the results of demographic analysis for Indian Ocean SPL and the distribution of estimate of *r* was shown in Fig. 1. The results indicated that SPL productivity was low, with the intrinsic rate of increase r=0.12-0.23 y^{-1} and a flat-top distribution.

For the CMSY method, the potential assumption of final depletion (B_{last}/B_0) caused the most uncertainty, and this parameter can perhaps affect the decision of stock status directly. For all scenarios, the geometrical mean of MSY ranged from 161.12MT to 217.01MT, and all of them are higher than the mean Catch from 2018 to 2020($C_{2018-2020}$ = 45.87). It's different to the result of fishing mortality, the result based on biomass indicated the status is overfished. In general, all scenarios indicated the stock status is overfished but not overfishing. Given the potential assumption of CMSY where the value of B_{MSY}/K is 0.5 and lower than most shark species, the result might be overestimated in stock status.

Table 1 Biological information for demographic analysis of Indian Ocean SPL

Parameter	Unit	Value	Reference	Area
L_∞	cm-TL	319.72		
K	$year^{-1}$	0.25	Chen et al,1990	Pacific
t_0	Year	-0.41		
t_{max}	Year	30	Smith, 1997	Gulf of Mexico
W-L	Kg-TL	W=0.00355 x $L^{3.11}$	Fish base	Globe
t_{mat}	year	*U* (14 - 18)	Smith, 1997	Gulf of Mexico
LS	pups	*U* (14 - 41)	White, 2008	Indonesian waters
Sex ratio	*ratio*	1:1	Marie, 2019	Pacific

Table 2 Prior distribution of key parameters for SPL in the Indian Ocean

Scenarios	r	K_{low}	K_{high}	B_{sta}/B_0	B_{last}/B_0
CMSY_1	Demographic analysis	2073.17	16585.33	U[0.2, 0.6]	U[0.01,0.4]
CMSY_2	Demographic analysis	2073.17	16585.33	U[0.2, 0.6]	U[0.2,0.6]
CMSY_3	U[0.05,0.5]	995.12	39804.8	U[0.2, 0.6]	U[0.01,0.4]
CMSY_4	U[0.05,0.5]	995.12	39804.8	U[0.2, 0.6]	U[0.2,0.6]

Table 3. Result of demographic parameters for Indian Ocean SPL

Parameter	Mean	Median	Min	Max
λ	1.19	1.18	1.13	1.26
r	0.17	0.17	0.12	0.23
t_{x2}	4.14	4.11	2.98	5.75
R_0	30.76	30.14	15.34	65.91
G	20.17	20.20	17.38	22.98

Table.4 Biological reference points of CMSY methods for SPL in the Indian Ocean (t)

Parameter	CMSY_1	CMSY_2	CMSY_3	CMSY_4
r	0.20	0.20	0.31	0.29
r_CV	11.89	11.63	46.17	39.90
$K(B_0)$	3418.94	3354.12	2069.92	3011.44
K_CV	19.92	19.53	46.40	59.47
C_{2020}/MSY	0.22	0.22	0.24	0.18
MSY	170.98	171.06	161.62	217.01
B_{MSY}	1709.47	1677.06	1034.96	1505.72
$B_{2020}/B_{\mathrm{MSY}}$	0.29	0.87	0.36	0.90
F_{MSY}	0.10	0.10	0.16	0.14
$F_{2020}/F_{\mathrm{MSY}}$	0.77	0.26	0.66	0.20

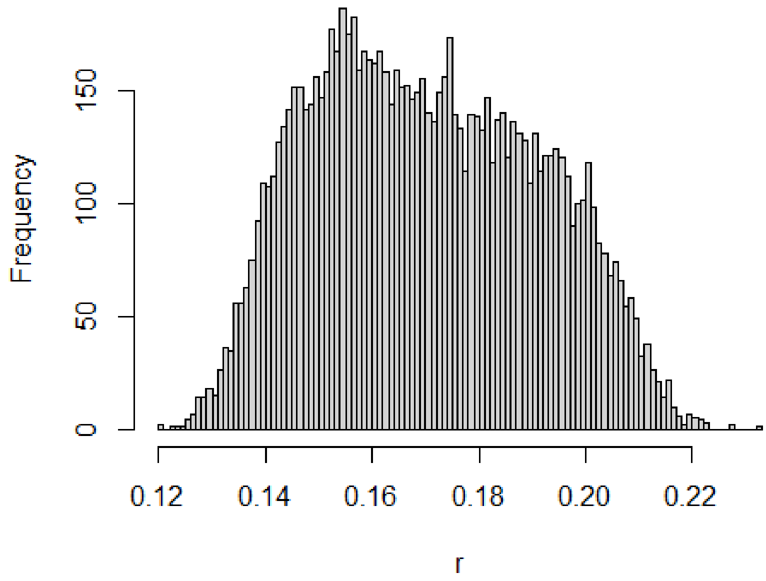

Figure 1. Prior distribution of parameter *r* conducted by demographic analysis

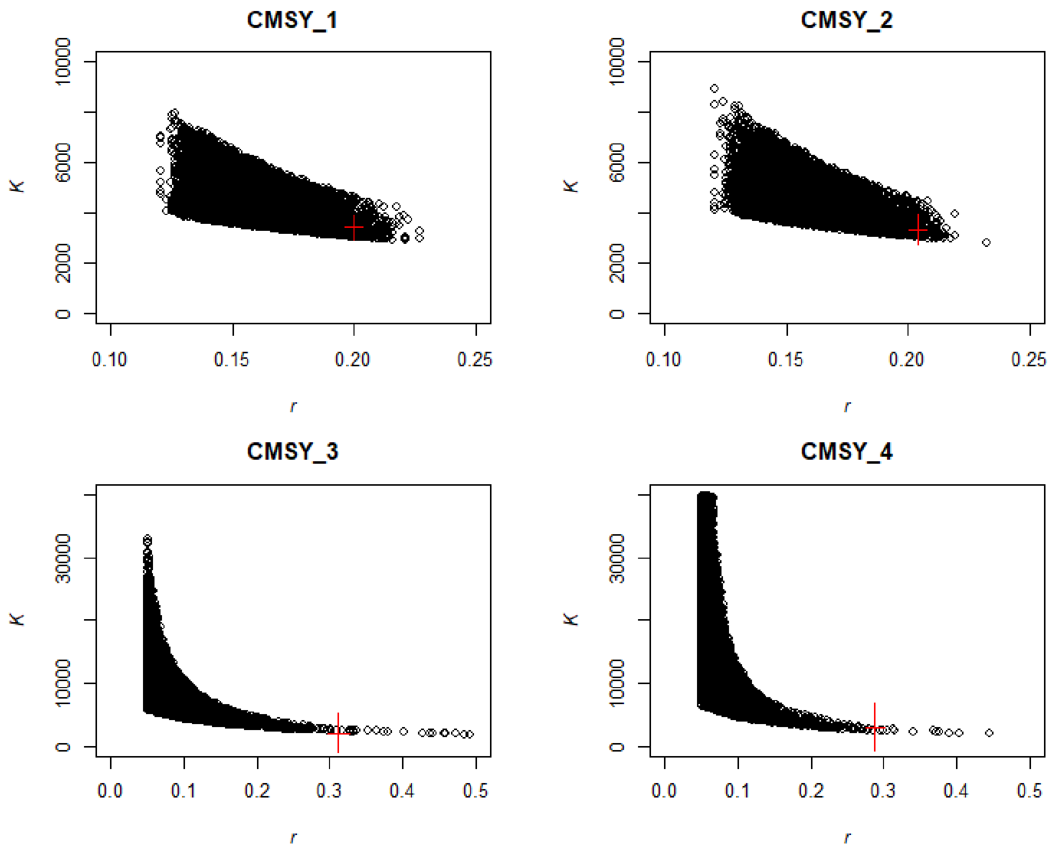

Figure 2. Posteriori distribution of *r*-*K* pairs in CMSY model

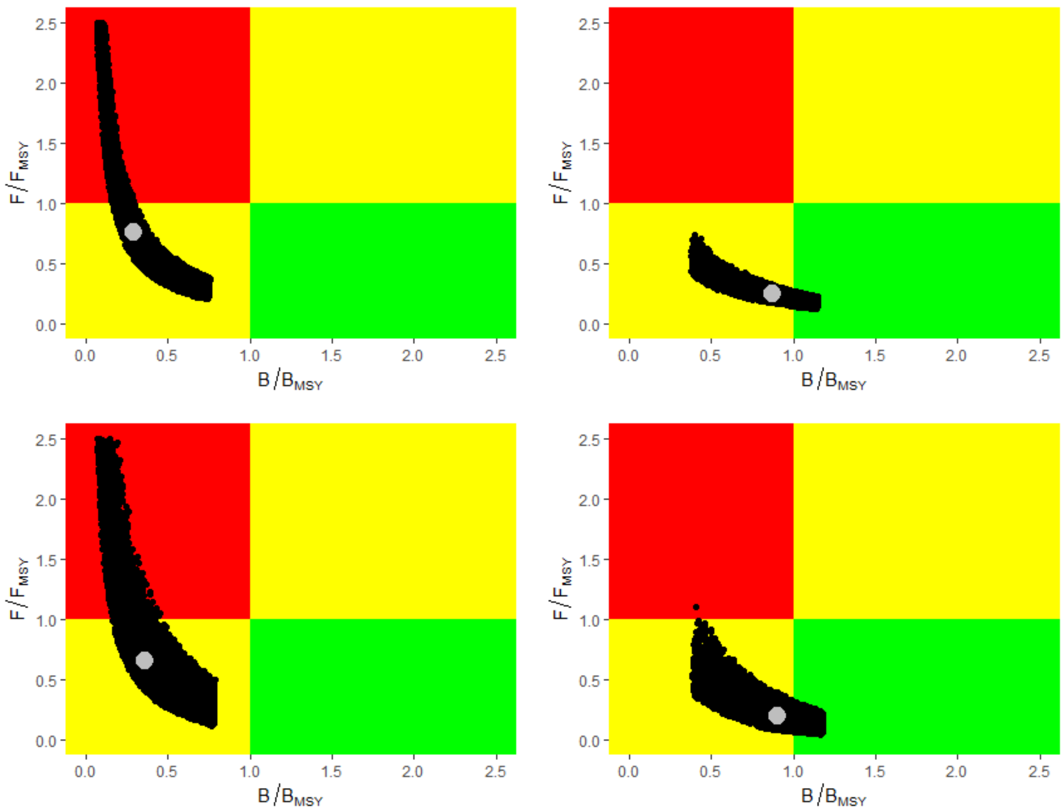

Figure 3. Kobe plot of CMSY method for SPL in the Indian Ocean

Acknowledgements
This paper was supported by the National Natural Science Fund of China (32072981) and Project on the Survey and Monitor-Evaluation of Global Fishery Resources (Stock status and utilization potential in tuna fishery).

References

Chen CT, Leu TC, Joung SJ, Lo NC. Age and growth of the scalloped hammerhead, Sphyrna lewini, in northeastern Taiwan waters. 1990

Smith CL. National Audubon Society field guide to tropical marine fishes of the Caribbean, the Gulf of Mexico, Florida, the Bahamas, and Bermuda. Alfred A. Knopf; 1997.

Marie AD, Herbinger C, Fullsack P, Rico C. First reconstruction of kinship in a scalloped hammerhead shark aggregation reveals the mating patterns and breeding sex ratio. Frontiers in Marine Science. 2019 Nov 1;6:676.

White WT, Bartron C, Potter IC (2008) Catch composition and reproductive biology of *Sphyrna lewini* (Griffith & Smith) (Carcharhiniformes, Sphyrnidae) in Indonesian waters. J. Fish Biol. 72: 1675–1689.

Froese R, Demirel N, Coro G, et al. Estimating fisheries reference points from catch and resilience[J]. Fish and Fisheries, 2017, 18(3) 506-526.

Caswell, H., 2006. Matrix population models. Encyclopedia of environmetrics.

Aires-da-Silva, A.M., Gallucci, V.F., 2007. Demographic and risk analyses applied to management and conservation of the blue shark (*Prionace glauca*) in the North Atlantic Ocean. Marine and Freshwater Research, 58(6), 570-580.