Preliminary stock assessment for yellowfin tuna *Thunnus albacares* in the Indian Ocean using age structured assessment program (ASAP)

Yang Wang[1], Zhe Geng[1,2], Jiangfeng Zhu[1,2]

1.College of Marine Living Resource Sciences and Management, Shanghai Ocean University,999 HuchengHuan Road, Shanghai 201306, China;
2.Key Laboratory of Oceanic Fisheries Exploration, Ministry of Agriculture and Rural Affairs, 999 HuchengHuan Road, Shanghai 201306, China

Summary

This study conducted a stock assessment for Indian Ocean yellowfin tuna (*Thunnus albacares*) using Age Structured Assessment Program (ASAP), based on fishery-specific catch and catch-at-age data (1976-2022). The assessment considered that the yellowfin tuna stock were subject to 4 fisheries, i.e., Longline fishery (LL), Purse seine with free school (PS-FS), Purse seine with log school (PS-LS), and Other fisheries (OT) . Joint catch-per-unit-effort (CPUE) series from longline fisheries of Japan, Korea, and Taiwan,China were used as abundance indices for fitting the model. In addition to base case model, sensitivity analysis was conducted as to two key parameters (i.e., steepness of Beverton-Holt stock-recruitment relationship and CPUE index in different regions). The assessment results, including MSY and related biological reference points, were sensitive to the steepness and CPUE assumptions. However, both the base case and sensitivity analyses suggested that the Indian Ocean yellowfin tuna was experiencing overfished and overfishing.

Contents

1 Introduction

Stock assessment of yellowfin tuna depends on the Stock Synthesis 3 model since 2015 (Langley, 2015). The most recent assessment was conducted in 2021(Fu et al.,2021) which suggests that the stock is overfished and experiencing overfishing. Therefore, the Indian Ocean Tuna Commission (IOTC) adopted an Interim Plan for Rebuilding the Indian Ocean Yellowfin Tuna Stock (Res 21/01).

This working paper presented a stock assessment of Indian Ocean yellowfin tuna using Age Structured Assessment Program (ASAP, Version 3; Legault and Restrepo, 1998; NOAA Fisheries Toolbox, 2013). ASAP has been used as an assessment tool for assessing many commercially exploited stocks, e.g., red grouper, yellowtail flounder, Pacific sardine, Greenland halibut, Gulf of Maine cod, and Florida lobster (see NOAA Fisheries Toolbox, http://nft.nefsc.noaa.gov).

The assessment included a base case model and sensitivity analyses designed for the consideration of alternative key assumptions regarding population dynamics (i.e., CPUE index and the stock-recruitment relationship). Stock status was evaluated based on fishing mortality and spawning stock biomass based reference points.

2 Biological parameters and assumptions

2.1 Stock structure

Based on the Indian Ocean Regional Tuna Tagging Program (RTTP-IO) indicated that yellowfin tuna frequently travel over large distances, supporting the assumption that they are part of a single biological stock in the Indian Ocean (Artetxe-Arrate et al, 2021). The yellowfin tuna stock structure in the Indian Ocean is considered as a single stock. Ongoing researches including genetic studies and otolith microchemistry, continues to investigate possible sub-populations to improve the accuracy of stock assessments and management strategies (Grewe et al. 2020).

2.2 Movement

This study didn't consider the movement since the model does not allow movement to be modeled.

2.3 Growth model

The length-weight relationship of Indian Ocean yellowfin tuna based on the equations used to convert from standard length into round weight displayed in the IOTC website (https://iotc.org/WPTT/25/Data/13-Equations). Based on gear types, the length-weight equation parameters are categorized into those for purse seine (PS), pole and line, and gillnet gears, and those for longline and other gears. Von Bertalanffy growth equation derived from the Farley's study. Based on the results, we applied the 2-stage VB model. The small fish (< ~55 cm fork length, FL) grows faster than adult fish, therefore, the model showed a change in otolith growth at ~55 cm FL.

2.4 Reproduction

The fraction of year elapses before spawning occurs (before spawning stock biomass calculation) was assumed to be 0.2, implying yellowfin tuna spawns during December to March (Muhling et al. 2017). The maturity was model using length-based logistic function suggested by Zudaire et al. (2022) (Figure1).

2.5 Natural mortality

In this study, natural mortality (M) for yellowfin tuna was estimated using a methodology grounded in biological characteristics, informed by recent advancements from Hoyle (2021), Maunder et al. (2023), and Artetxe-Arrate et al. (2024). The primary method adopted follows a Lorenzen-type relationship (Lorenzen, 1996), where M is initially high for juvenile fish, decreases as they age, and increases again post-maturity. This relationship was linked to length and growth parameters ($L\infty$ and k) to rescale mortality across different ages. The reference mortality rate was derived using an assumed maximum age (Amax) of 11.7 years (Farley et al., 2023), reflecting age-specific survival variations within the population (Figure2).

3 Data

3.1 Definition of fisheries

Purse seine and longline are the main gears catching yellowfin tuna in the Indian Ocean. Prior to 1980, yellowfin tuna were primarily caught by longline fisheries. In the 1980s and 1990s, total catches increased due to the development of purse seine fisheries and the expansion of established methods, such as fresh-tuna longline, gillnet, and baitboat. Purse seine catches then became dominant, especially in free school operations, which contributed to peak catches in the early 2000s. From 2015 to 2023, purse seine remained the primary gear type, accounting for around 35% of total catches. The purse seine method includes free school and log (FAD-associated) school types, with recent years showing about 70% of purse seine catches from log-associated operations. The majority of yellowfin tuna catches are taken from the western equatorial region of the Indian Ocean. The threat of piracy between 2008 and 2012 caused many purse seine and longline vessels to avoid waters off Somalia, Kenya, and Tanzania, impacting catch levels, particularly for freezer longliners.

Based on the characteristics of the fisheries, for this study, yellowfin tuna are assumed to be subject 4 fisheries: longline (LL, fleet1) (including deep-freezing, fresh, exploratory, targeting swordfish longline), purse seine - free school (PS-FS, fleet2), purse seine - log school (PS-LS ,fleet3), other fisheries (OT, fleet4). Catch by fisheries was shown in Figure 3.

3.2 Basic fisheries data

Catch data (total catch and catch-at-age) are basic fishery data for assessment using ASAP. The time spans of catch data of fisheries maintained by IOTC Secretariat are different: LL (1952-2022), PS-FS (1977-2022), PS-LS (1977-2022), OT(1952-2022). In this study, fishery-specific total catch and catch-at-age for 1976-2022 were used as basic data by year for conducting the current stock assessment based on the availability of CPUE and size frequency data. Catch data is the raised catch. We did not include the data for the years pre-1976 since the trial runs indicated that doing so (i.e. increasing too many parameters need to be estimated) always caused non-convergences, probably due to the fishery statistics quality for the earlier period of fishery was poor. Catch-at-age data was estimated by the size frequency data. The age composition for catch for Fleet 1,2,3,4 was shown in Figure 4.

3.3 Indices of abundance

Standardised CPUE indices (1976-2023) were derived using a hurdle generalized linear model (GLM) from longline catch and effort information provided by Japan, Korea, and Taiwan,China (Matsumoto et al. 2024). Joint CPUE was estimated different regions based on the model structure used in the SS3 stock assessment model (Urtizberea et al, 2024). As majority fisheries conducted in R1, we used the index in R1 in the base model. It worth to note that there has an exceptionally high peak of CPUE indices in 1976-78.

4 stock assessment

4.1 Model configurations

The ASAP uses forward computations assuming separability of fishing mortality into year and age components to estimate population sizes given observed catches, catch-at-age, and indices of abundance. Technical details of the ASAP model can be found in Legault and Restrepo (1998) and NOAA Fisheries Toolbox (2013).The objective function in ASAP is the sum of a number of model fits and two penalties. There are two types of error distributions in the calculation of the objective function: multinomial and lognormal. Multinomial distribution is assumed for catch-at-age data, with effective sample size iteratively adjusted based on tentative model runs. The lognormal error distribution is assumed for total catch (in weight), abundance indices, and stock-recruitment relationship (recruitment deviation).

The CV for total catch in model fit was assumed to be 0.3 for each of four fisheries and constant for the whole time period. The CV of index data equal 0.3.

Beverton-Holt stock recruitment (S-R) model was adopted in the assessments. Steepness was regarded as most important parameter influencing stock assessment results. The steepness was assumed at 0.8 for the base case.

The Effective sample size (ESS) for catch-at-age for each fishery was estimated by the sample number of the size frequency data.To avoid extreme values, assign a value of 10 to numbers less than 10 and a value of 100 to numbers greater than 100. The ESS range is 10-100.

4.2 Parameter estimation

The following parameters are assumed to be known for the present yellowfin tuna stock assessment in the Indian Ocean (see previous sections for their values):

(1) Length-at-age and weight-at-age;
(2) Age-specific maturity;
(3) Age-specific natural mortality rates;
(4) The deviation for indices of abundance;
(5) The steepness of the B-H stock-recruitment relationship.

The following parameters are to be estimated in the stock assessment in the Indian Ocean:

(1) Recruitment in each year from 1976 through 2022;
(2) Catchability coefficients (q, constant over time) for the abundance indices.
(3) Selectivity curves for the four fisheries. The selectivity curves for longline fishery were assumed to be Double Logistic (four parameters). The selectivity curves for Purse seine and other fisheries were assumed to be Single Logistic (two parameters).
(5) Initial population size and age structure;
(6) Fully recruited fishing mortality (F_{mult}) for each fleet for the first year, and deviations for F_{mult} for the remaining years.

4.3 Management quantities

The program computes a number of biological reference points (BRPs) based on the estimated selectivity pattern, weights at age, natural mortality rate, and relative fishing intensity among fleets in the terminal year of the assessment (i.e., 2022). The reference points computed are F_{MSY}, $F_{current}/F_{MSY}$, SSB_{MSY}, $SSB_{current}/SSB_{MSY}$, MSY, $C_{current}/MSY$. The term “current” denoted last year in the model (i.e., 2022).

4.4 Base case and sensitivity analysis

The base case model is chosen so as to most probably represent the real state of nature of the Indian Ocean yellowfin tuna stock based on current knowledge available. The steepness of B-H stock-recruitment relationship and CPUE index were known as key uncertainty sources for many fisheries stock assessments. Therefore, these two parameters were subject to sensitivity analysis using their alternative assumptions (Table 1). Thus, combining steepness assumptions and CPUE assumptions produced 8 scenarios which were used to conduct the present assessment. Base case applied the steepness as 0.8, and CPUE index from R1.

4.5 Retrospective analyses

Retrospective analyses were performed by successively removing the last 4 years of the data (index and catch) and re-running the model to estimate parameters. The key population parameters derived from each analysis were compared. Retrospective analysis was only conducted for the base case model.

4.6 Stock assessment results

The assessment results presented in the following sections are likely to change in future assessments because (1) future data may provide evidence contrary to these results, and (2) the assumptions and constraints used in the assessment model may change. Future changes are most likely to affect the estimates of biomass, recruitment, and fishing mortality.

4.6.1 Model fit diagnostics

There were totally 260 parameters estimated for the present model configurations (base case). Model fit diagnostics was done by looking at likelihood components, the fits of total catch and abundance index. They are shown in Figures 5-7. The model fit the time series of total catch closely except for the first year, it may due to the exceptionally high peak of CPUE indices. Overall, the model fit the CPUE series closely except for the period of 1985-1990.

4.6.2 Recruitment estimates

The recruitment time series for Indian Ocean yellowfin tuna were shown in Figure 8. The first recruitment regimes shifted at around 1977, which much higher level with high recruitment variation. The B-H stock-recruitment relationship curve was shown in Figure 9.

4.6.3 SSB, fishing mortality, catchability, and selectivity estimates

The trends in spawning stock biomass and fishing mortality estimates were shown in Figure 10. The SSB of yellowfin tuna showed a decreasing trend since 1980, coincided with the increasing trend of fishery mortality. Catchability of abundance indices was given in Figure 11. The fishery-specific selectivity-at-age curve was shown in Figure 12.

4.6.4 Retrospective pattern

Retrospective analyses were conducted by removing one year (2022) ,two years (2022 and 2021), three years (2022, 2021, 2020), and four years (2022, 2021, 2020, 2019) of data (Figures 13). The retrospective analyses showed the same trend in the total stock numbers and spawning stock biomass as the base case model, with the Mohn's Rho equals -0.12 and -0.21, respectively . The estimates of average fishing mortality indicates poor model fit with Mohn's Rho equals 0.7.

4.6.5 Biological reference point estimates

Biological references points for yellowfin tuna calculated based on parameter estimates from stock assessment models were given in Table 2. The MSY-related management reference points exhibited significant sensitivity to the steepness parameter and the choice of CPUE index used in the models. When steepness was set to 0.8 with the CPUE index from Region 1 (S1, base case), the current fishing mortality (F_{curr}) was 2.95 times the level corresponding to F_{MSY}, indicating that the fishing pressure was much higher than the sustainable level. In contrast, when the steepness parameter was adjusted to 0.7 (S2), the F_{curr}/F_{MSY} ratio increased to 3.53, suggesting even higher fishing pressure relative to sustainable limits.

The models also demonstrated variability in terms of spawning stock biomass (SSB) estimates. In scenarios where the CPUE index from Regions 2 or 3 was used (S4 and S5), the SSB_{MSY} could not be estimated due to non-convergence, indicating potential issues with model stability under these data configurations. When combining CPUE indices from multiple regions (S7 and S8), the ratio of SSB_{curr}/SSB_{MSY} improved to 0.28 and 0.32, respectively, suggesting a slightly more favorable stock status when incorporating a broader data spectrum.

Similarly, catch-related reference points varied across scenarios. The C_{curr}/MSY ratio in the base case (S1) was 1.5, indicating that the current catch exceeded the sustainable level by 50%. However, when multiple CPUE indices were used (S7 and S8), the C_{curr}/MSY ratio decreased to around 1.45, suggesting a marginally lower level of overexploitation but still indicating unsustainable catch levels.

Overall, these findings highlight the model's sensitivity to steepness and CPUE index selection. The results suggest that using multiple data sources (S7 and S8) can slightly improve the model's robustness, although the stock remains in an overfished and overexploited state across most scenarios. Further refinement of model assumptions and inclusion of additional biological or environmental factors may be necessary to enhance the accuracy and reliability of the assessment.

5 Status of the stock

Eight assessment models were configured for the yellowfin tuna. Four models produced reasonable results. All the effective models suggest that the yellowfin tuna was experiencing overfished and overfishing.

6 Discussion

This work provide a sensitive analysis for age-structure based stock assessment for yellowfin tuna. With comparing the results of SS3 (Urtizberea et al, 2024), our model indicate that the reference points were sensitive to the catchability setting. The ASAP model can’t estimate the effort creep, therefore the catchability is constant over time.

Figures

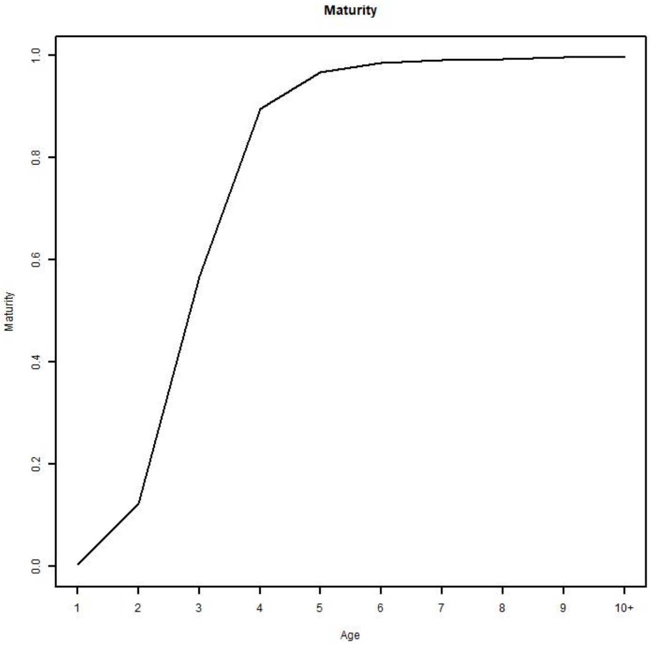

Figure 1 Maturity ogive for Indian Ocean yellowfin tuna

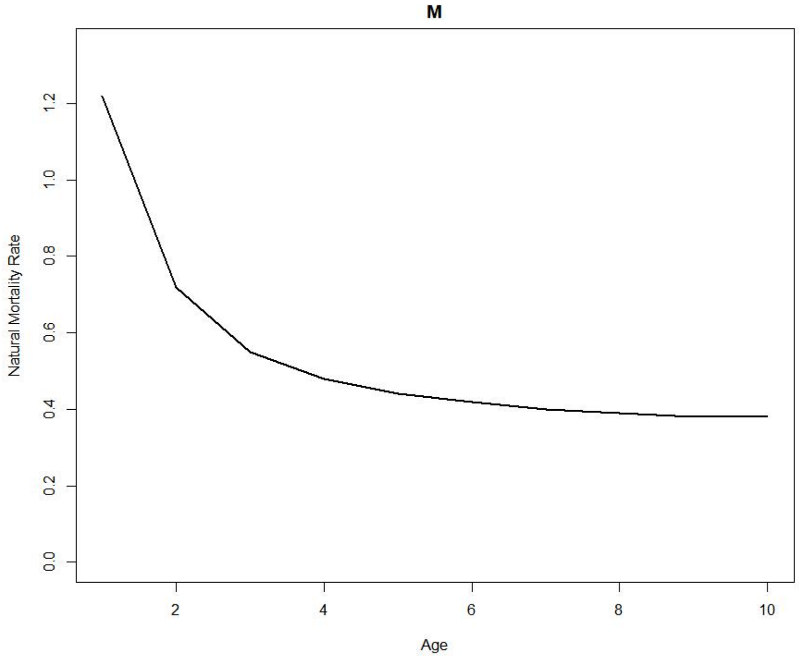

Figure 2 Natural mortality rates for Indian Ocean yellowfin tuna for base case model

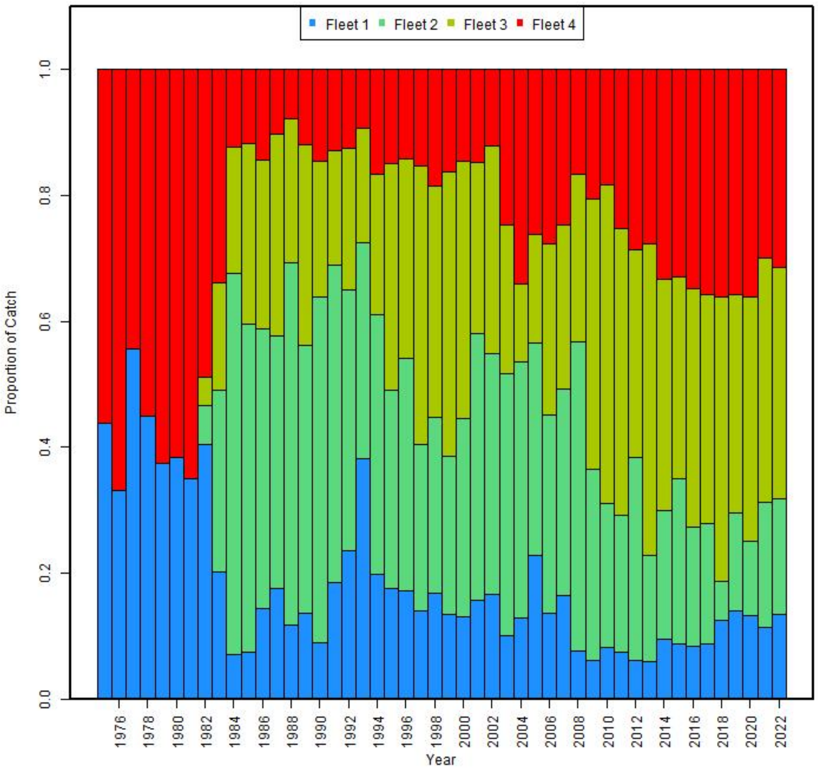

Figure 3 Proportion of catch by fleets of yellowfin tuna in the Indian Ocean during 1976-2022. Fleet 1: Longline fisheries; Fleet 2: Purse seine fisheries with free school;

Fleet 3: Purse seine fisheries with log school; Fleet 4: other fisheries.

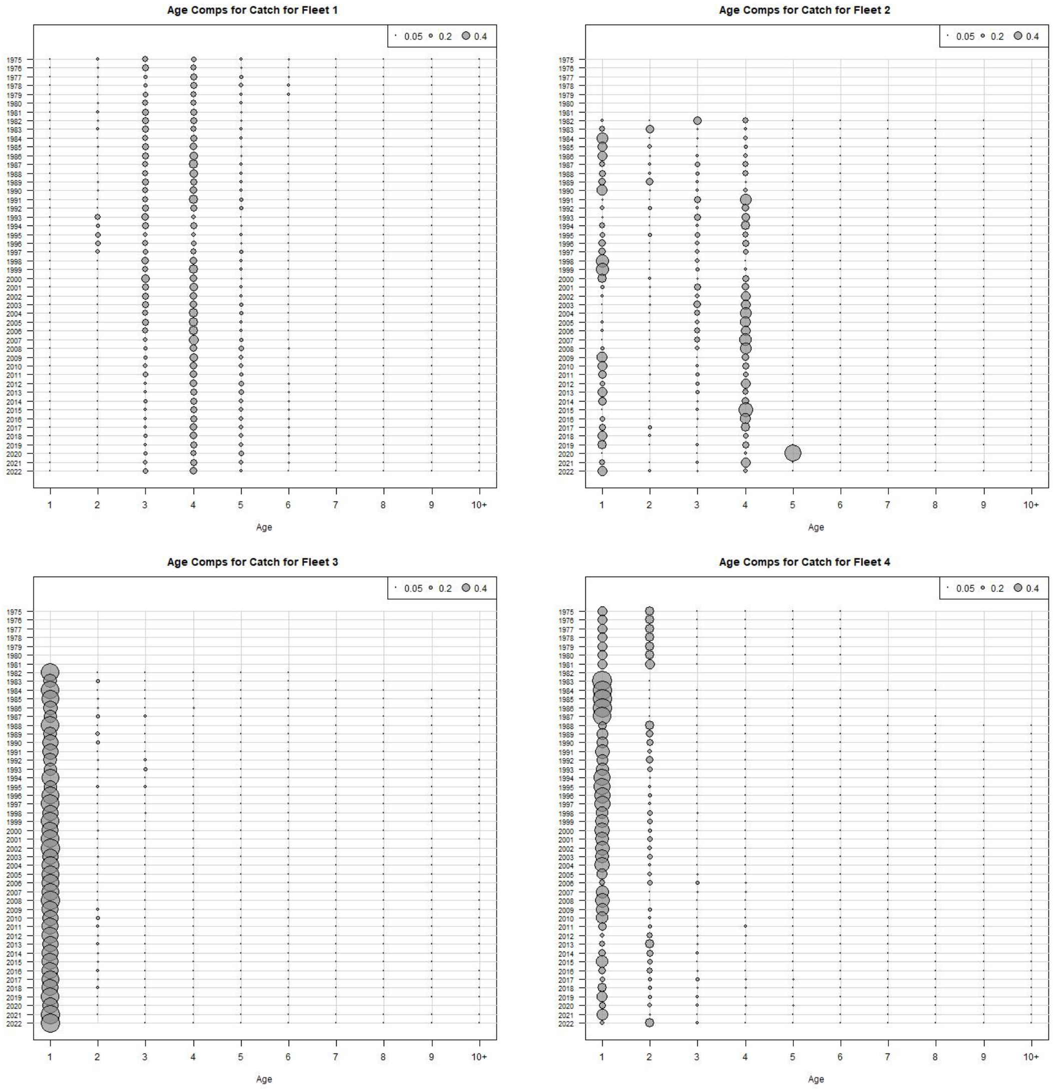

Figure 4 Age composition of catch by fleets of yellowfin tuna in the Indian Ocean during 1976-2022 . Fleet 1: Longline fisheries; Fleet 2: Purse seine fisheries with free school; Fleet 3: Purse seine fisheries with log school; Fleet 4: other fisheries

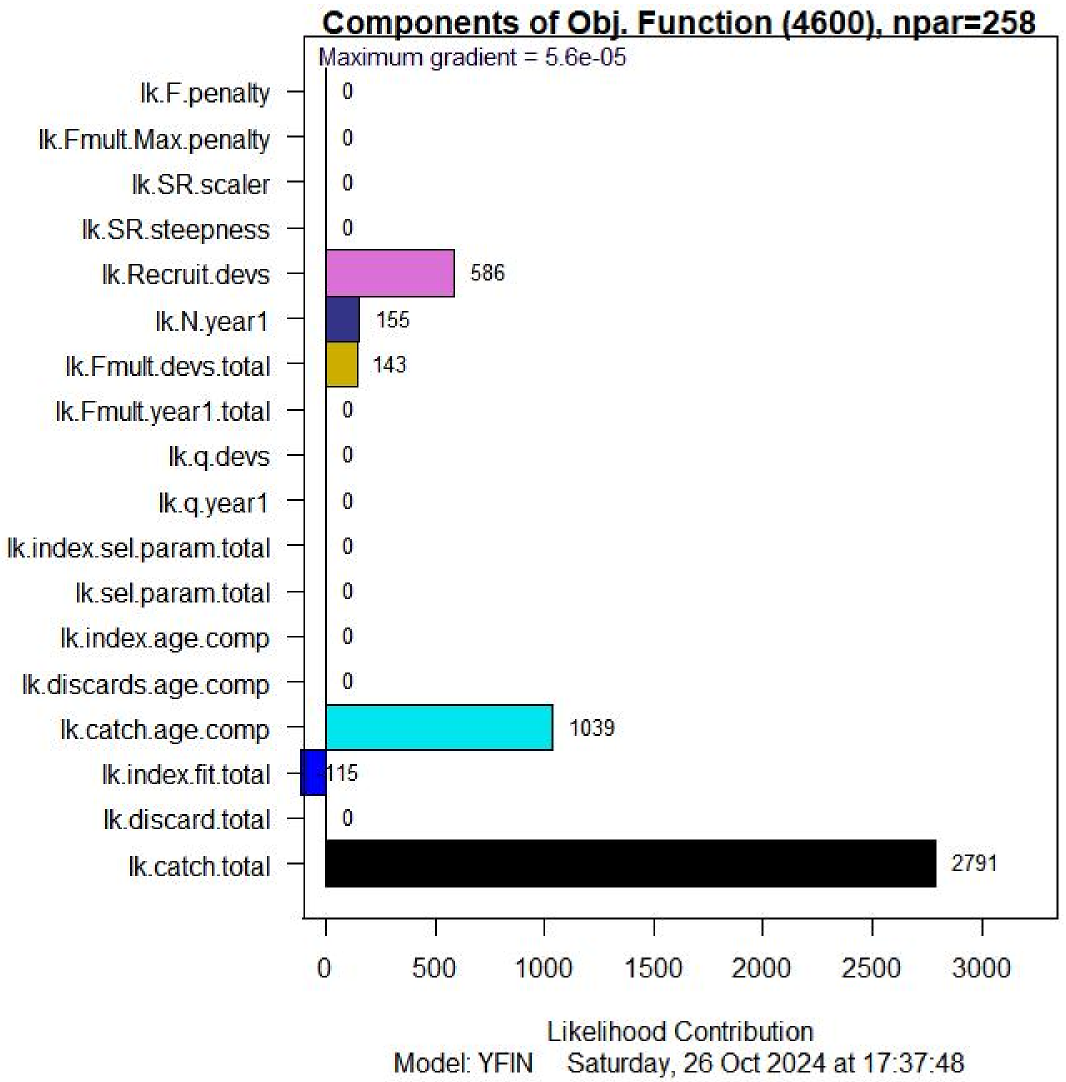

Figure 5 Likelihood contributions of different components in the objective function for the base case model

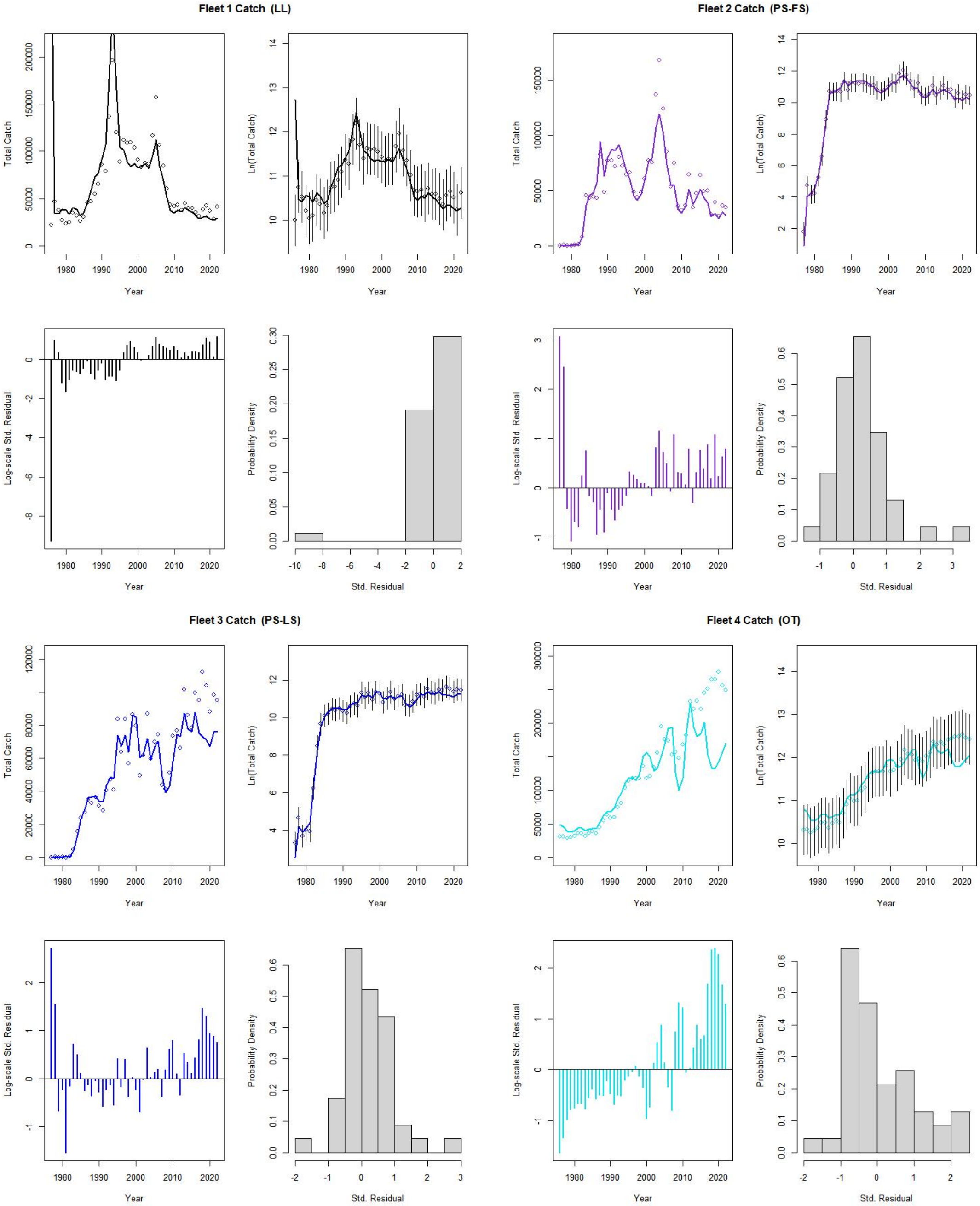

Figure 6 Model fits of total catch data for the base case model

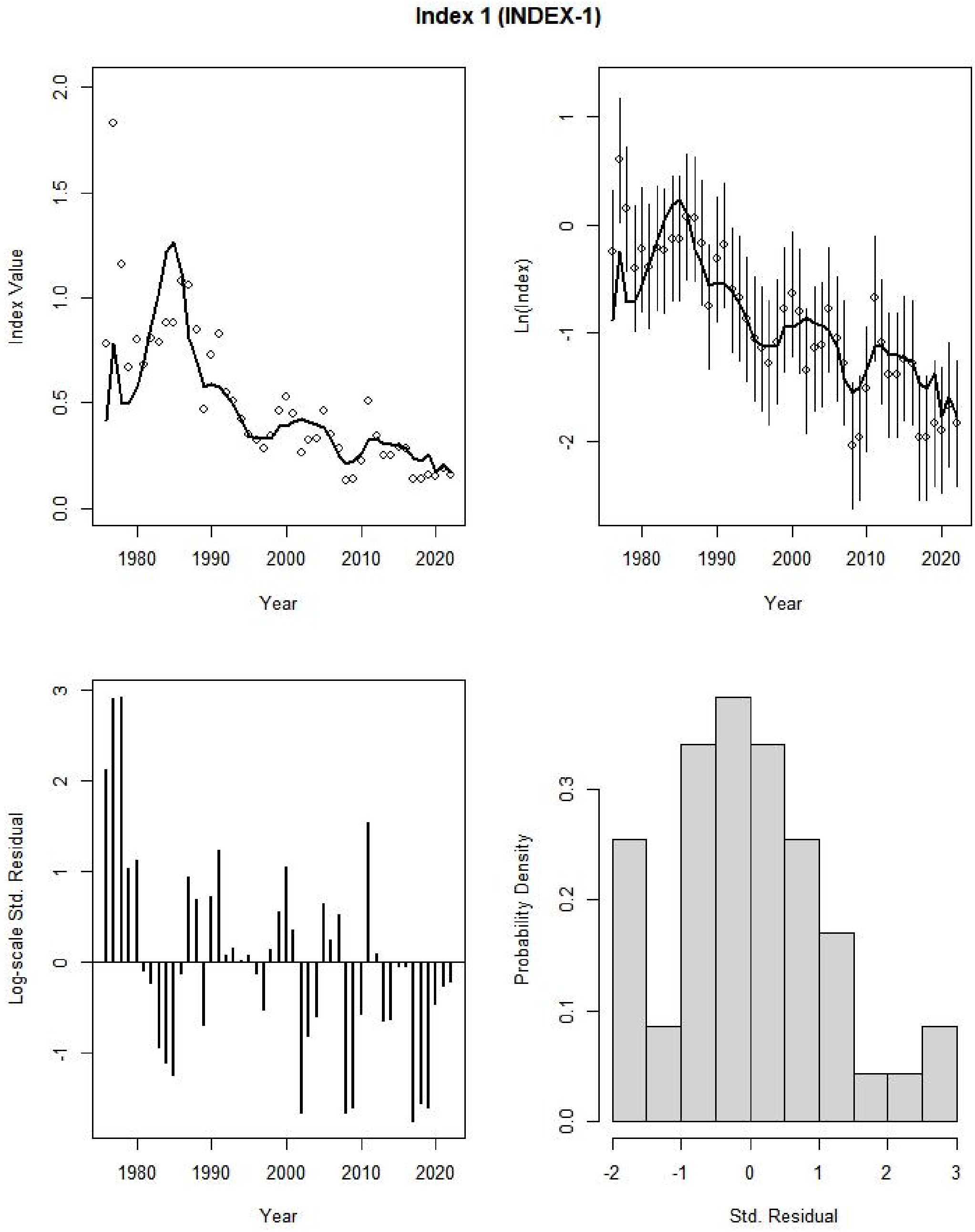

Figure 7 Model fits of abundance indices for the base case model

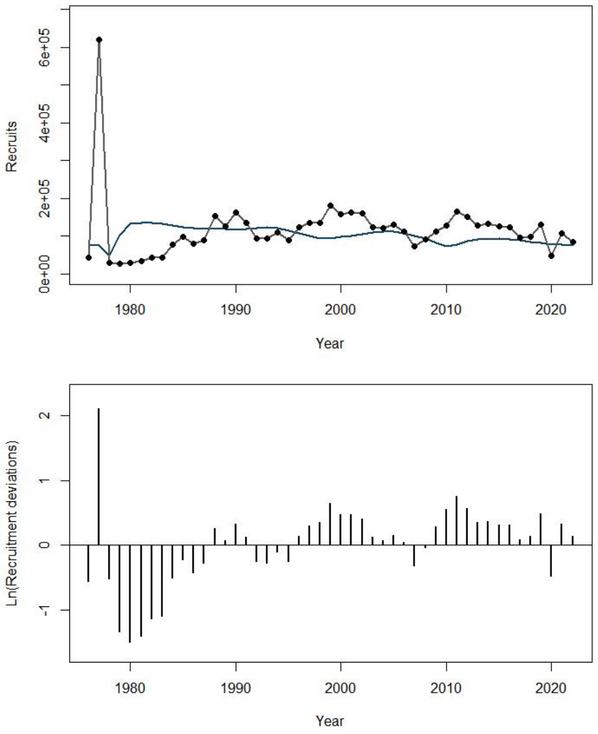

Figure 8 Estimated recruitment for the base case model

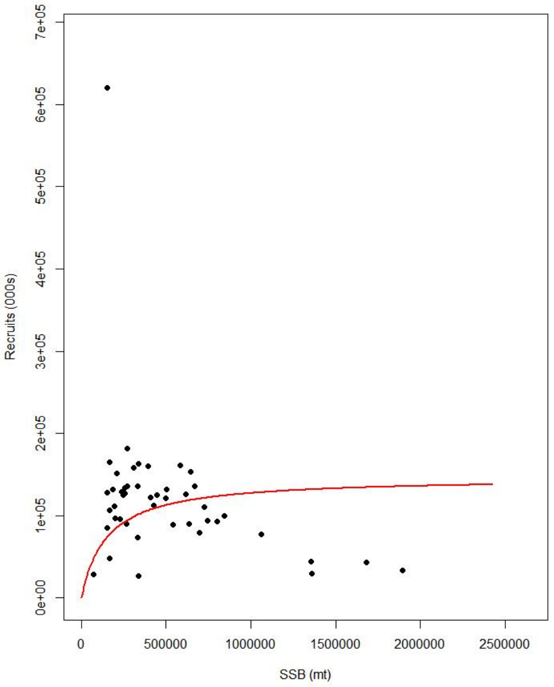

Figure 9 Observed and estimated (red line) spawning stock biomass and recruitment trend for the base case model

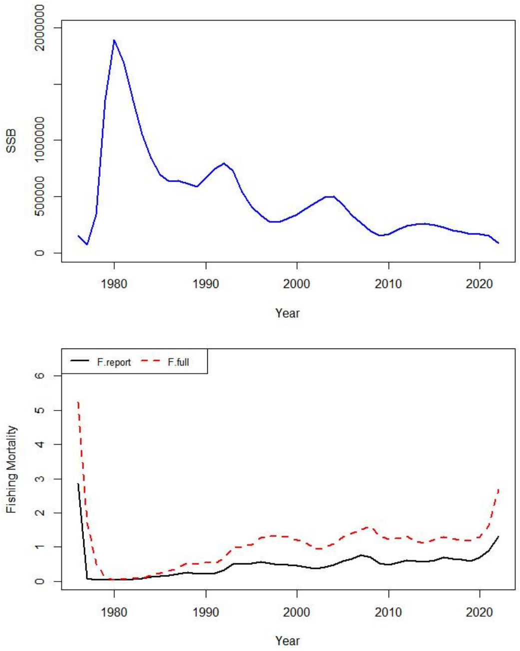

Figure 10 Spawning stock biomass (SSB) and fishing mortality estimates for the base case model

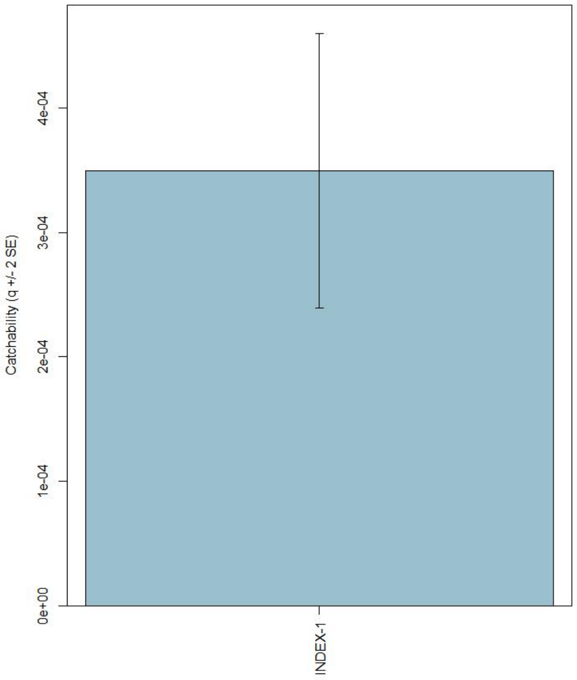

Figure 11 Catchability estimates of two abundance indices for the base case model

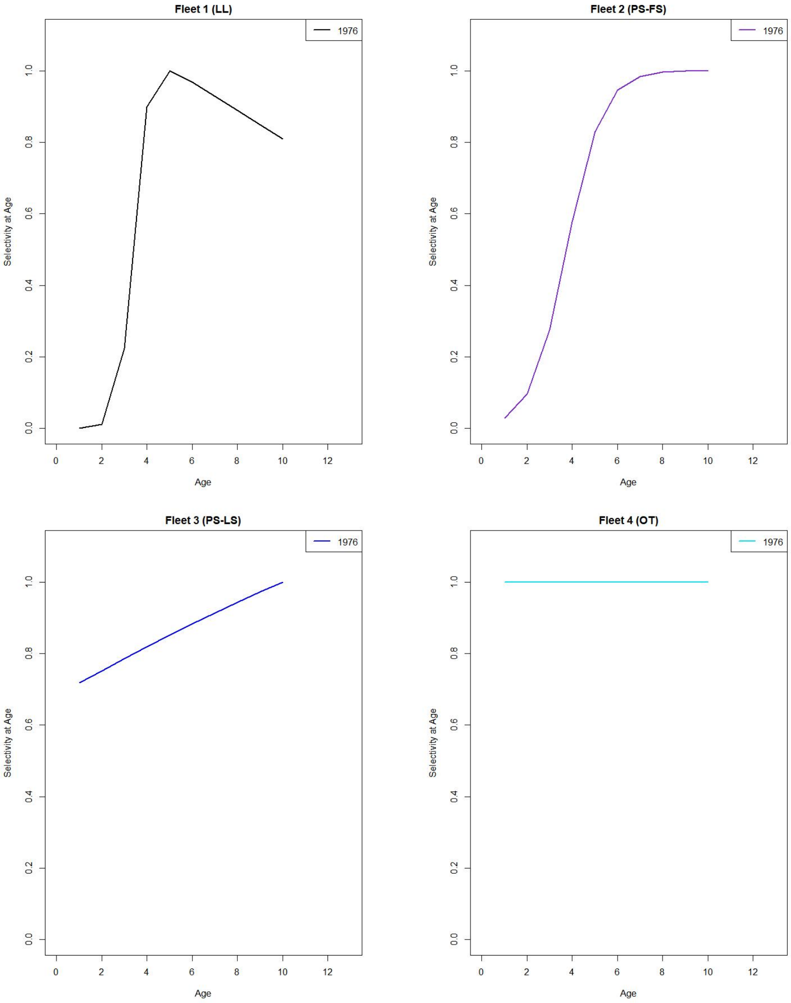

Figure 12 Selectivity-at-age estimates of each fishery for the base case model

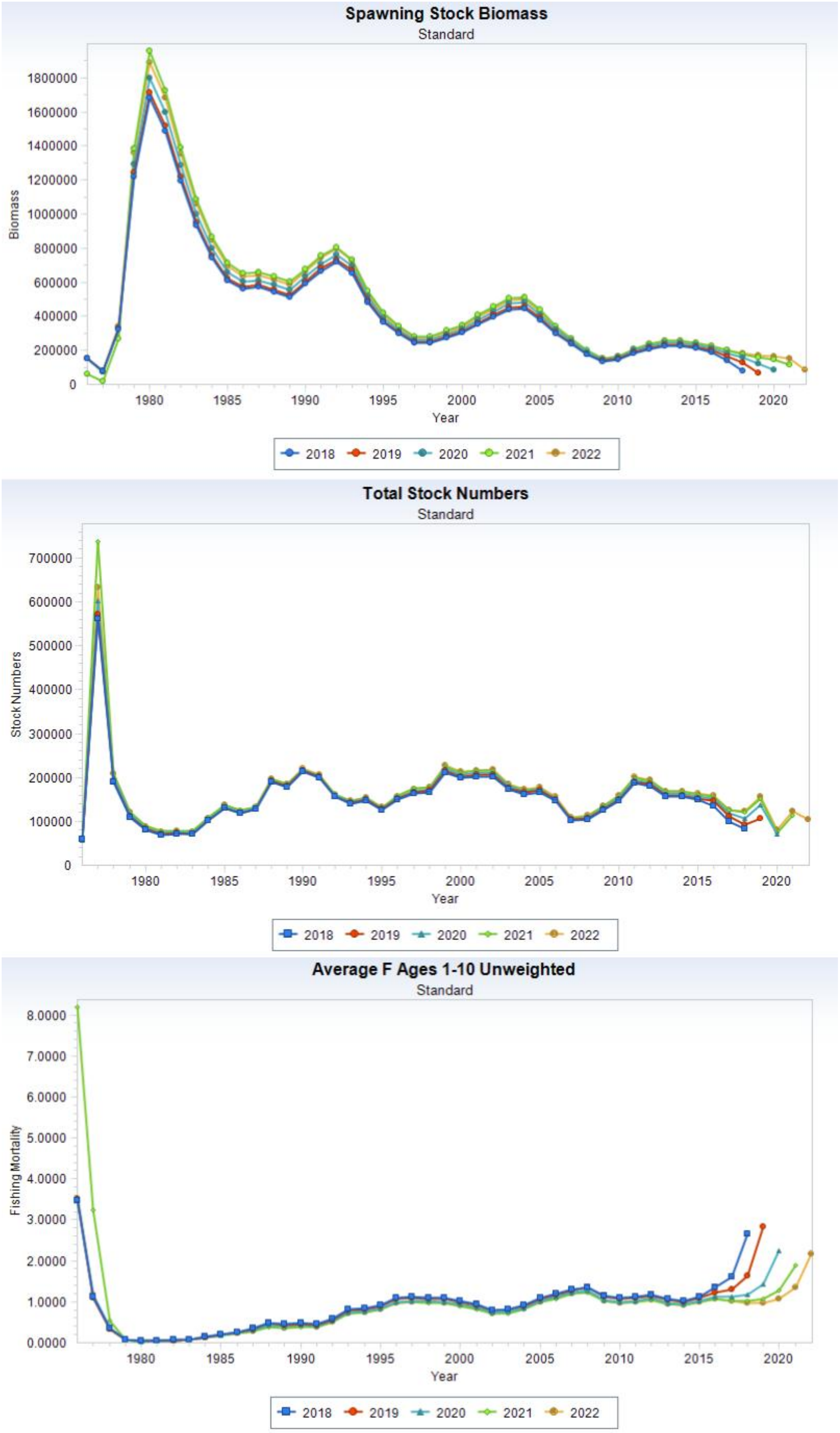

Figure 13 Retrospective comparisons of estimates of the spawning stock biomass, total stock numbers and average fishing mortality

Tables

Table 1 Different scenarios for ASAP stock assessment of yellowfin tuna in the Indian Ocean

Scenarios	Description
S1	h=0.8, CPUE index in R1
S2	h=0.7, CPUE index in R1
S3	h=0.9, CPUE index in R1
S4	h=0.8, CPUE index in R2
S5	h=0.8, CPUE index in R3
S6	h=0.8, CPUE index in R4
S7	h=0.8, CPUE index in R1+R2
S8	h=0.8, CPUE index in R1+R2+R3

Table 2 Biological reference points for base case assessment model and sensitivity analyses for Indian Ocean yellowfin tuna. Unit for catch and biomass: metric ton.

	S1	S2	S3	S4	S5	S6	S7	S8
F_{curr}	1.3	1.2					0.84	0.79
F_{MSY}	0.44	0.34					0.42	0.4
F_{curr}/F_{MSY}	2.95	3.53					2	1.97
SSB_{curr}	84395.5	96908					172743	199708
SSB_{MSY}	588452	921033	Not converged				618609	626680
SSB_{curr}/SSB_{MSY}	0.143	0.1					0.28	0.32
C_{curr}	413108	413108					413108	413108
MSY	276335	335170					285680	288230
C_{curr}/MSY	1.5	1.25					1.45	1.43
	base case							

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