Indian Ocean Tuna Commission
Commission des Thons de l'Ocean Indien

IOTC–2025–WPTmT09-10

Stock assessment of albacore tuna (*Thunnus alalunga*) in the Indian Ocean using Stock Synthesis

9th IOTC Working Party on Temperate Tuna
21 – 259 July 2025
Victoria, Seychelles - Hybrid Virtual Meeting

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1 Executive summary

This paper presents a stock assessment of albacore tuna (*Thunnus alalunga*) in the Indian Ocean using Stock Synthesis (version 3.30.23.02 https://nmfs-ost.github.io/ss3-website/). The albacore tuna assessment model is an age structured (14 years), spatially aggregated (1 region) and two sex model. The catch, effort, and size composition of catch are grouped into 23 fisheries covering the time period from 1950 through 2023. Fifteen indices of abundance, fourteen of which are from longline fisheries were considered for this analysis. At the time of publication of this document, these indices of abundance have not been updated since the 2022 assessment and so span the time period 1975-2020. Therefore, the indices of abundance do not contain data for the final three years of the assessment. As these are the major component predicting biomass within the stock assessment model, this represents a major point of uncertainty within the model outputs. Updated indices of abundance may become available at the time of, or prior to, the assessment meeting, at which point the model may be updated to include these indices.

Although the stock status reference points are expected to change in relationship to the update indices of abundance, preliminary estimated abundance trends show a decreasing stock throughout the time frame of the model, and spawning stock abundance has decreased to approximately 1.15 times SSB_{MSY}. Fishing mortality (F) has increased over the model time frame with F_{2023}/F_{MSY} = 1.3. These results are based on the updated model '*Run_16_From13_SzAtAge_Lambda*'. The reader is reminded that these results are subject to revision.

Albacore tuna are most often caught in longline fisheries in the Indian Ocean tuna fisheries, though some bycatch occurs in the purse seine fisheries as well as other mixed gear fisheries.
This stock assessment was developed based on the 2019 and 2022 assessments along with updates to the data and parameterization. A diagnostic case model is referred to in the main text when presenting the model parametrisation and diagnostics. The upcoming 9th meeting of

the Indian Ocean Tuna Commission Working Party on Temperate Tuna and Bycatch (WPTmT09) will recommend the final parameterisation as a base case model for the provision of stock status.

2 Introduction

Commercial fisheries for albacore tuna (*Thunnus alalunga*) have operated in the Indian Ocean since the early 1950s. The earliest known exploitation was by the Japanese longline fishery in the 1950s, followed by the Korean (KOR) and Taiwanese (TWN,China) longline fisheries in the mid and late 1950s (Kim et al. 2010; Chen 2009). Driftnets were employed in the albacore fishery from the early-1980s until 1992 when an international ban on driftnet fishing came into force. Taiwanese and Indonesian longline catch has recently accounted for around 70% of the total catch. Between 2008 and 2011, following the onset of piracy in waters off Somalia, part of the longline fleets that had traditionally targeted tropical tunas or swordfish in those waters moved towards albacore fishing grounds in the southern part of the Eastern Indian Ocean. Like albacore fisheries in other oceans, the Indian Ocean fishery is characterized by smaller fish at higher latitudes. Unlike other oceans however, there is no significant troll or pole and line fishery for albacore, and since the ban on the driftnet fishery there has been no large-scale targeting of small fish.

Stock assessments of the Indian Ocean albacore stock have been conducted in the past using several different methods, including the non-equilibrium production model ASPIC (Chang et al. 2012, Matsumoto et al. 2012, Matsumoto et al. 2014, Matsumoto 2016), the age-structured production model ASPM (Nishida et al. 2012, Nishida et al. 2016), a Bayesian biomass dynamic model (Guan et al. 2016), and Stock Synthesis (SS) (Kitakado et al. 2012, Hoyle et al. 2014, Langley & Hoyle 2016, Langley 2019, Rice 2022).

The most recent (2022) assessment using Stock Synthesis incorporated data to 2020 (Rice 2022). The assessment incorporated longline CPUE indices for albacore from a collaborative project between Japan (JAP), Taiwan (TWN,China), Korea (KOR), and the IOTC, similar to the work done in 2016 (Hoyle et al 2019. Hoyle et al. 2015, Hoyle et al. 2016). The standardised CPUE indices were derived from operational-level longline data from the three fleets, incorporating cluster analyses to address the effects of target changes and standardisation models included vessel effects and spatial effects. The project built on a study applying similar methods to Indian Ocean bigeye and yellowfin tuna (Hoyle et al. 2015). This analysis is currently being updated, and new indices may be available during or just prior to the WPTmT09 Assessment Meeting, however at present, the model includes the same indices used in the 2022 assessment.

The 2019and 2022 assessments investigated the interactions between the key data sets (CPUE indices and length composition data) and the uncertainty associated with the key biological parameters (natural mortality (M) and the stock recruitment relationship steepness (*h*)). This assessment, similar to the 2022 and 2019 assessments used the fleets-as-areas approach. While the 2019 assessment used four longline fleets, and four corresponding CPUE series (LL1 – LL4), the 2022 and the current (2025) assessment further disaggregate the longline fisheries by quarter. The CPUE in the southwest Indian Ocean are thought to mostly likely to represent the abundance of the albacore tuna stock (Rice 2022, Langley 2019). This area represents the main target fishery with more consistent fishing operations and a significant proportion of the albacore biomass in the Indian Ocean (Rice 2022, Langley 2019). The previous assessment (Rice 2022) included suggestions based on the WPTmT_07 meeting and incorporated changes to the fleet structure, use of the length-frequency data and data weighting.

The previous assessment meeting (WPTmT08) noted that regarding the assessment results:

1) Mirroring of selectivity for fishery F16 (LL 4, quarter 4) to F8 (LL 2, quarter 4) may not be appropriate because the catch-at-size distributions are very different between the southern and northern fisheries. The WPTmT **SUGGESTED** that F16 should be mirrored to F15 (LL4, Quarter 3).

2) The model is very sensitive to changes/updates in length composition data, so the WPTmT **SUGGESTED** that the weighting of length composition data for individual fisheries should be given careful consideration. (particularly LL 3). The WPTmT **NOTED** the length composition data in the northern fishery are fitted poorly (there are

obvious large positive residuals in the upper size range), which may indicate that the variance of size-at-age is not sufficient.

3) The WPTmT **NOTED** that while the sensitivity run which increases CV of the size-at-age to 10% could improve the residual patterns (in the upper size range), it appears to have caused the selectivity in Q2 and Q3 fisheries in LL1 fisheries to be poorly estimated, resulting in a large bias in the predicted mean length for these two fisheries. This suggests that there may be some complicated interactions between growth and selectivity, as well as length composition data, that need to be investigated further. For example, the double normal selectivity in the southern fishery has been constrained to be asymptotic, which may be inconsistent with the albacore population's vulnerability to this fishery

These suggestions have been included in the current assessment.

The WPTmT08 adopted a subset of the stock synthesis (SS) model scenarios for the determination of the stock status of Indian Ocean albacore and the formulation of management advice. The WPTmT08 agreed that the final set of model options should include alternative models based on the CPUE indices for the northwest and southwest. The two indices effectively monitor different components of the albacore stock. It is considered that the CPUE in the western area (LL1 & LL3) may best represent the abundance of albacore. The western area also contains a significant proportion of the Indian Ocean's albacore biomass. Changes in targeting have an impact on the eastern indices (LL2 & LL4).

In advance of the current assessment, a preparatory meeting was held in February 2025 to compile the data sets for the assessment (IOTC 2025). The meeting reviewed the recent biological studies, catch data and suggested parameterisation of the assessment in advance of the WPTmT09 assessment meeting. Similar to the 2022 assessment this assessment reference case has been developed under a scenario where the Southwest CPUE is considered as most representative, with longline and purse seine length frequency included, the ‘other fisheries’ length data is excluded.

This report presents the preliminary results of the 2025 stock assessment modelling of Indian Ocean albacore tuna using Stock Synthesis (Version 3.30.23_02). The assessment results will be finalized at the WPTmT09 meeting.

3 Methods

3.1 Data

There are many different fleets catching albacore tuna in the Indian Ocean, with the main fleets consisting of longline fleets from distant water fishing nations. The data used in the albacore tuna assessment consist of fishery specific catch and length composition data along with standardised longline CPUE indices. The details of the configuration of the fishery specific data sets are described below.

There is enough uncertainty about the selectivity assumptions with respect to time, and the interannual variability with respect to the numbers of size composition data, that the size composition data are not expected to be very informative about year-class strength. Hence, in the assessment presented here, the length-composition data are down weighted so as to inform the selectivity and recruitment but not alter the model fit to the abundance trend.

3.2 Spatial stratification

The 2016 assessment partitioned the Indian Ocean into four quadrants demarcated at 25°S latitude and 75°E longitude (Langley & Hoyle 2016). The spatial stratification was primarily adopted to partition the longline fisheries by the size of fish caught; the longline fisheries in the southern area tend to catch albacore that are considerably smaller than the fisheries in the northern area (Chen et al. 2004, Geehan & Hoyle 2013, Nikolic et al 2013). Higher longline CPUE for albacore has been associated with the North Subtropical Front in the southern Indian Ocean (30–35°S latitude) where SST was 15–19°C (Lan et al 2011). There is no indication of a longitudinal trend in the size of albacore caught by the longline fisheries (Geehan & Hoyle 2013) and the overall distribution of the southern longline fishery is continuous throughout the southern region (Figure 1). However, during the history of the fishery there were periods when there was an appreciable separation between the operation of the longline fishery in the southwestern and south-eastern quadrants of the Indian Ocean, most notably during the 1960s and 1970s (Figure 2). To account for potential longitudinal variation in the key fishery data sets, the northern and southern areas of the Indian Ocean were partitioned at 75°E longitude. An investigation of the stock structure of Indian Ocean albacore by morphometric and DNA sequence methods categorized samples into two major groups partitioned by 90°E longitude suggesting that there may be two albacore stocks in the Indian Ocean (Yeh et al. 1995). Thus, the spatial stratification of the assessment data sets can be applied to approximate the more complex stock structure within the Indian Ocean.

The four regions of the Indian Ocean were used to define the spatial domain of the model fisheries and define the region-specific longline data sets for the CPUE analyses (Hoyle et al 2016 and 2019, Kitado et al 2022). There are apparent differences in the trends in albacore CPUE indices between the two southern areas over the last decade.

3.3 Temporal stratification

The time period covered by the assessment is 1950-2023 representing the period for which catch data are available from the commercial fishing fleets. The model was further stratified by quarter of the calendar year (Jan-Mar, Apr-Jun, Jul-Sep, Oct-Dec) and the various data sets were compiled accordingly.

3.4 Definition of fisheries

The spatial stratification was applied to define model fisheries based on region and fishing gear. These “fisheries” are considered to represent relatively homogeneous fishing units, with similar selectivity and catchability characteristics. As an update for this assessment the single aggregate longline fisheries by region have been separated into quarterly fisheries, thus there are sixteen longline fisheries, as opposed the previous assessment which used four.

A total of twenty-three fisheries were defined, including 16 longline fisheries (one per quarter per region), two driftnet fisheries, one purse seine fishery and four 'other' fisheries that account for the troll, sport fish, and miscellaneous fisheries by region (Table 2).

Longline northwest (LL1): The composite longline fishery in the north-western region was initially developed by the Japanese fleet in the mid-1950s. Data for the Taiwanese (TWN,China) fleet are available from the late 1960s and the fleet has operated continuously since then. Japanese fishing effort declined in the early 1970s and remained relatively low until the mid-1990s. Fishing effort by the Japanese fleet recovered to a moderate level during the late 1990s and 2000s but was at a relatively low level from 2010. The composite longline fishery included effort by the Korean longline fleet during the late 1970s and 1980s. Limited albacore catches have been taken by other fleets, most notably the Chinese longline fleet operating during the last decade.

Longline northeast (LL2): The composite longline fishery in the north-eastern region has a similar composition to the LL1 fishery. The Japanese fleet was the dominant component of the fishery during 1953-1970 and continued to operate at a lower level over the subsequent years. Data for the Taiwanese (TWN,China) fleet's operations in the area are available from the late 1960s, while the Korean fleet primarily operated in the fishery during 1976-1987.

Longline southwest (LL3): The composite longline fishery in the south-western region was dominated by the Japanese fleet from the inception of the fishery in the late 1950s until the introduction of the Taiwanese (TWN,China) fleet in the mid-1960s. Since the early 1970s, most of the catch was taken by the Taiwanese (TWN,China) fleet. There was a short period of higher Japanese catch during 2004-2008.

Longline southeast (LL4): The composite longline fishery in the south-eastern region was dominated by the Japanese fleet from the inception of the fishery in the late 1950s until the introduction of the Taiwanese (TWN,China) fleet in the early 1970s. During 1974-2006, most of the catch was taken by the Taiwanese (TWN,China) fleet. Japanese longline catches increased from 2006 and in recent years considerable catches have also been taken by China and Korea.

Driftnet fisheries: Driftnet fisheries were defined for the south-western (**DN3**) and south-eastern (DN4) regions. These fisheries were comprised exclusively of driftnet vessels flagged to TWN,China, which operated in the southern waters of the Indian Ocean from 1982 until 1992 when the UN adopted a worldwide ban on driftnets.

Purse seine: A single purse seine fishery (**PS1**) was defined as virtually all purse seine catch was taken within the north-western region. The purse seine fishery is made up of various fleets although most of the catches of albacore are reported by purse seiners flagged to the European Union and other fleets under EU ownership, including the Seychelles (86% of the total catches of albacore over the time series). The purse seine catches of Iran, Japan, Mauritius, Thailand, and the Republic of Korea are also included in the fishery.

Other: A miscellaneous ("**Other**") fishery was defined for each of the regions. The "**Other**" fisheries include various coastal longline, gillnet, trolling, hand lines and other minor artisanal gears, which are used in coastal countries of the Indian Ocean. Collectively, the "**Other**" fisheries account for a small proportion of the Indian Ocean albacore catch (2% of the entire catch). Most of the catch was reported by Indonesia with the remainder of the catches reported by Mauritius, Réunion and Mayotte (EU), Comoros, Australia, South Africa, and East Timor.

3.5 Total catch

Catch data were compiled by IOTC secretariat based on the fishery definitions (IOTC-2025- IOTC-2025-WPTmT09-AS-ALB_02_SS3.xlsx). All catches were expressed in metric tonnes (t). There were minor changes in the gear specific catch histories from the previous assessment (Rice 2022). The longline fisheries for albacore developed from the mid-1950s and total annual catches averaged about 17,000 t during 1960-1980 (Figure 3). Catches increased during the period of driftnet fishing in the late 1980s and early 1990s and continued to increase with the expansion of the longline fishery in the late 1990s to reach a peak in catch of 40-45,000 t in 1998-2001. Total catches declined to about 30,000 t in 2003-2006 and have since fluctuated between 33-43,000 t per annum (Figure 3). During the last decade (2014-2023), the longline fisheries have accounted for 90% (down from 95% in the 2022 assessment) of the total albacore catch apportioned amongst the regions as follows: northwest 19%, northeast 15%, southwest 47% and southeast 19%. Most of the catch from the southern longline fisheries occurs during the 2nd and 3rd quarter of the year, similar to catches from the north-western longline fishery (compared to the previous assessment when catches were predominantly taken in the 4th quarter).

Longline in the northwest region (LL1). **Fishing Fleets 1-4.** The longline catch was relatively low from the north-western region during the late 1980s and early 1990s immediately following the reduction in fishing by the Korean fleet and during a period of low catch by the Japanese fleet. The high catches in 2000 and 2001 were predominantly attributable to higher catches by the Taiwanese (TWN,China) fleet in those years (Figure 3). Annual catches averaged about 7,000 t per annum over approximately the last decade (2014-2023), with the average catch by quarter being 1206, 742, 907, and 1489 mt for quarters 1-4 respectively.

Longline in the northeast region (LL2). **Fishing fleets 5-8.** The higher catches from the fishery in the late 2000s (2007 and 2008) are primarily attributable to higher catches by the Taiwanese (TWN,China) fleet in 2007 and 2008 and the Indonesian longline fleet during 2009 and 2010. Catches were generally declining from the early 2000’s to the approximately 2015, after which they increased in all quarters (Figure 2), and averaged 1185, 800, 1011, 1411 mt .by quarter (1-4 respectively) over 2014-2023.

Longline in the southwest region (LL3) **Fishing fleets 9-12.** The high catches from the fishery during 1996-2002 are primarily attributable to a considerable increase in catch by the Taiwanese (TWN,China) fleet during that period (Figure 2). Annual catches dropped markedly in 2003 and the catch from the Taiwanese (TWN,China) fleet remained relatively low during 2003-2005. Annual catches increased steadily since about 2006, most notably in region 2. Quarterly catches averaged 887,1382, 1292 and 1012 by quarter (1-4 respectively) between 2014-2023, with the highest level of catch of nearly 21,000 mt in 2019, followed by 18,000 mt in 2023.

Longline southeast region (LL4) **Fishing Fleets 13-16.** Longline catches from the south-eastern region reached an historically high level of about 14,000 mt in 2022. This is an unusually high catch, as annual catches have remained steady around 5-7000 mt in recent years. Average quarterly catches are about 895, 1500, 1343, and 852 mt for quarters 1-4 respectively for the past 10 years (2014-2023).

3.6 Relative abundance indices

Like the 2022 assessment, for each of the four regions, standardised CPUE indices for albacore tuna were derived using generalized linear models (GLM) from operational longline catch and effort data provided by Japan, Korea, and Taiwan, China (Kitakado et al 2022). Contrary to the 2019 assessment data from the Seychelles was not used. Cluster analyses of species composition data by vessel-month for each fleet were used to separate datasets into fisheries that are believed to target different species or species compositions. Selected clusters were then combined and standardized using generalized linear models. In addition to the year-quarter, models included covariates for vessel identity, 5 square location, effort and cluster. The analysis is a refinement of the approach used to derive the CPUE indices included in the 2016 and 2019 albacore stock assessment (Hoyle et al 2016, Hoyle et al. 2019).

Four sets of CPUE indices by year-quarter were derived based on different treatment of the fishing vessel variable in the CPUE modelling, resulting in one LL fleet by region (Kitakado et al 2020). These four regional CPUE series were then dis-aggregated by quarter, resulting in 14 CPUE series pertaining to quarters 1-4 for regions 1-3 and quarters 2 & 3 for region 4. Models were run for the period 1975-2020, the early time period included in the previous assessment was not considered as previous assessments have highlighted that the large decline in the CPUE indices during the early period (1960- 1970) was not consistent with the relatively low catches taken from each of these regions during the period (Langley & Hoyle 2016, IOTC 2019).

CPUE indices for regions 1-3 incorporated the effects of target and effort in the delta-component and all the effects including the quarter-space interactions in the positive lognormal component. Due to instability with same model with data from region 4, the log-normal model was used an alternative approach. The study authors note that the diagnostics plots show some deviation from the normal distribution.

The CPUE indices from region 1 are characterized by a decline in the magnitude and variability of the indices through the timeseries (Figure 4). The CPUE indices from region 2 are characterized by higher and more variable CPUE in quarter 2, compared to the other quarters, of which quarters 3 and 4 are the most stable. The CPUE series from region 3 are similar to region 2 with higher and more variable CPUE in quarter two, with lower and less variable standardized values in quarter 3, 4, and to an extent in region 1. The high variability in the region 3 CPUE indices during the later part of the 1970s may have been primarily attributable to a shift in targeting behaviour (Figure 4).

A short time series of annual Taiwanese (TWN,China) driftnet CPUE indices is available from 1985–1992 (Chang & Liu 1995) (Figure 5). The indices exhibit a high degree of interannual variability with high CPUE indices for 1987 and 1990. The reliability of the indices as an index of albacore abundance is unknown, although the high variability may provide some indication of variation in year class strength during the period given that the driftnet fisheries typically catch a relatively narrow length range of albacore (corresponding to fish of about 1–2 years old). The annual indices were assumed to represent the relative abundance in the first quarter of the year (corresponding to the peak season of DN catch).

3.7 Size composition data

Longline fishery

Size frequency data are available for the Japan longline fishery from 1965. Length and weight data were collected from sampling aboard Japanese commercial, research and training vessels. Weight frequency data collected from the fleet (as live weight) have been converted to length frequency data via a weight-length key. Levels of sampling aboard the Japanese composite longline fleet over time were uneven in terms of both the sampling platform (commercial and non-commercial vessels) and sampling source (fishermen, scientists, observers). While in recent years most of the samples available have come from scientific observers on commercial vessels, in the past samples came from training and research vessels (scientists), and commercial vessels (fishermen).

Length frequency data from the Taiwanese (TWN,China) longline fleet are also available from 1980. In recent years, length data are also available from other fleets and periods (e.g. Indonesia fresh tuna longline, Seychelles, etc.). Prior to the mid-2000s the length frequency data set is dominated by sampling from the Taiwanese (TWN,China) deep-freezing longline fleet. Length samples from this component come from commercial vessels and include lengths recorded by fishermen and, to a lesser extent, lengths measured by scientific observers on some of those vessels in recent years. A review of the Taiwanese (TWN,China) length frequency data identified major differences in the length frequencies of albacore recorded before and after 2003, with most of the smaller albacore missing from the length distributions since that year (Geehan and Hoyle 2013 and Hoyle et al 2021). Following the previous assessment concerns regarding the reliability of these data, all length samples collected from the Taiwanese (TWN,China) longline fleet via logbooks from 2003–onwards were excluded from the length composition data sets.

Purse seine fishery

Purse seine fisheries catch adult albacore, as a bycatch (approximately 90-120 cm TL), in the western central Indian Ocean. Albacore lengths are measured in port, by enumerators, during the unloading of purse seiners flagged in the EU and Seychelles. Length samples are available from the fishery from 1990-2020. The ESS of the individual samples was determined in the same manner as described for the longline fisheries.

Driftnet fishery

Driftnets catch juvenile or sub-adult albacore (62-75 cm) (Figure 15). The 2019 assessment was the first time length composition data were available from the Indian Ocean fishery. The data are from sampling of the Taiwanese (TWN,China) driftnet catch during 1985-1991. These data were recently provided to IOTC by T. Nishida (IOTC 2019). The same data were included in the 2022 and 2025 assessments.

Length Frequency Data Weighting

Given the recommendation of the WPTmT08 that the length composition data weighting by fisheries should be given careful consideration the following protocol was adopted:

1) A minimum annual sample size of 30 fish measured by fleet and quarter was adopted
2) The initial effective sample size (ESS) was calculated as the square root of the number of fish measured following the methods outlined in Rice et al. 2025 (*in prep*).
3) The samples were assigned a relatively low ESS due to concerns regarding the reliability of the length samples from some key data sets.

4 Model Assumptions

The most important model assumptions are described in the following sections. Standard population dynamics and statistical terms are described below, while equations can be found in Methot (2000, 2009). Attachment 1 is the template specification file for all of the models and includes additional information on secondary elements of model formulation which may be omitted in the description below. All of the specification files are archived with the IOTC Secretariat. Table 2 lists the assumptions for the sensitivity runs.

4.1 Software

The analysis was undertaken with Stock synthesis SS V3.30.23.02, 64-bit version (Methot 2000, 2009, executable available from http://nft.nefsc.noaa.gov/SS3.html), running on MS Windows™ 10). Typical function minimisation of the fully disaggregated model on a 3.0 GHz personal computer required about 25 minutes. Additional simplifications and aggregations could probably reduce the minimisation time further, without significant loss to the stock status inferences.

4.2 Population Dynamics

The assessment model was structured by sex and age with age classes of 0-13 years and an aggregate age class of 14+ fish. The model commences in 1950 at the start of the available catch history and continues to 2023. The initial population age structure was assumed to be in an unexploited, equilibrium state. Model years are partitioned into four quarterly seasons. A single spatial structure for the Indian Ocean albacore stock was used in conjunction with the quarterly disaggregated survey and fisheries, based on the partitioning of the Indian Ocean into four regions (Figure 1).

4.3 Biological inputs and assumptions

Sex Ratio

Across all oceans there are documented differences in the patterns of sex ratio at recruitment and at older ages and larger sizes, these patterns are likely to be caused by features of albacore biology. Males have been shown to grow considerably larger than females in the north Pacific

(Chen et al. 2012), south Pacific (Williams et al. 2012), north Atlantic (Santiago and Arrizabalaga 2005), and Mediterranean (Megalofonou 2000). However, there is no evidence for unbalanced sex ratio at the age of recruitment. Sex ratio at recruitment was assumed to be equivalent (1:1).

4.4 Growth

The standard assumptions made concerning age and growth in the SS model are (i) the lengths-at-age are assumed to be normally distributed for each age-class; (ii) the mean lengths-at-age are assumed to follow a von Bertalanffy growth curve. Following the previous assessment this study used the Farley et al. (2019) estimation of the age and growth of Indian Ocean albacore. The study sampled albacore from the western Indian Ocean, primarily from the longline fishery with smaller fish also sampled from pole-an-line and purse seine fisheries. The sampled fish ranged in length from 74 to 108 cm FL for females and 67 to 115 cm FL for males (Farley et al. 2019).

Reproductive potential of female albacore was assumed to be equivalent to south Pacific albacore maturity-at length (Farley et al. 2014) (Figure 7). This ogive takes into account sex ratio, sexual maturity, spawning fraction, and fecundity and so represents female reproductive output at length. The ogive has fish attaining sexual maturity at about 85 cm and 50% reproductive potential is reached at about 92 cm (Figure 7). When converted to age using the Indian Ocean albacore growth curve (Farley et al. 2019), sexual maturity is attained at about age 4 years and 50% reproductive potential is reached at about 5 years.

4.5 Natural mortality

Natural mortality was assumed to be 0.3 for both sexes, based on the previous assessment and the value applied in the north Pacific and the north Atlantic albacore stock assessments. Age specific natural mortality at age could be investigated in a sensitivity analysis, however it was not done in the 2025 assessment as the main abundance indices were not updated.

4.6 Recruitment

The model partitions the population into 14 year-quarter age-classes in one region (Figure 1). The last age-class comprises a “plus group” in which natural mortality and other characteristics are assumed to be constant. The population is “monitored” in the model at year quarter time steps, extending through a time window of 1950-2023. The main population dynamics processes are as follows:

Recruitment in the model occurs in the fourth quarter of each year, reflecting the summer spawning season (and the ageing protocol that assumed a birthday of 1 December Farley et al. 2019). Recruitment was based on a Beverton-Holt (BH) stock recruitment relationship (SRR) and annual deviates were estimated for the period of the model where there were the most data (1975−2021). Deviates from the SRR were given a small penalty, so that recruitment estimates in periods with less data were estimated closer to the mean. The applied penalty assumed that the true standard deviation of recruitment deviates (σR) is 0.3, reflecting the upper range of the magnitude in the. variation of recruitment deviates estimated during preliminary modelling. Imperfections in models and lack of full information in the data cause models to underestimate recruitment variability. Recruitment variability is assumed to be lognormally distributed, therefore mean recruitment is higher than median recruitment. Equilibrium recruitment is meant to represent the average recruitment through time, so the median value in the recruitment function must be bias-corrected upwards. Following Methot and Taylor (2011), the bias correction was adjusted across the time series according to the relationship between the assumed and estimated recruitment variability. Recruitment deviates were estimated for 1975−2021.

The final model options included one value of steepness of the BH SRR (h = 0.8). This value is considered to be in the middle of the plausible range of steepness values for tuna species such as albacore tuna and is routinely adopted in tuna assessments conducted by other tuna RFMOs.

4.7 Initial population state

In the previous assessment it was assumed that the albacore tuna population was at an unfished state of equilibrium at the start of the model (1950) with the beginning of longline fishing occurring in the following years (at least from the 1950s onwards), this assessment follows the same methodology.

4.8 Selectivity Curves and Fishing Mortality

Selectivity is fishery-specific and was assumed to be time-invariant. A double- normal functional (Method 2015) form was assumed for all selectivity curves. No sex-specific length data were available, all length data were aggregated. Length composition data was split by quarter and region, fishery F16_LL4_Q4 was mirrored to F8_LL2_Q4 due to poor fits in the initial modelling.

A double normal selectivity was estimated for the purse seine fishery (PS1). The availability of length composition data from the driftnet fishery enabled the estimation of a selectivity function for this method. The selectivity was parameterised as a double normal function and assumed to be equivalent for the two fisheries (DN3 & DN4).

No reliable length frequency data are available for the four “Other” fisheries. The selectivity of the “Other” fisheries was assumed to be equivalent to the selectivity of the driftnet fishery. Initial modelling indicated that the model results were not sensitive to the selectivity assumed for the four “Other” fisheries due to the small magnitude of the catch associated with each of these fisheries. Length composition data was down weighted so that the data can inform removals by fisheries from the correct age class and inform recruitment but not determine the scale or trend of the population.

Fishing mortality was modelled using the hybrid method where the harvest rate using Pope’s approximation then converts it to an approximation of the corresponding F (Methot & Wetzel 2013).

4.9 Parameter estimation and uncertainty

Model parameters were estimated by maximising the log-likelihoods of the data plus the log of the probability density functions of the priors, and the normalized sum of the recruitment deviates estimated in the model. For the catch and the CPUE series we assumed lognormal likelihood functions while a multinomial was assumed for the size data. The maximisation was performed by an efficient optimisation using exact numerical derivatives with respect to the model parameters (Fournier et al. 2012). The Hessian matrix computed at the mode of the posterior distribution was used to obtain estimates of the covariance matrix. This was used in combination with the Delta method to compute approximate confidence intervals for parameters of interest.

4.10 Profile Likelihood

An investigation of the information content in the data components was undertaken via the use of profile likelihood on the global scaling parameter (R0) (Lee et al 2014). The negative log likelihood of a specific parameter or data component should, in theory, decline to an obvious minimum. In situations where this does not happen, at least from one side, there may be insufficient information within the data to estimate other parameters. Virgin recruitment (R0) is an ideal scaling parameter because it is proportional to the unfished biomass. Profiles were run with the natural log of virgin recruitment, ln(R0), fixed at various values above and below the model estimated value; the corresponding likelihood profile quantified how much loss of fit was contributed by each data source. One of the primary uses of the likelihood profile is to identify conflicting data and provide a rationale for down weighting or excluding any data.

4.11 Hierarchical cluster analysis

A hierarchical cluster analysis (HCA) was used to identify groupings of CPUE series that represented similar, or same states of nature. The goal of this analysis was to develop a framework for identifying groupings of CPUE series that were similar, so that the model did not include trends that implied conflicting states of nature (i.e. increasing and decreasing). The methods were adapted from those recently implemented in an Atlantic shortfin mako assessment conducted by the International Commission for the Conservation of Atlantic Tunas (ICCAT 2017). As noted in the Atlantic shortfin mako assessment (ICCAT 2017):

> "*it is not uncommon for CPUE indices to contain conflicting information. However, when CPUE indices are conflicting, including them in a single assessment (either explicitly or*

after combining them into a single index) tends to result in parameter estimates intermediate to what would be obtained from the data sets individually. Schnute and Hilborn (1993) showed the most likely parameter values are usually not intermediate but occur at one of the apparent extremes. Including conflicting indices in a stock assessment scenario may also result in residuals not being identically and independently distributed (IID) and so procedures such as the bootstrap cannot be used to estimate parameter uncertainty. Consequently, when CPUEs with conflicting information are identified, an alternative is to assume that indices reflect hypotheses about states of nature and to run scenarios for single or sets of indices that represent a common hypothesis."

The HCA used methods conducted in R using FLR (http://www.flr-project.org/) and the *diags* package. FLR provides a set of common methods for reading these data into R, plotting and summarizing them to assess the consistency in the CPUE trends. The CPUE time series along with a *lowess* smoother fitted to CPUE each year using a general additive model (GAM) to compare trends for the CPUEs. It is important to note that the hierarchical cluster analysis is sensitive to the overlap in the time series as well as specific trends in the indices. The HCA use years in analysis of the CPUE series so that the trends can be comparable across indices. The results should be interpreted carefully, nevertheless the HCA identified possible groupings of time-series.

The first group identified by the HCA was characterized by time-series which were positively correlated with each other, LLCPUE4_Q2, LLCPUE4_Q3, LL_CPUE3_Q2, LLCPUE3_Q3. Which corresponds to the Southern areas in the austral winter. The second group was region 3 where the CPUEs for quarters 1-4 were positively correlated, as were the four CPUE for region1, though two regions were not positively correlated.

Because CPUEs with conflicting information were identified, it may be reasonable to assume that the indices reflect alternative hypotheses about states of nature and to run separate scenarios for each group. As previously, the diagnostic model option incorporates a single set of longline CPUE indices (from the south-western fishery).

4.12 Selection of a diagnostic case.

During the data prep meeting (April 2025) the WPTmT noted that the previous assessments investigated a wide range of structural assumptions, and those results informed to structure of the most recent assessment. For the current assessment, there are no additional data to enable any further investigation of some of the main structural assumptions related to spatial structure, fishery selectivities, initial conditions and recruitment estimation.

Instead, this assessment focussed on the development of the individual fleets, and surveys by quarter primarily to accommodate the differences in the length composition and CPUE trends amongst the four regional longline fisheries. This is consistent with the 'fleets as areas' approach. The initial model was based around the assessment model that used the -Southwest - CPUE(Region 3), with longline and Purse Seine length frequency. Sensitivity runs using the other CPUE time series and combinations of CPUE were investigated. Groupings of CPUE series will be chosen by the WPTmT which will seek to use the results of the HCA, other diagnostics as well as expert opinion to select the most appropriate parameterization and CPUE series groupings.

4.13 Benchmark and Reference Point Methods

Benchmarks included estimates of absolute population levels and fishing mortality for the terminal year, 2023 (F_{2023}, SSB_{2023}, B_{2023}). These values are reported against reference points relative to MSY levels, and depletion estimates (relative to virgin levels).

4.14 Diagnostics and additional model runs

Model diagnostics will be completed when the updated CPUE series are available.

5 Results

In this section we focus on the results from the diagnostic case model and the key results and diagnostics for this model. We then comment on any important differences in both outputs and model diagnostics for the sensitivity analyses, and present preliminary results.

Stock Synthesis 3 was implemented here as a length-based age-structured stock assessment model (Methot and Wetzel 2013; e.g., Wetzel and Punt 2011a, 2011b). Stock synthesis utilizes an integrated modelling approach (Maunder and Punt 2013) to take advantage of the many data sources available for the Indian Ocean stock of albacore tuna. An advantage of the integrated modelling approach is that the development of statistical methods that combine several sources of information into a single analysis allows for consistency in assumptions and permits the uncertainty associated with each data source to be propagated to final model outputs (Maunder and Punt 2013).

5.1 Diagnostic case model

The choice of model parameters and data inputs reflected the input of the WPTmT09 data prep meeting and the available updated data for biology and life history to the extent possible. This will be further refined by input at the WPTmT assessment meeting. This case was built around the SW CPUE run.

Model Fits to Abundance Indices

The model was able to fit the general trends of the indices of abundance (Figure 10). Although the CPUE series for quarter 2 underestimates the CPUE in the recent years of the model, while the index from quarter 4 overestimates the final period of the model with respect to the index estimates. Indices 1 and 3 exhibit annual variation in addition to a decline starting around 2010 and lasting until 2016 or 2016 before increasing. The indices for quarter 2 and 4 also show this trend to a lesser extent. The model does not quite fit this trend. The spawning output was estimated to increase slightly in the late 1990s to the early 2000s followed by a period of decline coincident with the increase in catch (Figure 2) and decline in the CPUE series.

Fits to the Length composition

The overall fit to the length data was generally good (Figure 13). Fleet specific annual length samples were often quite different, i.e. left skewed one year and bimodal the next, which accounts for the small amount of misfit in the aggregated samples. Pearson residuals of the fit to the length compositions were generally small – on the order of 2 to -2 and did not show any temporal trend (Figures 14-16).

Stock-recruitment Parameters

The predicted virgin recruitment (R0; number of age 0) was approximately 17,000,000 animals and the number of recruits was relatively constant from the early 1950s through the early 1980s, after which estimated recruitment experienced large fluctuations from about 1980-2020 (Figure 16). The bias correction estimated in the model is shown in Figure 17. The corresponding estimated stock recruitment relationship and annual deviations are also shown in Figure 18.

Fishing Mortality

Estimated F/F_{MSY} and fleet-specific instantaneous fishing mortality rates are presented in Figures 20 and 21 respectively. Fishing mortality was relatively low from the 1950 to the mid-1990s, which is in accordance with low catches and effort during that period. In the late 1980s fishing mortality increased with the advent of driftnet fishery. Starting in the late-1990s overall fishing mortality increased, with large fluctuations in the individual fisheries contribution to the overall fishing mortality. Since the early 2000s the overall fishing mortality has been increasing but is below F_{MSY} (i.e. overfishing is not occurring) for the entire time series.

Estimated stock status and other quantities

The estimated equilibrium yield curve for the diagnostic case model is shown in Figure 21. The estimated MSY is approximately 47,000 mt and this is predicted to occur at 21.5% of the unfished biomass (Figure 21), which is less than the standard Schaefer production model (0.5 SSB_0). The diagnostic case model estimates that the total biomass of the stock was at approximately 100% of the unfished level at the start of the model period (Figure 11) and steadily decreased to an estimate of SB_{2020}/SB_{MSY} = 1.9 that corresponds with F_{2020}/F_{MSY} = 0.62. Recruitment is fairly well estimated throughout the model time period (Figure 8), with recent recruitment estimated to be lower than the implied stock recruitment curve due to deviations implied by the length data. The estimates of recruitment were quite tightly constrained to the stock recruitment curve for the initial period of the model when there was no length information to inform the model. The main trends in the population dynamics can be explained through the estimated fishing mortality which was greatly increased in the 1990s and early 2000s due to the increase in catch (Figures 19 and 20).

6 Conclusion

The overall scale of the estimated stock biomass is lower than the previous assessment, though the general downward trend in SSB is similar to both the 2019 and 2022 assessments.

The current assessment, as with the previous assessment depends largely on the time series of southwestern longline CPUE indices and the catch history from the entire fishery. The main drivers of this assessment are the trend in the catch and CPUE series. The results of this assessment must be treated with caution as the CPUE indices have not been updated since the previous assessment, and so there is considerable uncertainty in the associated stock status from the reference model.

7 Acknowledgements

The authors would like to thank the IOTC staff for their help in preparing the data as well as all of the member countries that submitted data and analyses. This assessment benefited from the discussion and contribution of the WPTmT data prep attendees.

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9 Tables

Table 1. Fishery and survey definitions for the Indian Ocean Albacore Assessment

ID Number	Fleet/ Survey Name	Gear(s)	Region	Quarter	Selectivty	Notes
1	F1_LL1_Q1	Longline	1	1	Estimated double normal	
2	F2_LL1_Q2	Longline	1	2	Estimated double normal	
3	F3_LL1_Q3	Longline	1	3	Estimated double normal	
4	F4_LL1_Q4	Longline	1	4	Estimated double normal	
5	F5_LL2_Q1	Longline	2	1	Estimated double normal	
6	F6_LL2_Q2	Longline	2	2	Estimated double normal	
7	F7_LL2_Q3	Longline	2	3	Estimated double normal	
8	F8_LL2_Q4	Longline	2	4	Estimated double normal	
9	F9_LL3_Q1	Longline	3	1	Estimated double normal[1]	
10	F10_LL3_Q2	Longline	3	2	Estimated double normal[1]	
11	F11_LL3_Q3	Longline	3	3	Estimated double normal[1]	
12	F12_LL3_Q4	Longline	3	4	Estimated double normal[1]	
13	F13_LL4_Q1	Longline	4	1	Estimated double normal[1]	
14	F14_LL4_Q2	Longline	4	2	Estimated double normal[1]	
15	F15_LL4_Q3	Longline	4	3	Estimated double normal[1]	
16	F16_LL4_Q4	Longline	4	4	Mirrored to Fleet 15	
17	F17_DN3	Driftnet	3	NA	Fixed Double normal	
18	F18_DN4	Driftnet	4	NA	Mirrored to fleet 17	
19	F19_PS1	Purse Seine	1	NA	Fixed Double normal	
20	F20_Other1	Other*	1	NA	Mirrored to fleet 17	
21	F21_Other2	Other*	2	NA	Mirrored to fleet 17	
22	F22_Other3	Other*	3	NA	Mirrored to fleet 17	
23	F23_Other4	Other*	4	NA	Mirrored to fleet 17	
24	LLCPUE1_Q1	Longline	1	1	Mirrored to fleet 1	
25	LLCPUE1_Q2	Longline	1	2	Mirrored to fleet 2	
26	LLCPUE1_Q3	Longline	1	3	Mirrored to fleet 3	
27	LLCPUE1_Q4	Longline	1	4	Mirrored to fleet 4	
28	LLCPUE2_Q1	Longline	2	1	Mirrored to fleet 5	
29	LLCPUE2_Q2	Longline	2	2	Mirrored to fleet 6	
30	LLCPUE2_Q3	Longline	2	3	Mirrored to fleet 7	
31	LLCPUE2_Q4	Longline	2	4	Mirrored to fleet 8	
32	LLCPUE3_Q1	Longline	3	1	Mirrored to fleet 9	
33	LLCPUE3_Q2	Longline	3	2	Mirrored to fleet 10	
34	LLCPUE3_Q3	Longline	3	3	Mirrored to fleet 11	
35	LLCPUE3_Q4	Longline	3	4	Mirrored to fleet 12	
36	LLCPUE4_Q2	Longline	4	2	Mirrored to fleet 14	
37	LLCPUE4_Q3	Longline	4	3	Mirrored to fleet 15	
38	DNCPUE4	Driftnet	4	NA	Mirroed to fleet 17	

*Other inclues: Coastal Longline, gillnet, trolling, handlines, and artisanal gear.

1. LL3 and LL4 are not constrained to approximate full selectivity for the largestlengths

Table 2. Recent catch data for Albacore in the Indian ocean.

			Catch (MT)	
Longline Fleet No.	Region	Quarter	Average (2010-2020)	Max (2010-2020)
1	1	1	2,001	2,322
2	1	2	287	629
3	1	3	601	1,619
4	1	4	5,030	7,035
5	2	1	1,235	2,289
6	2	2	1,357	2,345
7	2	3	1,912	4,129
8	2	4	1,006	1,549
9	3	1	854	1,957
10	3	2	7,068	10,165
11	3	3	5,735	7,142
12	3	4	692	1,092
13	4	1	344	542
14	4	2	4,072	6,360
15	4	3	2,363	3,873
16	4	4	193	469

10 Figures

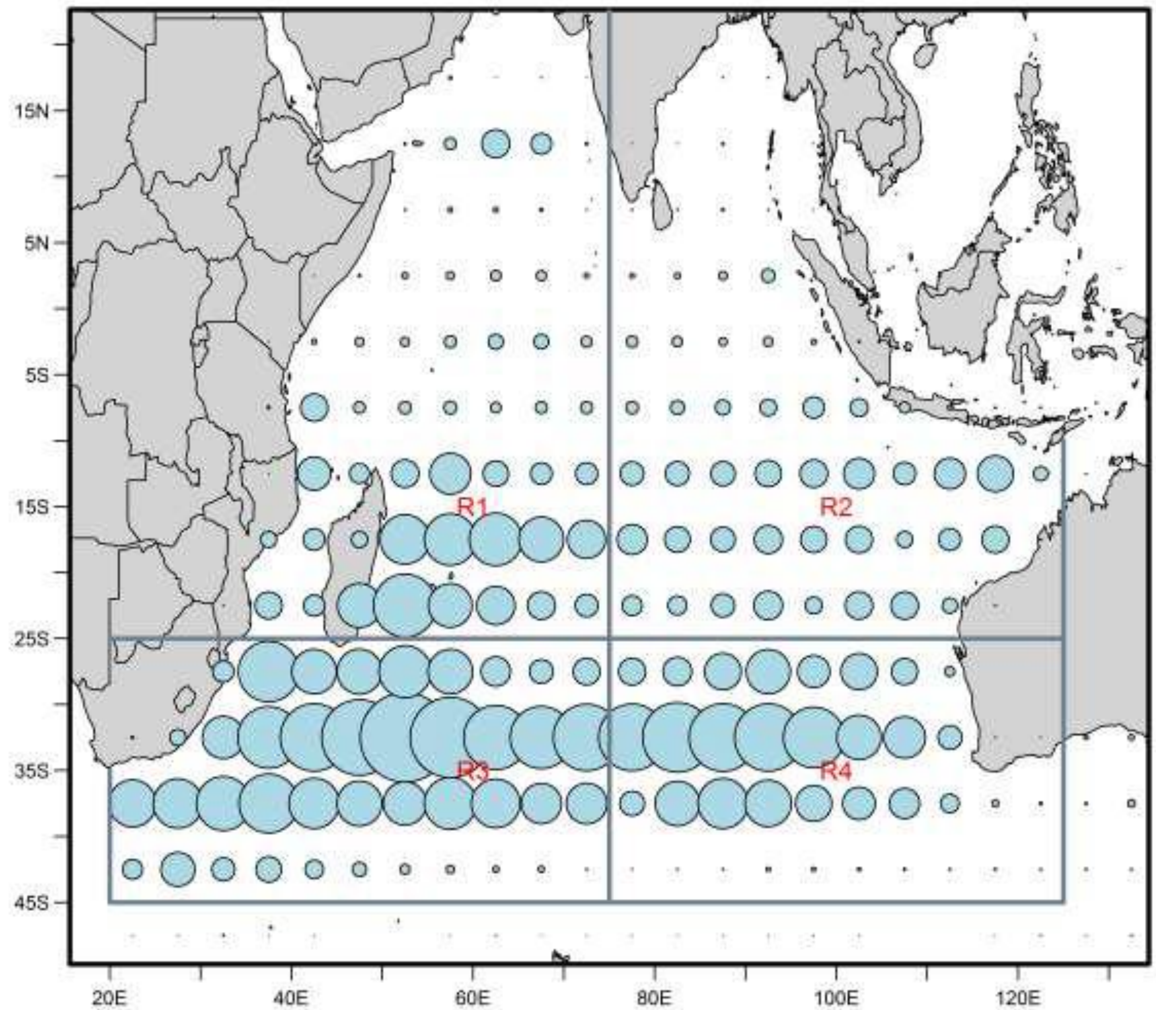

Figure 1. Spatial stratification of the Indian Ocean for the definition of the fisheries. The blue circles represent the aggregated Japanese and TW LL albacore catch (numbers of fish) by 5 degree cell from 1952-2017. The area of the circle is proportional to the magnitude of the catch (the largest circle represents a catch of 2.45 million fish).

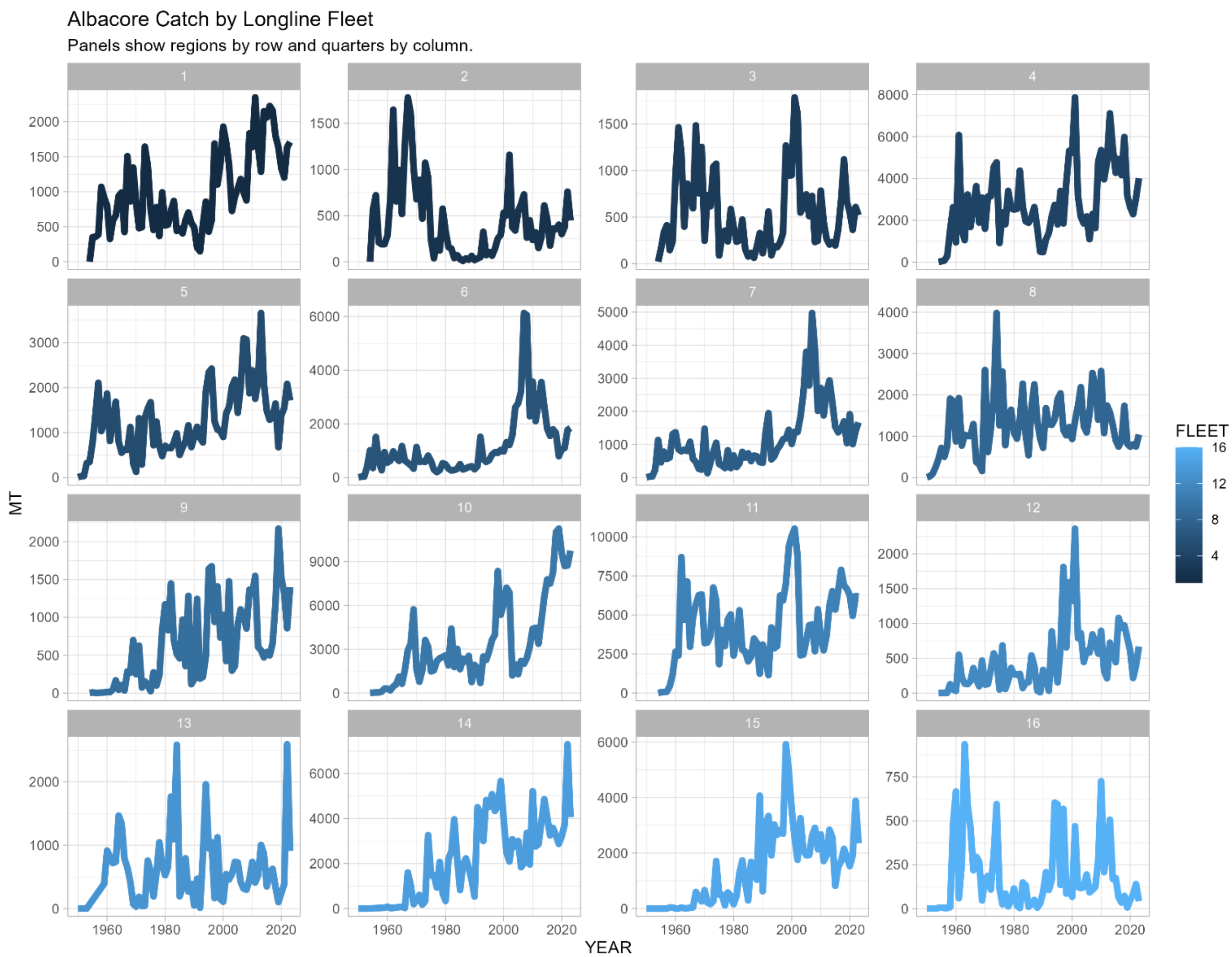

Figure 2. A comparison of Indian Ocean albacore longline catches. Rows indicate region (1-4) and columns indicate quarters (1-4).

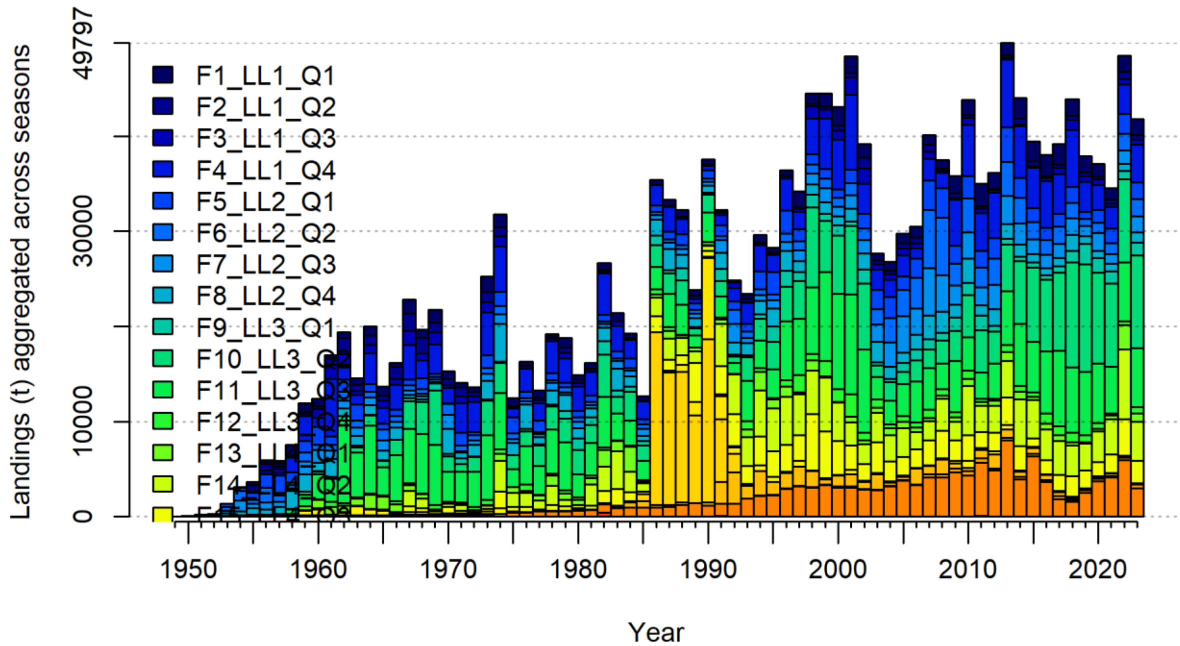

Figure 3. Total annual catch (1000s mt) of albacore tuna by fleet from 1950 to 2023. Fleet names indicate the fleet number, region and quarter, for example F1_LL1_Q1 is Fishing Fleet 1, in Region 1(LL1) and quarter1.

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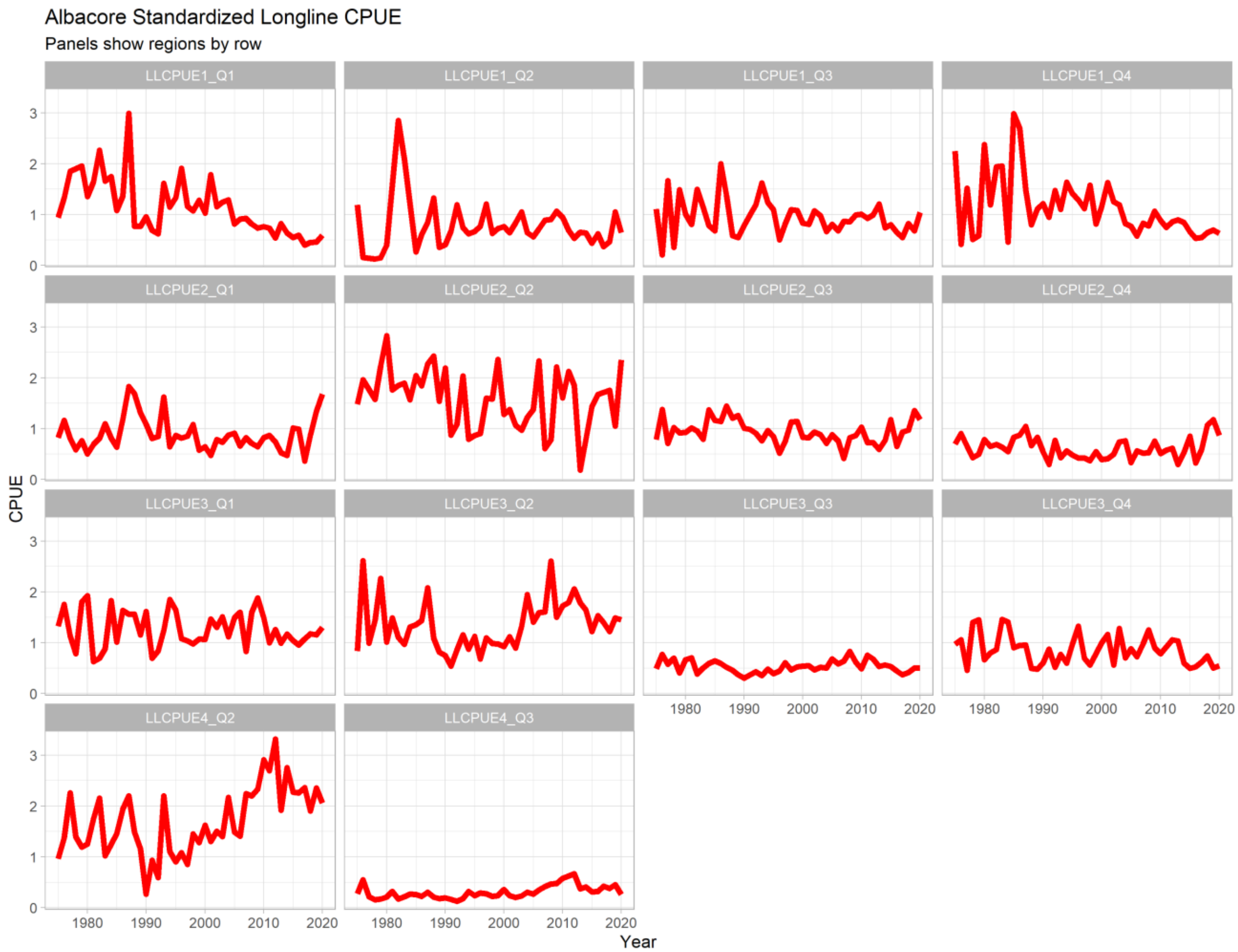


Figure 4. Standardized CPUE indices for the longline fisheries by region and quarter (LL 1-14) from 1975-2020. The figure shows the region in row, and individual quarterly CPUE series in each column. Note that the bottom row, representing region 4, only had CPUE series for quarters 2 and 3.

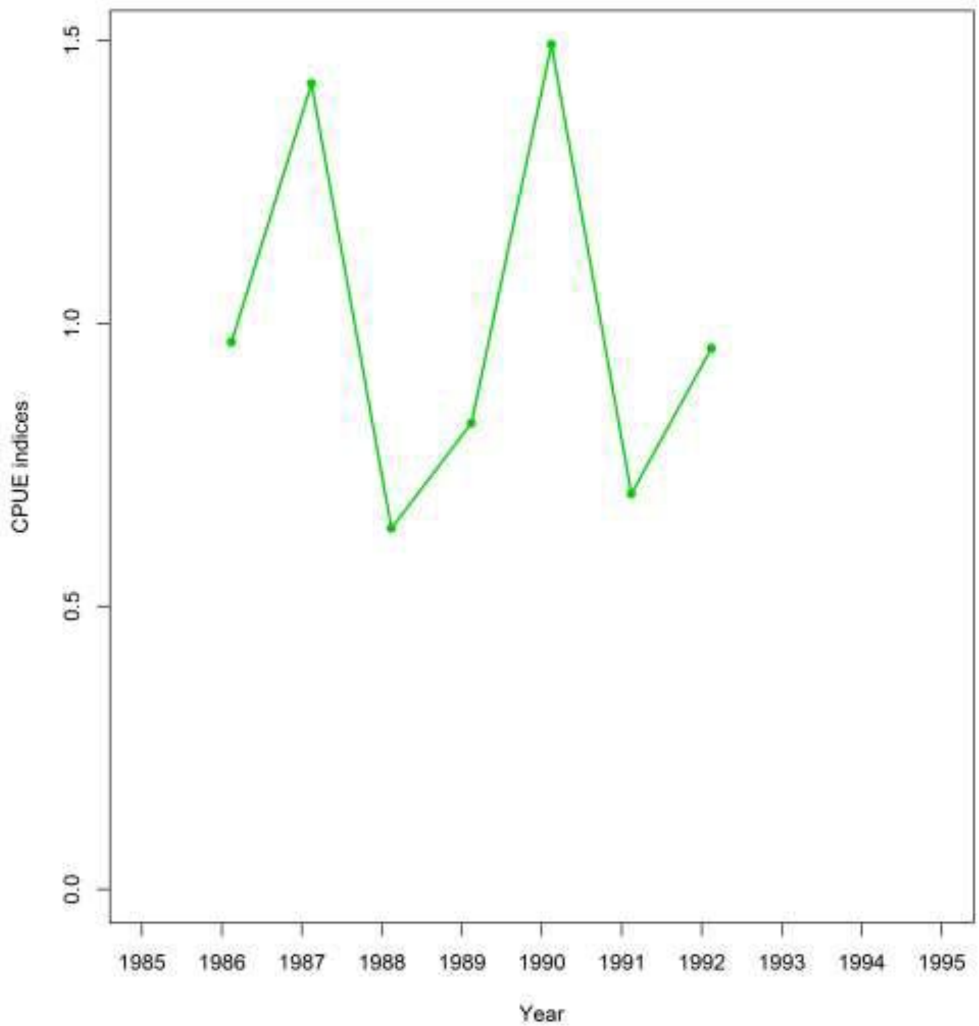


Figure 5 Annual driftnet CPUE indices (source: Chang & Liu 1995).

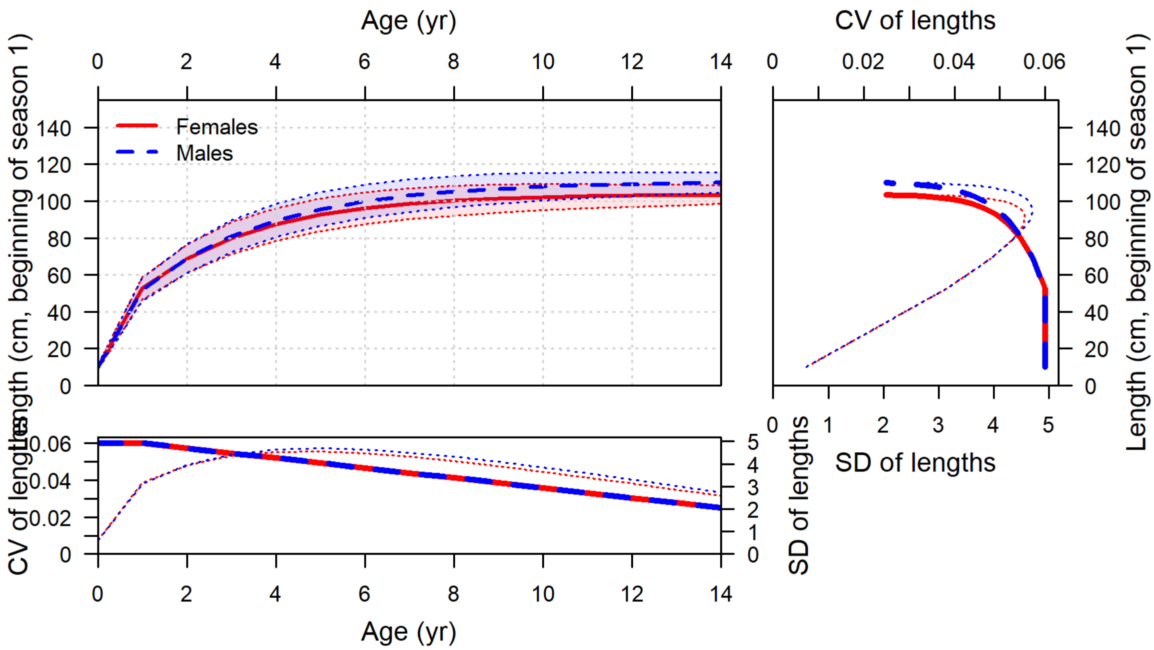


Figure 6. Growth function for female and male albacore.

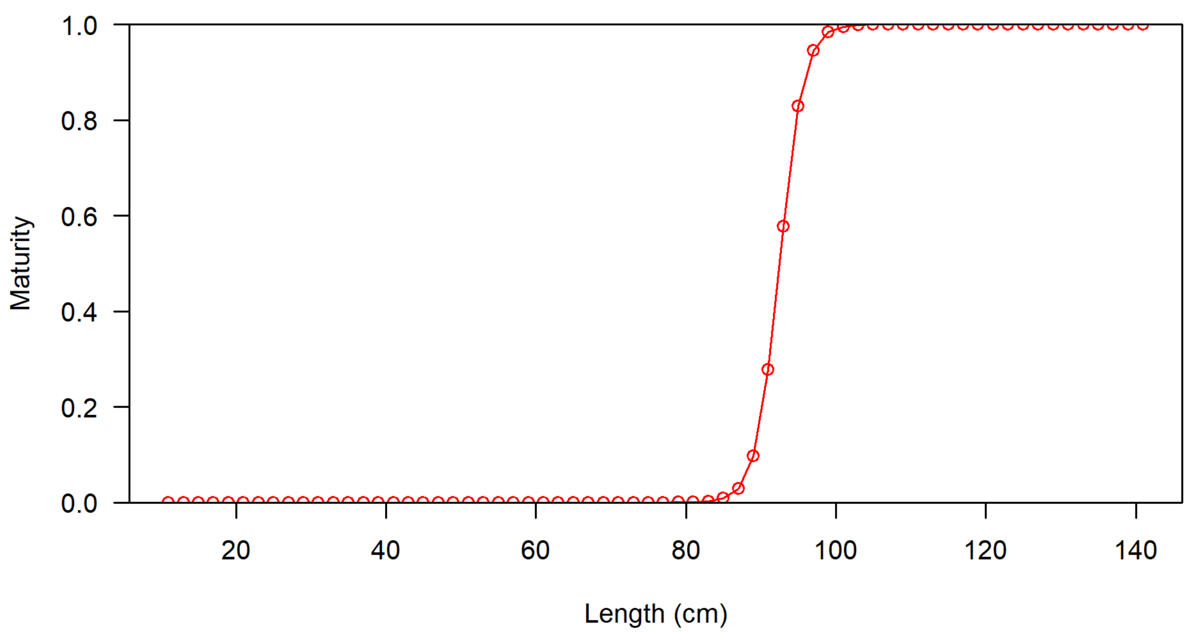


Figure 7 Maturity at length for female albacore in the Indian Ocean.

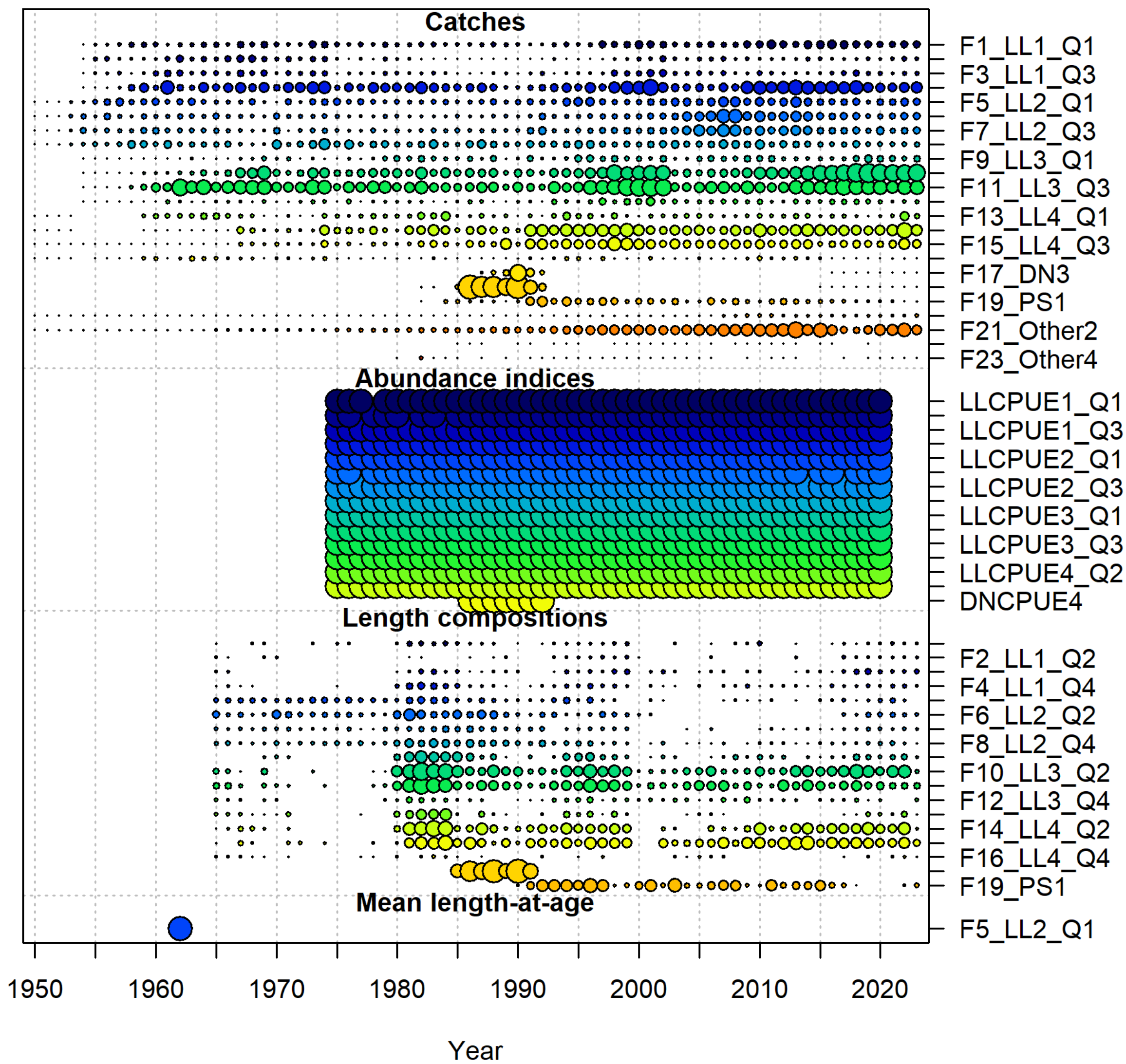


Figure 7: Temporal data coverage for the diagnostic case model for the assessment of albacore tuna.

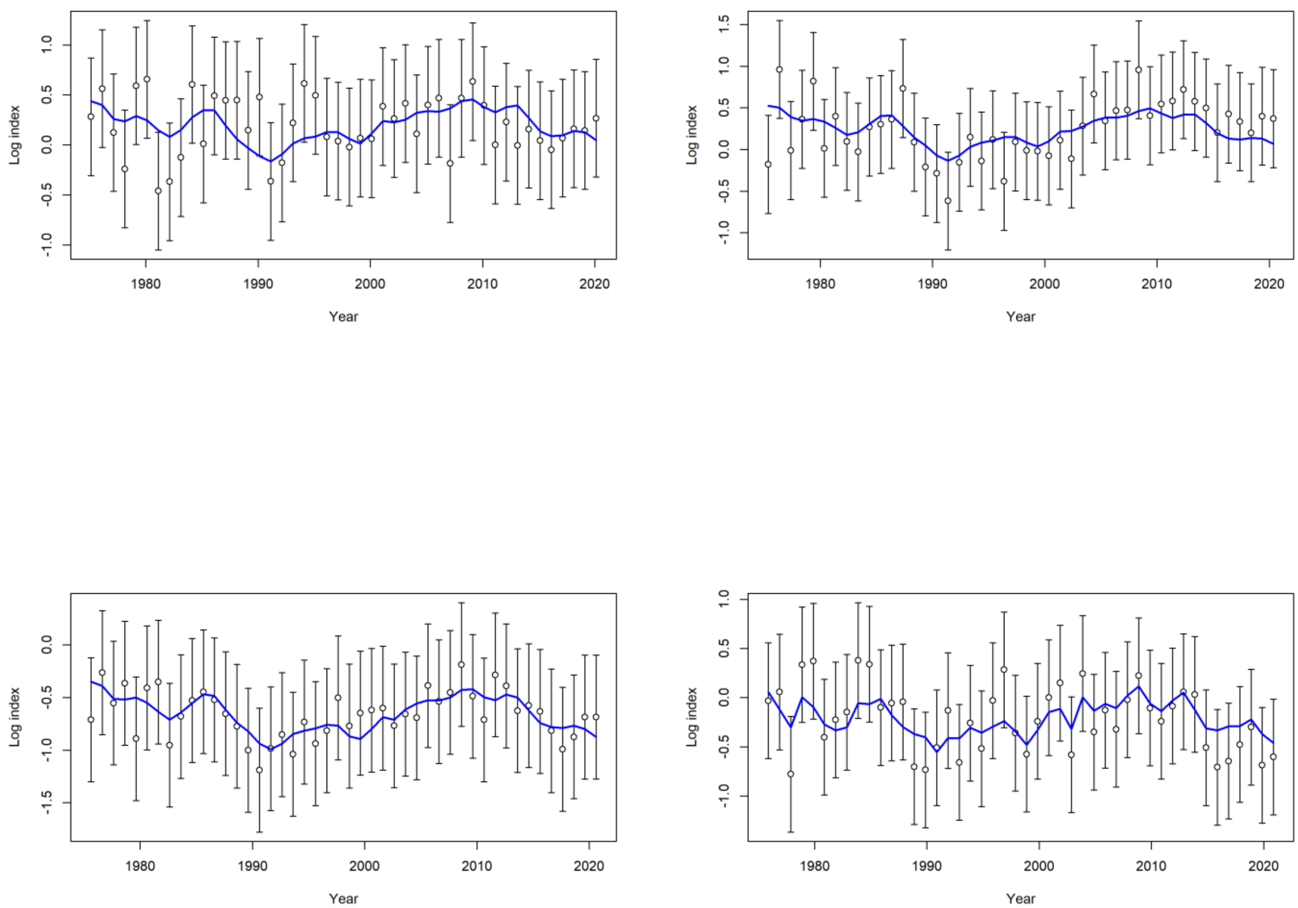
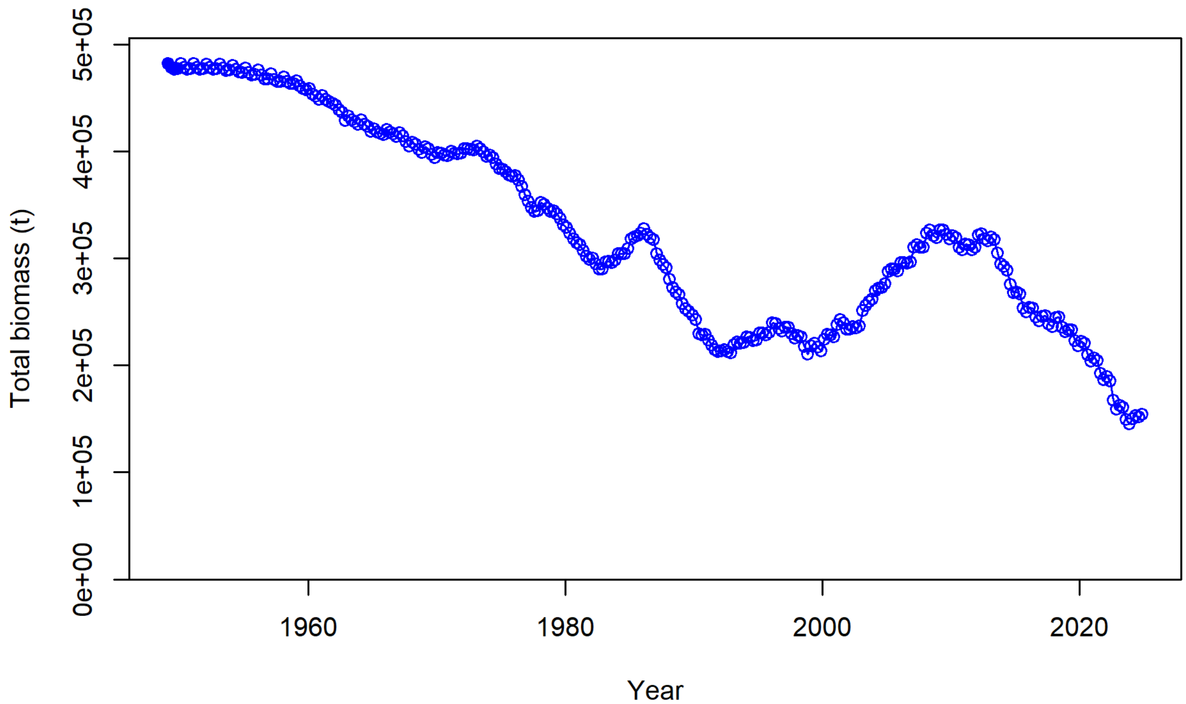


Figure 8: Diagnostic case fit to the CPUE series (shown on the log scale), from region 3. The top left panel is quarter 1, the top right is quarter 2, the bottom left is quarter 3, the bottom right is quarter 4.



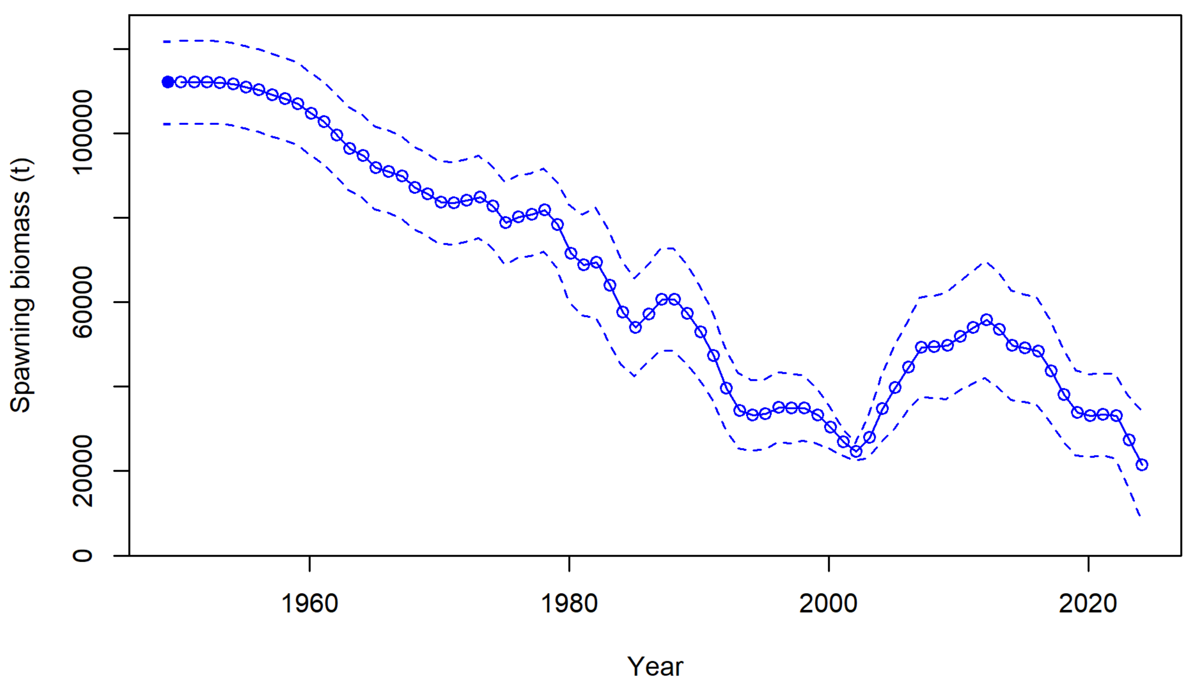


Figure 9: Total biomass (top) and spawning biomass for the diagnostic case parameterization model. The filled dot represents the pre-model estimate of unfished biomass.

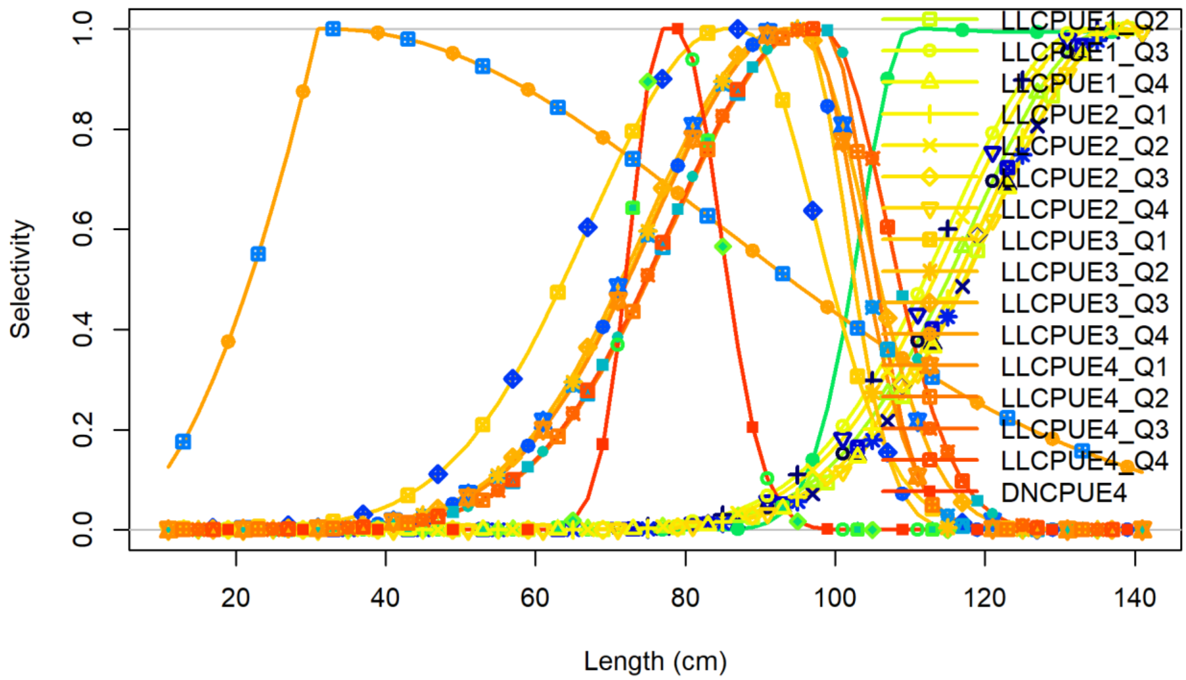


Figure 10: Selectivity curves estimated from the diagnostic case model for the assessment of albacore tuna in the Indian Ocean.

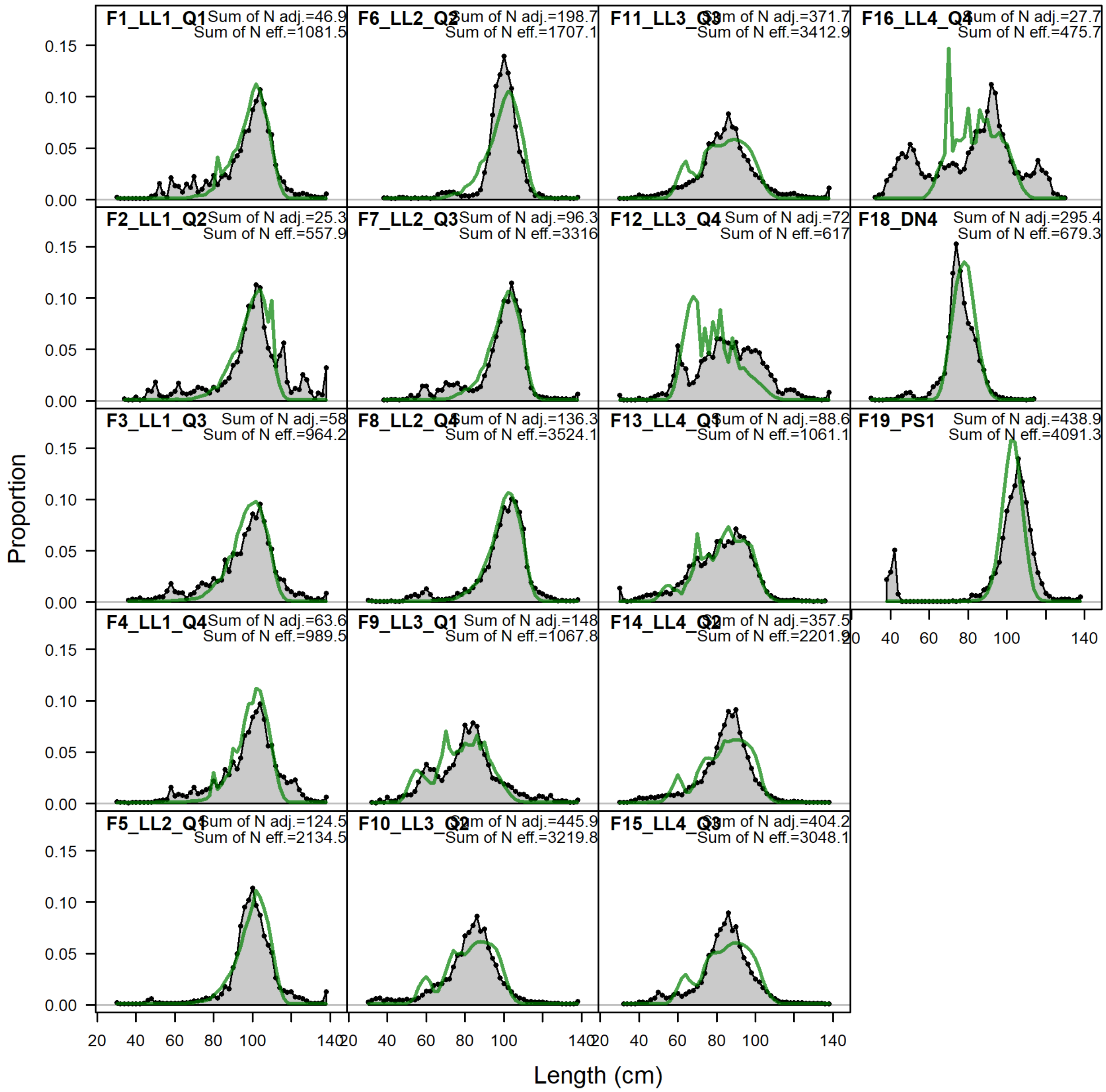


Figure 11 Fit to the length frequency data for the diagnostic case model for the assessment of albacore tuna in the Indian Ocean.

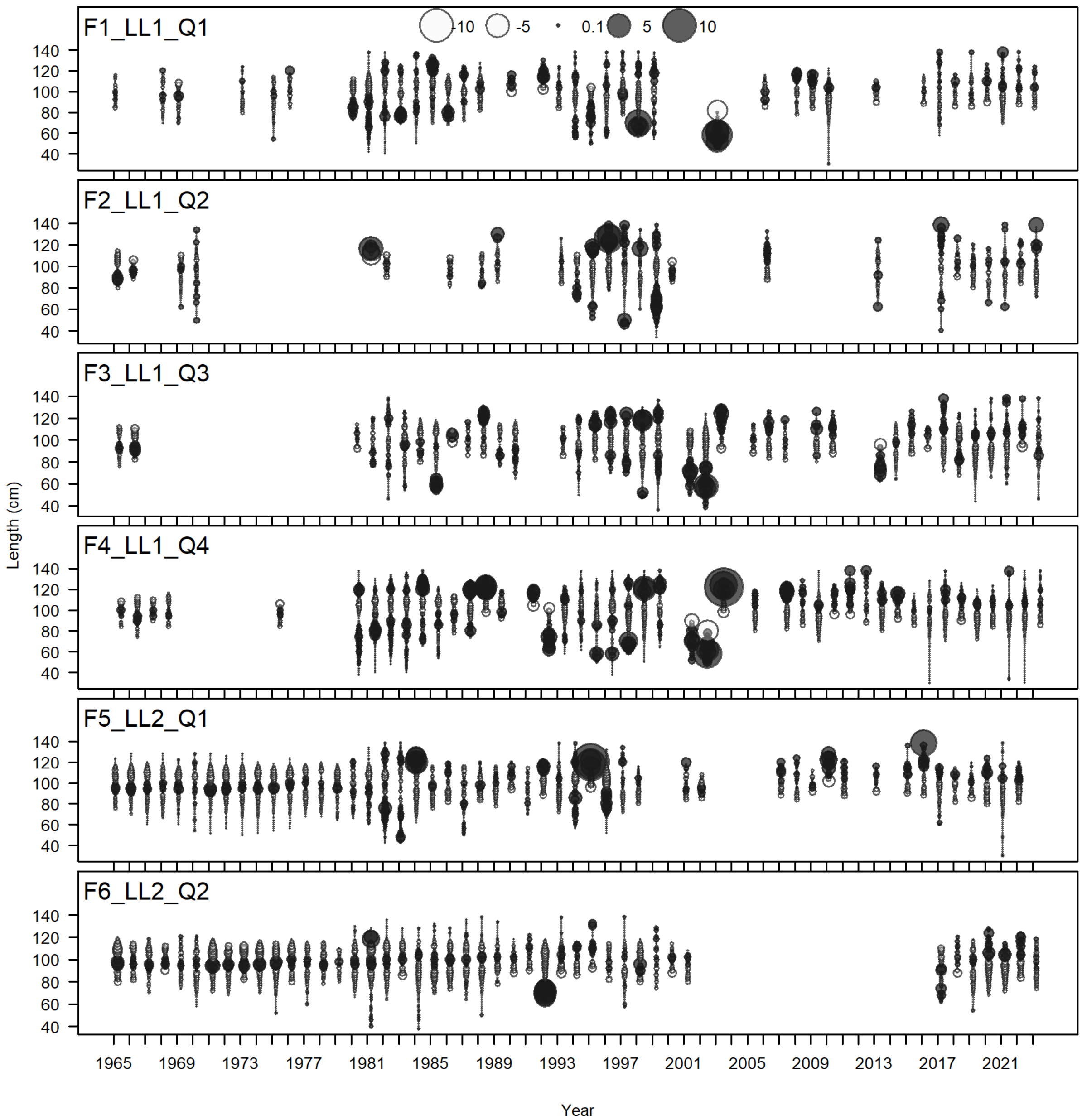


Figure 12. Residuals from the fit to the length frequency data for the diagnostic case model for the assessment of albacore in the Indian Ocean, Fleets 1-6. Closed bubbles are positive residuals and open bubbles are negative residuals, bubble sizes are scaled to maximum within each panel. Thus, comparisons across panels should focus on patterns, not bubble sizes.

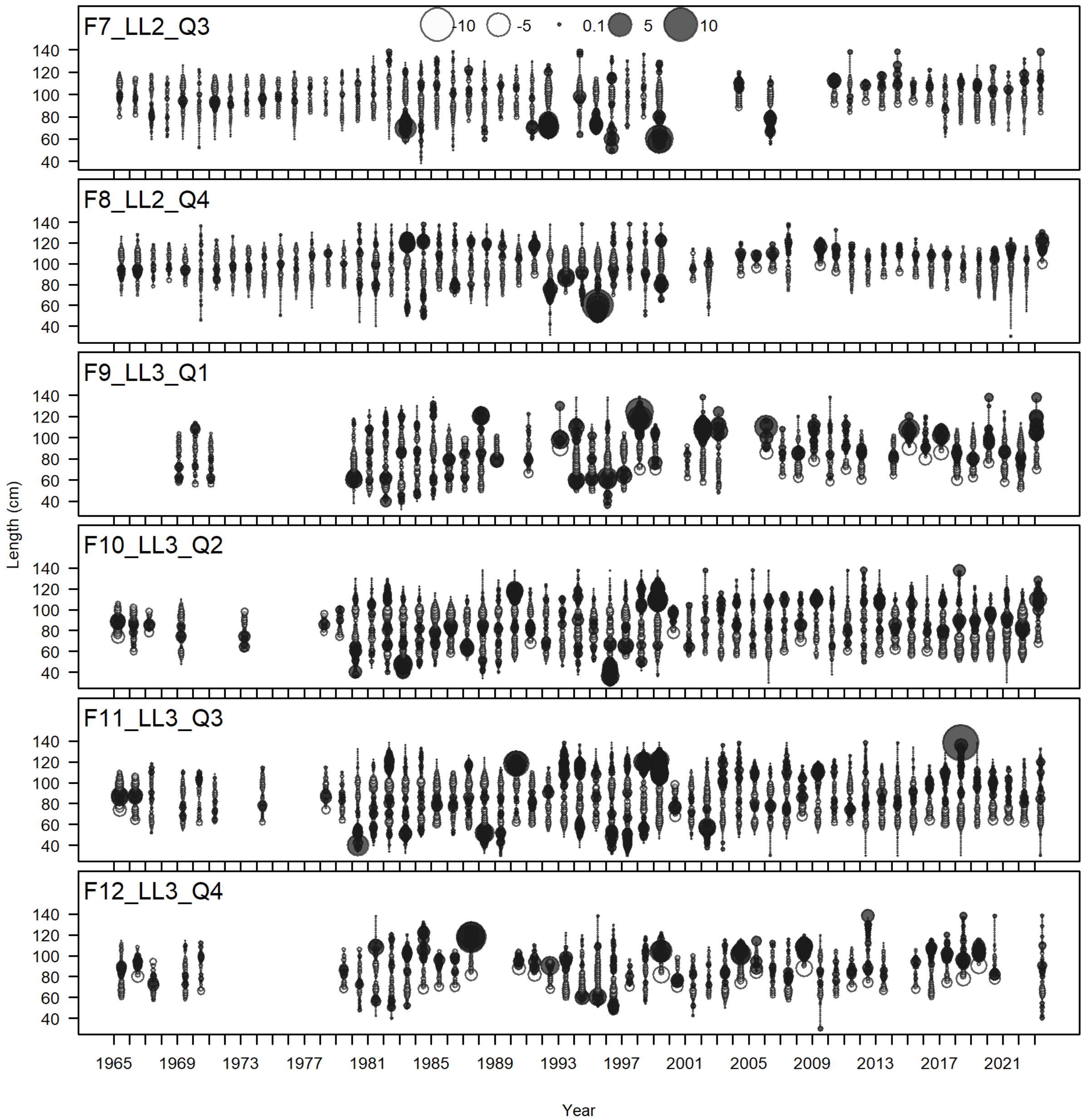


Figure 13. Residuals from the fit to the length frequency data for the diagnostic case model for the assessment of albacore in the Indian Ocean, Fleets 7-12. Closed bubbles are positive residuals and open bubbles are negative residuals, bubble sizes are scaled to maximum within each panel. Thus, comparisons across panels should focus on patterns, not bubble sizes.

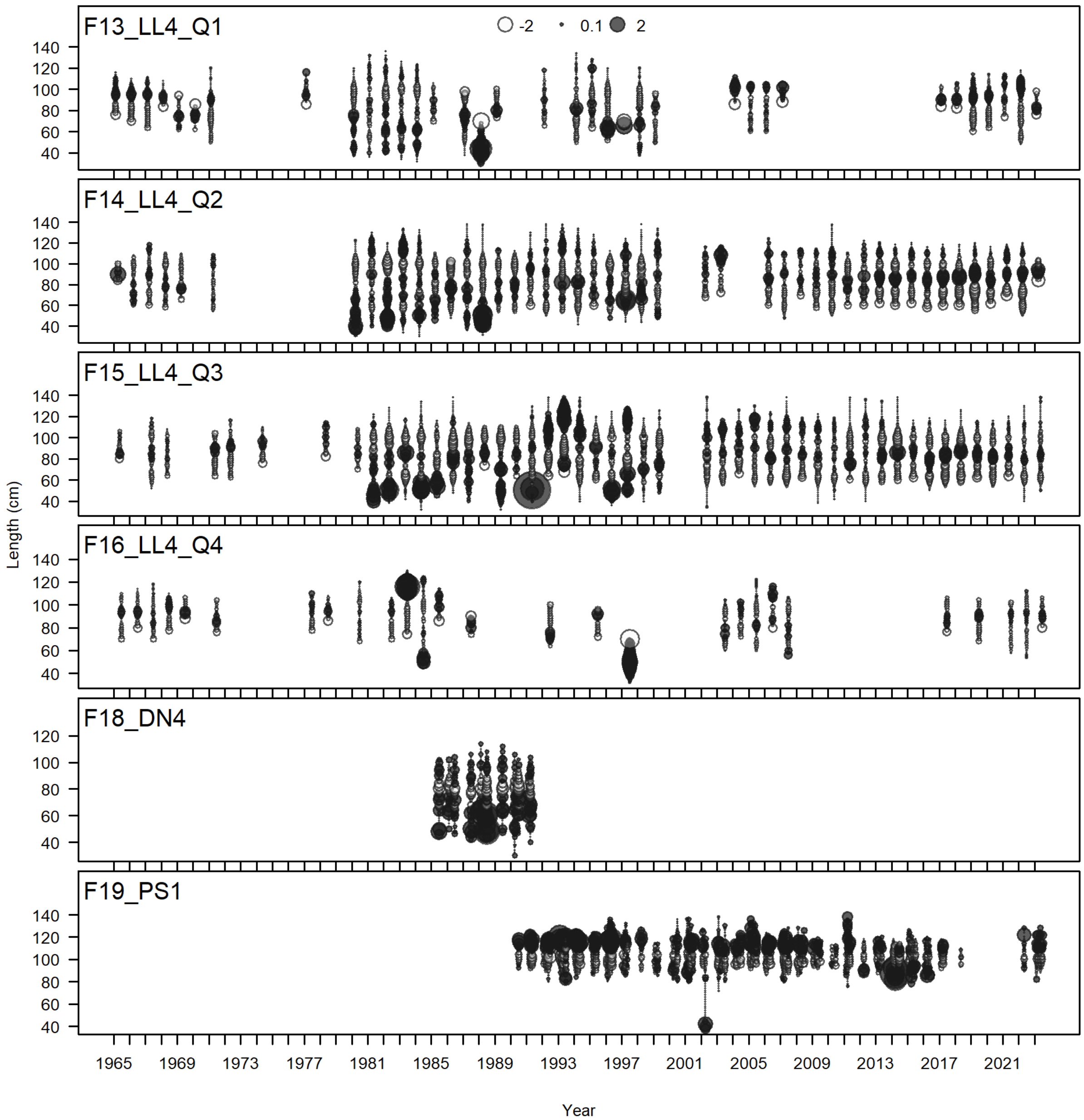


Figure 14 Residuals from the fit to the length frequency data for the diagnostic case model for the assessment of albacore in the Indian Ocean, Fleets 13-19. Closed bubbles are positive residuals and open bubbles are negative residuals, bubble sizes are scaled to maximum within each panel. Thus, comparisons across panels should focus on patterns, not bubble sizes.

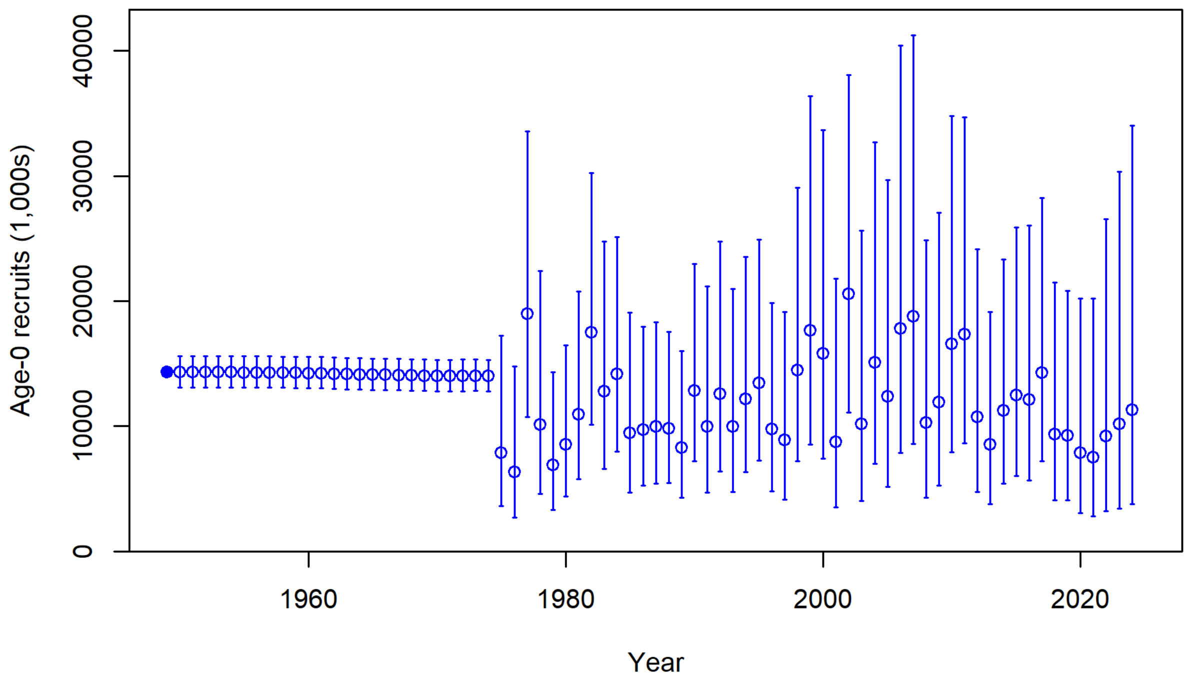


Figure 15. Estimated recruitment including the estimate of virgin recruitment (filled circle at the start of the time series) for the diagnostic case model for the assessment of albacore tuna in the Indian Ocean.

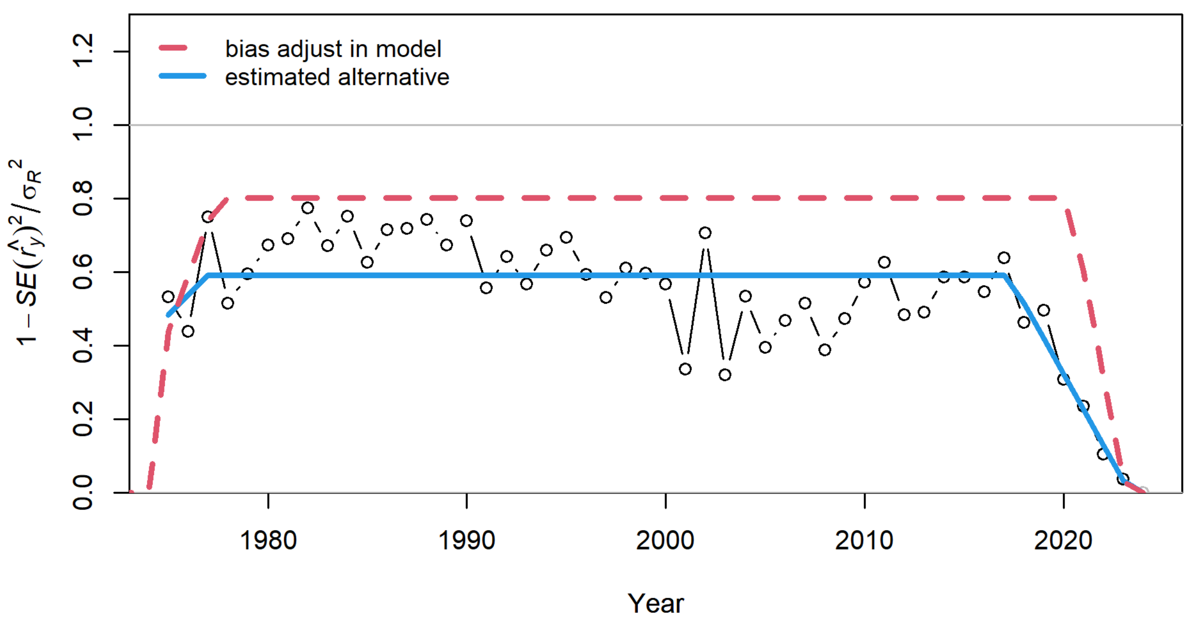


Figure 16 .Estimated bias adjustment in the model.

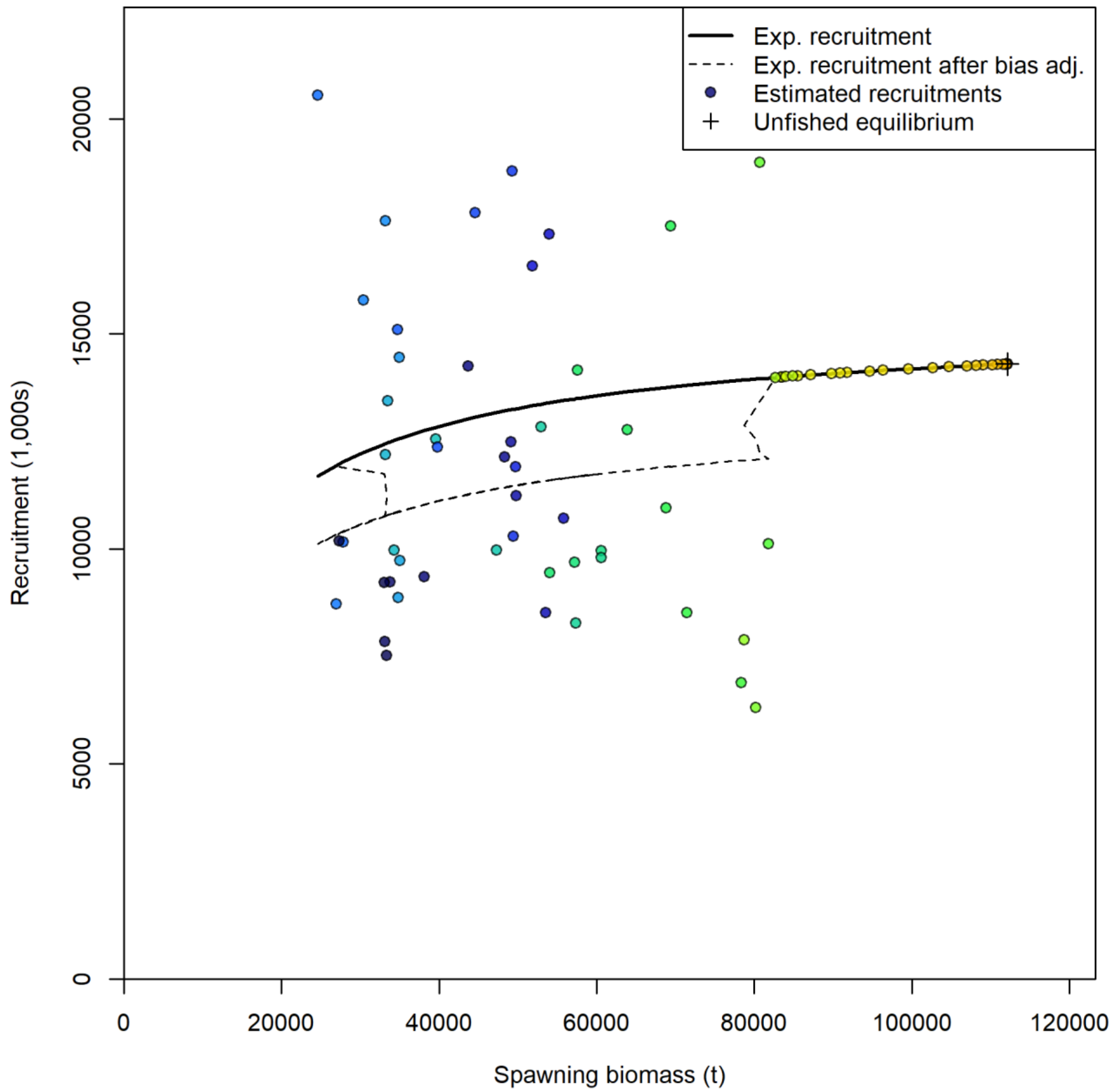


Figure 17. Stock recruitment curve used in the assessment and time series of estimates of recruitment deviations (colored points).

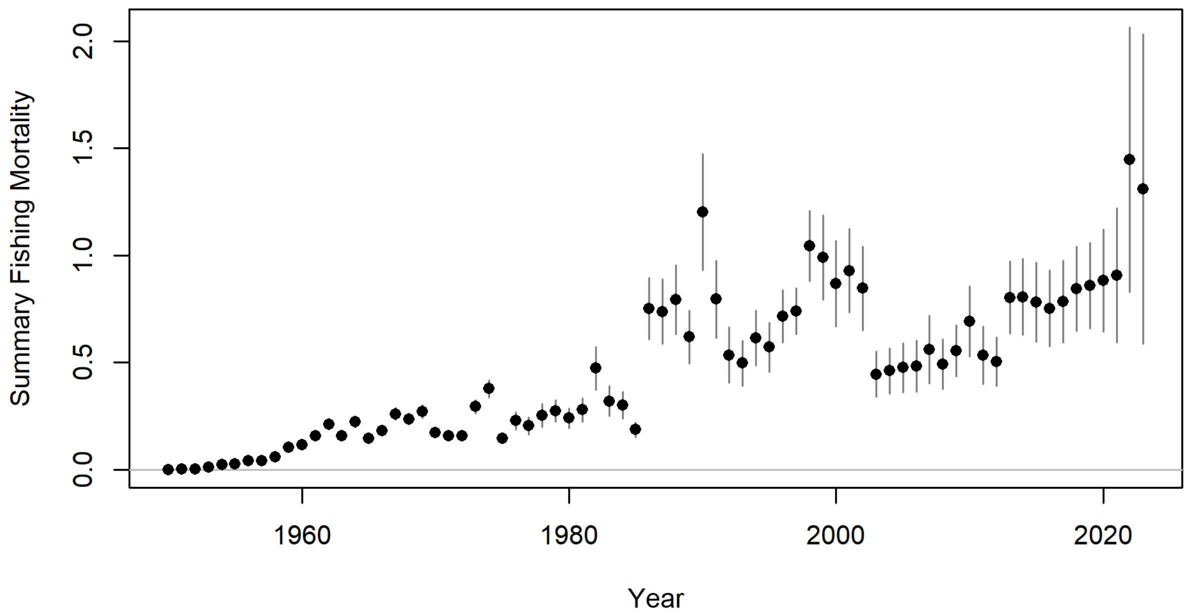


Figure 18. Estimated total fishing mortality/FMSY.

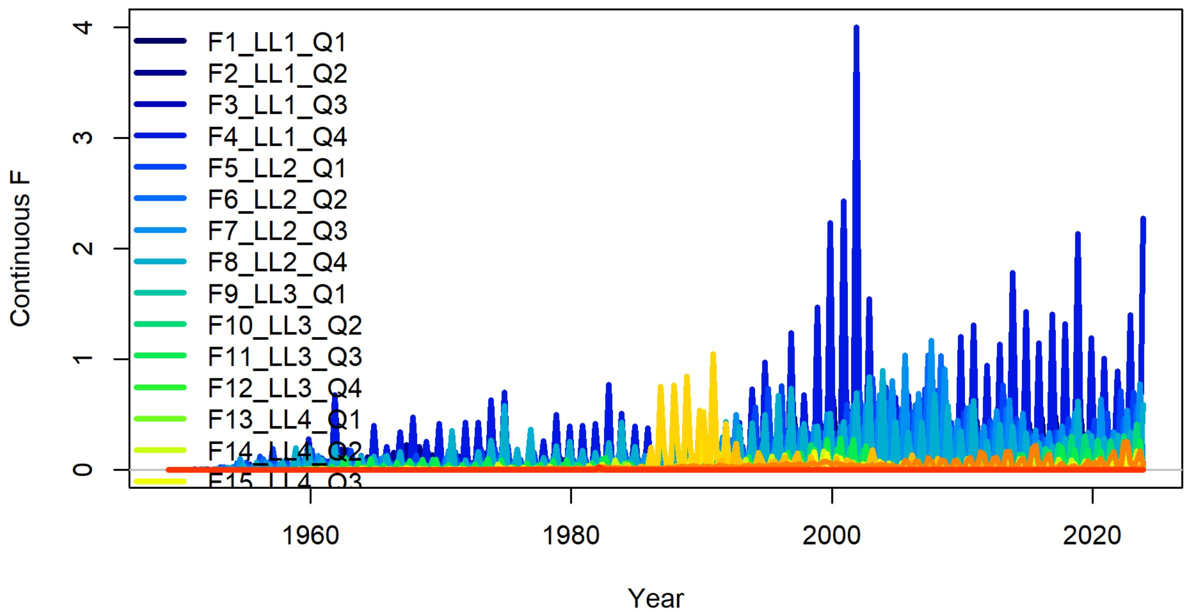


Figure 19. Estimated fleet specific fishing mortality by year for the base case model configuration.

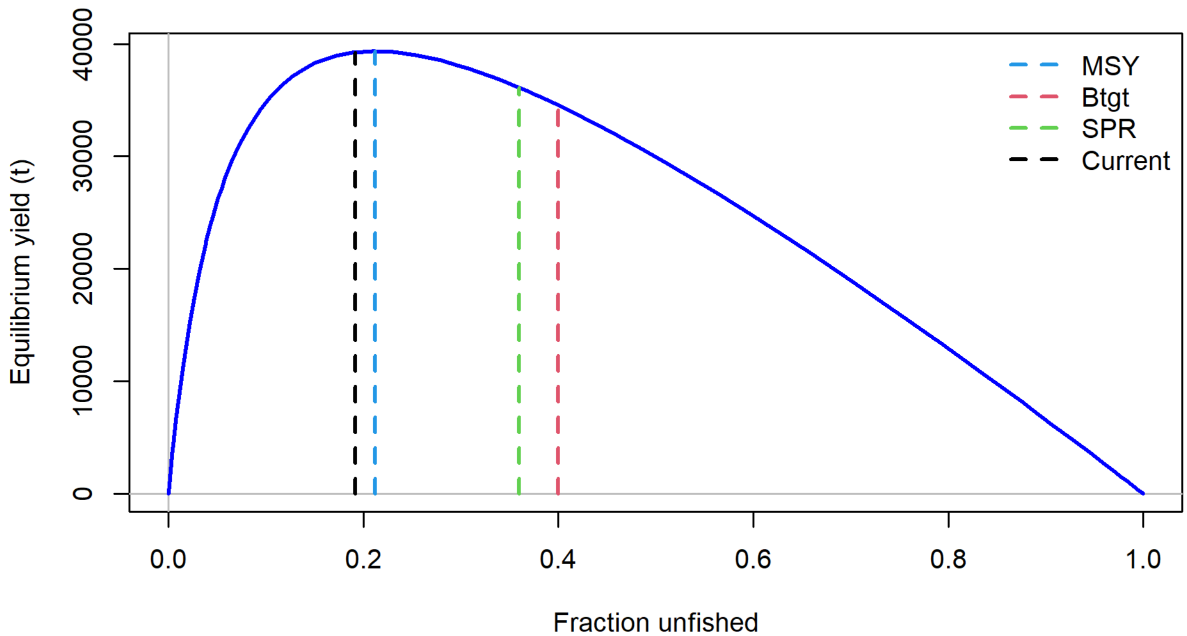


Figure 20. Equilibrium yield curve for the diagnostic case model for the assessment of albacore tuna in the Indian Ocean.

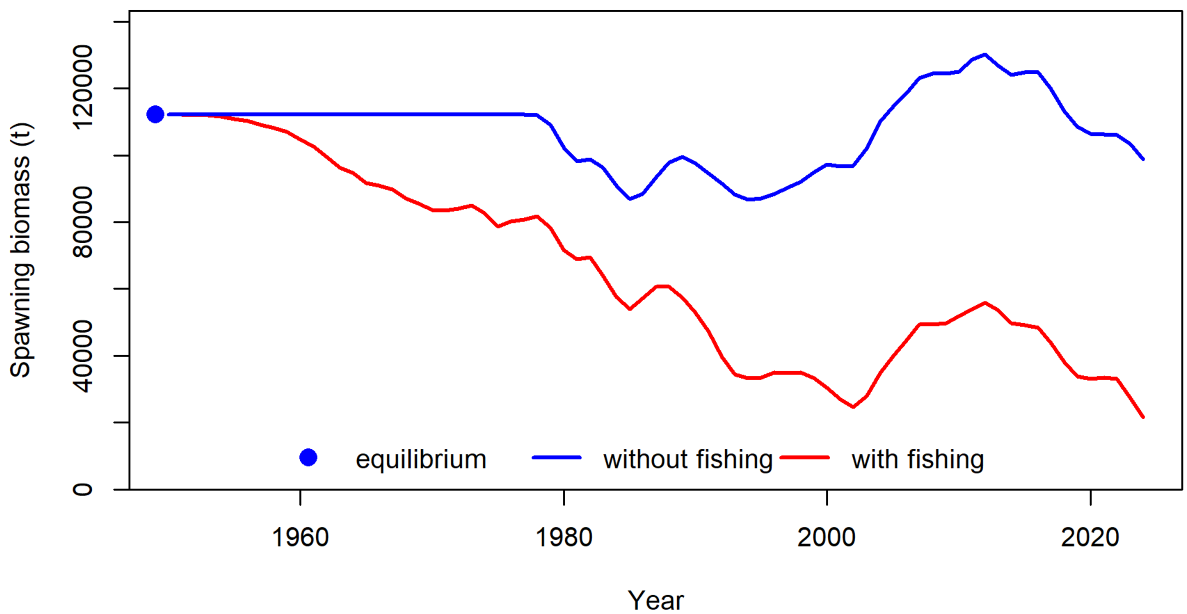


Figure 21. Dynamic B0 plot showing the spawning biomass under conditions no fishing and assuming the input catch series.