Preliminary 2024 stock assessment of yellowfin tuna in the Indian Ocean

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Contents

Executive Summary

This report presents a preliminary stock assessment for Indian Ocean yellowfin tuna (*Thunnus albacares*) using Stock Synthesis 3 (SS3). The assessment uses an age-structured and spatially-explicit population model and is fitted to catch rate indices, length-composition data, and tagging data. The assessment covers 1950 – 2023 and represents an update of the previous assessment model, taking into account progress and improvements made since the previous assessment. The assessment assumes that the Indian Ocean yellowfin tuna constitute a single spawning stock, modelled as spatially disaggregated four regions, with 21 fisheries. Standardized CPUE series from the main longline fleets 1975 – 2020 were included in the models as the relative abundance index of exploitable biomass in each region. The CPUE indices from EU Purse seine sets on free schools were included in a subset of models with the spatial and fleet structure revised to better accommodate the distribution and size structure of the purse seine fisheries. Indices based on associative and non-associative dynamics of yellowfin tuna with floating objects were also available, and the utility of these indices was examined in the assessment. Tag release and recovery data from the RTTP-IO program were included in the model to inform abundance, movement, and mortality rates.

1 Introduction

Prior to 2008, Indian Ocean (IO) yellowfin tuna (*Thunnus albacares*) was assessed using methods such as Virtual Population Analysis (VPA) and production models (Nishida and Shono 2007, 2005). In 2008, a preliminary stock assessment of IO yellowfin tuna was conducted using MULTIFAN-CL (Langley et al. 2008) enabling the integration of the tag release/recovery data collected from the large-scale tagging programme conducted in the IO in the preceding years. The MULTIFAN-CL assessment was revised and updated in the following years (Langley et al. 2009; Langley, Herrera, and Million 2010, 2011, 2012).

In 2015, the assessment of IO yellowfin tuna was implemented (Langley 2015), which used the Stock Synthesis 3 modelling platform (Methot and Wetzel 2013). SS3 is conceptually very similar to MFCL and the two platforms have yielded similar results. On basis of that assessment, the yellowfin tuna stock was determined to be overfished and subject to overfishing. At its 20th meeting, the Indian Ocean Tuna Commission (IOTC) adopted an Interim Plan for Rebuilding the Indian Ocean Yellowfin Tuna Stock (Res. 16/01).

The SS3 assessment was updated in 2016 (Langley 2016) and was revised and updated in 2018 (Fu et al. 2018). These assessments utilised new composite longline CPUE indices derived from the main distant water longline fleets, replacing the Japanese longline CPUE indices used previously. The 2018 assessment also included a comprehensive analysis of the main assumptions of the stock assessment. A model ensemble covering major components of structural uncertainty was used to characterise the stock status. The assessment estimated that the spawning stock biomass in 2017 was below SSB_{MSY}, and that fishing mortality was above F_{MSY}. Therefore, the stock status was determined to remain overfished and experiencing overfishing.

An external review of the 2018 assessment provided recommendations to improve model parametrisations (Methot 2019). An attempt was made to update the assessment in 2019, with extensive investigations of alternative spatial structures, data weighting and biological parameters (Urtizberea et al. 2019). Further analysis was conducted in 2020 to refine the process of model selection through an objective scoring system based on diagnostic metrics (Urtizberea et al. 2020).

The most recent assessment was conducted in 2021 (Fu et al. 2021), which also used SS3 as the modelling platform and was based on the four area spatial configuration as in 2018. This recent assessment included an standardised CPUE series from the main longline fleets as the main index, but also tested the inclusion of EU purse seine indices, operating on free schools and floating objects, and an index from the Maldivian pole and line fishery. A range of exploratory models were presented to address issues in observational datasets, improve the stability of the assessment model, and explore the effects of alternative model assumptions. Overall stock status estimates do not differ substantially from the 2018 assessment, estimating $SSB/SSB_{MSY} = 0.78$ and $F/F_{MSY} = 1.27$ for the last model year, which suggest that the stock is overfished and experiencing overfishing.

An external review of the 2021 assessment was carried out in 2023 (Maunder et al. 2023), and provided a set of recommendations for the next assessment implementation. This report documents the next iteration of the stock assessment of the IO yellowfin tuna stock for consideration at the 26th WPTT meeting. This stock assessment includes fishery and biological data up to the end of 2023 and its configuration is based on the 2021 assessment. It implements an age- and spatially-structured population model using SS3 (v3.30.22.1) and incorporates some revisions made by the last external review.

2 Background

2.1 Biology

Yellowfin tuna is a cosmopolitan species distributed mainly in the tropical and subtropical oceanic waters of the three major oceans, where it forms large schools. Spawning occurs mainly from December to March in lower latitudes with warmer waters and mesoscale oceanographic activity (Muhling et al. 2017), with the main spawning grounds west of 75°E. However, spawning activity has also been reported in the Oman Sea (Hosseini and Kaymaram 2016), Bay of Bengal (Kumar and Ghosh 2022), off Sri Lanka and the Mozambique Channel, and in the eastern IO off Australia Nootmorn, Yakoh, and Kawises (2005). The size at 50% maturity for this species in the IO was initially estimated at around 75 cm based on cortical alveolar stage (Zudaire et al. 2013), but an updated study suggests that it might be at a larger size ($\sim$ 101 cm) (Zudaire et al. 2022). Tag recoveries provide evidence of large movements of yellowfin tuna within the western equatorial region; however, few observations of large-scale transverse movements in the IO have been reported (Gaertner and Hallier 2015). Yellowfin dwell preferentially in the surface mixed layer and the thermocline (Pecoraro et al. 2017), above 200 m approximately (Sabarros, Romanov, and Bach 2015).

This species has a high metabolic rate and, therefore, it requires large energy supplies to fulfill the bioenergetics demands for movement, growth, and reproduction (Artetxe-Arrate et al. 2021). Feeding behaviour is largely opportunistic, with a variety of prey species being consumed, including large concentrations of crustacean that have occurred recently in the tropical areas and small mesopelagic fishes (Krishnan et al. 2024; Roger 1994; Duffy et al. 2017). Recent growth studies have generally supported a two-stanza growth curve, with a slow initial growth phase up to $\sim$ 60 cm followed by much faster growth (Farley et al. 2023). In addition, differences in mean length-at-age have been identified between males and females for fish older than four years. Environmental variability in the IO impacts the abundance and catch rates of this species. A significant negative association between the Indian Ocean Dipoles (IODs) and the catch rates of yellowfin tuna with a periodicity of approximately four years was observed (Lan, Evans, and Lee 2013; Lan, Chang, and Wu 2020). Likewise, Lan, Chang, and Wu (2020) also found that the El Niño Southern Oscillation (ENSO) had an impact on catch rates near the Arabian Sea.

2.2 Stock structure

Fisheries information indicates that adult yellowfin are distributed continuously throughout the entire tropical Indian Ocean, but some more detailed analysis of fisheries data suggests that the stock structure may be more complex. The tag recoveries may indicate that the western and eastern regions of the IO support relatively discrete sub-populations of yellowfin tuna. Studies of stock structure using DNA techniques have indicated that there may be genetically discrete sub-populations of yellowfin tuna in the northwestern IO (Dammannagoda, Hurwood, and Mather 2008) and within Indian waters (Kunal et al. 2013). A recent study of stock structure using the gene sequencing technology along with a basin-scale sampling design indicated genetic differentiation between north and south of the equator within the IO, and possibly additional genetic structure within the locations north of the equator (Grewe et al. 2020). Parasite composition and abundance suggest limited movement of yellowfin between Indonesian archipelago (eastern IO) and the Maldives (central IO) (Moore et al. 2019). Isotope studies have also suggested relatively limited movement, with resident behaviour at the temporal scale of their muscle turnover

(∼ 3 months) (Ménard et al. 2007). Otolith chemistry analyses concluded that fisheries operating in the western IO are mainly composed of fish with western origin, which suggest limited movement from east to west (Artetxe-Arrate et al. in review). These studies generally support the potential presence of population units of yellowfin tuna within the IO, despite that considerable uncertainty remains on sub-regional population structure in this region. This assessment assumes that the IO yellowfin tuna stock consists of several interconnected regional populations Figure 1 that have the same biological characteristics; however, we acknowledge that more studies are needed to reveal the structure of this species.

2.3 Fisheries

Yellowfin tuna are harvested with a diverse variety of gear types, from small-scale artisanal fisheries (in the Arabian Sea, Mozambique Channel and waters around Indonesia, Sri Lanka, the Maldives, and Lakshadweep Islands) to large gillnetters (from Oman, Iran and Pakistan operating mostly but not exclusively in the Arabian Sea) and distant-water longliners and purse seiners that operate widely in equatorial and tropical waters (ADD FIGURE CATCH). Purse seiners and gillnetters catch a wide size range of yellowfin tuna, whereas the longline fishery takes mostly adult fish (ADD FIGURE CATCH).

Prior to 1980, annual catches of yellowfin tuna remained below about 80,000 mt and were dominated by longline catches (Figure 2). Annual catches increased markedly during the 1980s and early 1990s, mainly due to the development of the purse-seine fishery as well as an expansion of the other established fisheries (fresh-tuna longline, gillnet, baitboat, handline and, to a lesser extent, troll). A peak in catches was recorded in 1993, with catches over 400,000 mt, the increase in catch almost fully attributable to longline fleets, particularly longliners flagged in Taiwan, which reported exceptional catches of yellowfin tuna in the Arabian Sea. The Taiwanese longline fishery in the IO has been equipped with super-cold storage. Since around 1986, the fleet has fished more frequently with deep sets.

Catches declined in 1994, to about 350,000 mt, remaining at that level for the next decade then increasing sharply to reach a peak of about 520,000 mt in 2004/2005 driven by a large increase in catch by all fisheries, especially the purse-seine (free school) fishery. Total annual catches declined sharply from 2004 to 2007 and remained at about 300,000 mt during 2007–2011. In 2012, total catches increased to about 400,000 mt and were maintained at about that level through 2013 to 2015. Total catches increased to an average of 430,000 mt between 2016 and 2019, and a maximum of close to 450,000 mt in 2019 (Figure 2), despite IOTC Resolution 17/01 which requested major fleets to substantially reduce their yellowfin catches below the 2014 or 2015 catch level. Furthermore, catch levels of about 440,000 mt reported for 2018 might be under-estimated (to some extent) because of changes in data processing methodology by European Union-Spain for its purse seine fleet for that year (IOTC 2021).

In recent years (2015–2023), purse seine has been the dominant fishing method harvesting 36% of the total IO yellowfin tuna catch (by weight), with the gillnet and handline fisheries, comprising 20% and 18% of the catch, respectively. There was a substantial increase in the catch by handline in 2020 (Figure 2). A smaller component of the catch was taken by industrial longline (5%), and the regionally important baitboat (4%) and troll (4%) fisheries. The recent increase in the total catch has been mostly attributable to an increase in catch from the gillnet and handline fisheries.

The purse-seine catch is generally distributed equally between free-school and associated (log and FAD sets) schools, although the large catches in 2003–2005 were dominated by fishing on free-schools. Conversely, during 2015–2023 the purse-seine catch was dominated (70%) by the associated fishery.

Historically, most of the yellowfin catch has been taken from the western equatorial region of the IO (44%; region 1b, ADD IMAGE SPATIAL CATCH) and, to a lesser extent, the Arabian Sea (26%), the eastern equatorial region (24%, region 4) and the Mozambique Channel (5%; region 2). The purse-seine and baitboat fisheries operate almost exclusively within the western equatorial region, while catches from the Arabian Sea are principally by handline, gillnet, and longline (see Figure 1). Catches from the eastern equatorial region (region 4) were dominated by longline and gillnet (around Sri Lanka and Indonesia). The southern IO (region 3) accounts for a small proportion of the total yellowfin catch (1%) taken exclusively by longline (see Figure 1).

In recent years (2008–2012), due to the threat of piracy, the bulk of the industrial purse seine and longline fleets moved out of the western waters of Region 1b to avoid the coastal and off-shore waters off Somalia, Kenya and Tanzania. The threat of piracy particularly affected the freezer longline fleet and levels of effort and catch decreased markedly from 2007. The total catch by freezing longliners declined to about 2,000 mt in 2010, a 10-fold decrease in catch from the years before the onset of piracy. Purse seine catches also dropped in 2007–2009 and then started to recover. Piracy off the Somali coast was almost eliminated by 2013 but longline catches have not recovered.

The sizes caught in the IO range from 30 cm to 180 cm fork length. Intermediate age yellowfin are seldom taken in the industrial fisheries, but are abundant in some artisanal fisheries, mainly in the Arabian Sea. Newly recruited fish are primarily caught by the purse seine fishery on floating objects and the pole-and-line fishery in the Maldives. Males are predominant in the catches of larger fish at sizes larger than 150 cm (this is also the case in other oceans). Medium sized yellowfin concentrate for feeding in the Arabian Sea.

3 Data

Catch and length information was provided by the IOTC Secretariat in a comma-separated values (CSV) format. These datasets and the metadata can be found online at the IOTC website: https://iotc.org/documents/WPTT/26AS/Data/01. The catch and length (LF) datasets were mainly composed of information about time (year and month), CPCs, gear type, school type, and grid code. In addition, the catch dataset had information on aggregated catch in weight (metric tons) and numbers, while the LF dataset had information on the number of fish sampled per fork length bin (cm) and the score of reporting quality (RQ) estimated by the Secretariat. The fork length bin width was 2 cm and the length bins spanned from 10 to 308 cm (i.e., a total of 150 length bins).

We processed the LF data following the next steps:

1. The number of sampled fish from 198 to 308 cm was summed and then assigned it to the length bin 198 cm.
2. We converted the length bin width from 2 to 4 cm for the stock assessment model. To do so, we summed the number of sampled fish from pairs of length bins (e.g., 10 and 12 cm were summed and assigned to 10 cm, 14 and 16 cm were summed and assigned to 14 cm, and so on). After this conversion, we had a total of 48 length bins.

3.1 Spatial stratification

The grid code was available for every observation in the catch and LF datasets, which contained information on the grid size, quadrant, and longitude and latitude of the corner of the grid. The grid size categories are shown in Table 1 and Figure 3. The catch dataset always reported information using a grid size of $5^{\circ} \times 5^{\circ}$ (category 6) while the LF dataset had diverse grid size categories. To produce the catch and length frequency inputs for SS3, we tested two different spatial aggregation approaches as described below.

3.1.1 Traditional spatial aggregation

This is the approach used in the 2021 assessment. In order to spatially aggregate the raw data per model area, we calculated the longitude and latitude of the center of the grid (called centroid hereafter). Then, we identified the model area that corresponded to a given grid based on its centroid as shown in Figure 4. Finally, we performed the spatial aggregation by summing the catch values and the number of sampled fish per length bin and averaging the RQ values per model area. As described, there is no any kind of spatial weighting during this process.

3.1.2 Standarized spatial aggregation

This approach homogenized the grids in the LF dataset in standard grids with $5^{\circ} \times 5^{\circ}$ resolution. This standardization procedure was not needed for the catch dataset since that information was always reported at a $5^{\circ} \times 5^{\circ}$ resolution. For LF grids with larger spatial resolution than $5^{\circ} \times 5^{\circ}$ (i.e., categories 1, 2, 3, and 4), the number of sampled fish per length bin was divided equally into standard grids while the RQ was repeated. We excluded standard grids that laid completely on land. For grids with smaller spatial resolution (i.e., category 5), the number of sampled fish per length bin was summed and the RQ was averaged. After this standardization procedure, we calculated the centroid of the standard grids, which were then used to assign model areas as shown in Figure 5. To perform the spatial aggregation, we tested two methods:

- *Without weighting*: We summed the number of sampled fish per length bin and averaged the RQ values per model area.
- *With weighting*: We aggregated the length frequencies and the RQ through a weighting process. To do so, we identified the catch (in numbers) that corresponded to a given LF observation (i.e., year, quarter, standard grid, CPCs, and gear type). We found a perfect match for about ~78% LF observations; however, there were missing catch data for some LF observations. In order to fill in these catch gaps, we followed this imputation procedure with four levels:
- Level 1: Fill in catch gaps with the average catch per grid for a given year, quarter, CPCs, and gear type.
- Level 2: Fill in catch gaps with the average catch per grid and quarter for a given year, CPCs, and gear type.
- Level 3: Fill in catch gaps with the average catch per grid, quarter, and CPC for a given year and gear type.
- Level 4: Fill in catch gaps with the average catch per grid, quarter, CPCs, and year for a given gear type.

Figure 6 shows the percentage of observation that needed each level of imputation.

3.2 Temporal stratification

The time period covered by the assessment spanned from 1950 to 2023, representing the period for which catch data are available from the commercial fishing fleets. The catch and LF data was temporally aggregated by quarter. In the assessment, we considered a quarterly time step (*quarters-as-years* approach), so having in total 296 model time steps. Therefore, recruitment was estimated every model time step (i.e., quarter), which allowed us to represent the continuous recruitment of yellowfin in equatorial regions.

3.3 Definition of fisheries

The assessment adopted the equivalent fisheries definitions used in the previous stock assessments (Table 2). These *fisheries* represent relatively homogeneous fishing units, with similar selectivity and catchability characteristics that do not vary greatly over time. Twenty-one fisheries were defined based on location (region), time period, fishing gear, purse seine set type, and type of vessel in the case of longline fleet (Table 3).

The longline fishery was partitioned into two main components:

- Freezing longline fisheries, or all those using drifting longlines for which one or more of the following three conditions apply: (i) the vessel hull is made up of steel; (ii) vessel length overall of 30 m or greater; (iii) the majority of the catches of target species are preserved frozen or deep-frozen. A composite longline fishery was defined in each region (LL 1–4) aggregating the longline catch from all freezing longline fleets (principally Japan and Taiwan).
- Fresh-tuna longline fisheries, or all those using drifting longlines and made of vessels (i) having fibreglass, FRP, or wooden hull; (ii) having length overall less than 30 m; (iii) preserving the catches of target species fresh or in refrigerated seawater. A composite longline fishery was defined aggregating the longline catch from all fresh-tuna longline fleets (principally Indonesia and Taiwan) in region 4 (LF 4), which is where the majority of the fresh-tuna longliners have traditionally operated. The catches of yellowfin tuna recorded in regions 1 to 3 for fresh-tuna longliners, representing only 3% of the total catches over the time series, were assigned to area 4.

The purse-seine catch and effort data were apportioned into two separate method fisheries: catches from sets on associated schools of tuna (log and drifting FAD sets; *PS LS*) and from sets on unassociated schools (free schools; *PS FS*). Purse-seine fisheries operate within regions 1a, 1b, 2 and 4 and separate purse-seine fisheries were defined in regions 1b, 2 and 4, with the limited catch, effort and length frequency data from region 1a reassigned to region 1b.

In the previous assessment, the region 1b purse-seine fisheries (log and free-school) were divided into three time periods: pre-2003, 2003–2006 and post-2006. This was mainly to maintain historical consistency (the temporal stratification was initially implemented to account for change in the length composition during the 2000s, but no selectivity changes were identified in the assessment and consequently the same selectivity was shared among the three time periods. For the current assessment, the temporal stratification was removed, reducing the 6 purse-seine fisheries in region 1b to 2 fisheries (log and free-school).

A single baitboat fishery was defined within region 1b (essentially the Maldives fishery). As with the purse-seine fishery, a small proportion of the total baitboat catch and effort occurs on the periphery of region 1b, within regions 1a and 4. The additional catch was assigned to the region 1b fishery.

Gillnet fisheries were defined in the Arabian Sea (region 1a), including catches by Iran, Pakistan, and Oman, and in region 4 (Sri Lanka and Indonesia). A very small proportion of the total gillnet catch and effort occurs in region 1b, with catches and effort reassigned to area 1a.

Three troll fisheries were defined, representing separate fisheries in regions 1b (Maldives), 2 (Comoros and Madagascar) and 4 (Sri Lanka and Indonesia). Moderate troll catches are also taken in regions 1a and 3, the catch and effort from this component of the fishery reassigned to the fisheries within region 1b and 4, respectively.

A handline fishery was defined within region 1a, principally representing catches by the Yemenis fleet. Moderate handline catches are also taken in regions 1b, 2 and 4, the catch and effort from these components of the fishery were reassigned to the fishery within region 1a.

For regions 1a and 4, a miscellaneous ("Other") fishery was defined comprising catches from artisanal fisheries other than those specified above (e.g. trawlers, small purse seines or seine nets, sport fishing and a range of small gears).

3.4 Catch

Describe catch per fishery, time series, etc. This is Figure 3.

3.5 Indices

3.5.1 Longline CPUE

Standardised CPUE indices were derived using generalized linear models (GLM) from longline catch and effort data (aggregated by month and 1° grid resolution) provided by Japan, Korea, Taiwan, and China (Matsumoto et al. 2024). Cluster analyses of species composition data for each fleet were used to separate datasets into fisheries understood to target different species. Selected clusters were then combined and standardized using generalized linear models. Yellowfin catch (numbers of fish) was the dependent variable of the positive catch model (lognormal error structure), while the presence/absence of yellowfin tuna in the catch was the dependent variable in the binomial model. In addition to the year-quarter, models included covariates for 5° square location, number of hooks, and vessels (that accounted for 50% of the total effort). The CPUE for the temperate regions 2 and 3 incorporated the cluster variable to indicate the targeting effect, whereas the tropical regions 1 and 4 used hooks between floats (HBF). The CPUE indices represented the time series of abundance (1975–2020) for each of the four model regions (1, 2, 3, and 4). The data from region 1a is not included in the standardization and the index for region 1b is assumed to index the abundance for the whole of region 1.

The standardized quarterly CPUE indices included in the assessment are shown in Figure 8. In general, the overall trends in the updated CPUE indices are similar to those included in the previous assessment, but the updated indices in regons 1, 3, and 4 have larger declines, especially in the early years. For region 3, the updated analysis is based on an aggregated dataset in which there were fewer vessels targeting yellowfin tuna and much less catch and effort, so the information is more scarce (Matsumoto et al. 2024).

For the regional longline fisheries, a common catchability coefficient (and selectivity) was estimated in the assessment model, thereby, linking the respective CPUE indices among regions. This significantly increases the power of the model to estimate the relative (and absolute) level of biomass among regions. However, as CPUE indices are essentially density estimates it is necessary to scale the CPUE indices to account for the relative abundance of the stock among regions. For example, a relatively small region with a very high average catch rate may have a lower level of total biomass than a large region with a moderate level of CPUE.

The approach used was to determine regional scaling factors that incorporated both the size of the region and the relative catch rate to estimate the relative level of exploitable longline biomass among regions. This approach is similar to that used in the Western and Central Pacific Fisheries Commission (WCPFC) regionally disaggregated tuna assessments. Hoyle (2018) proposed a set of regional weighing factors for IO yellowfin based on aggregated longline catch effort data. The authors recommended the estimates by method '8' for the period 1979–1994 (referred to as '7994m8', see Table 2 of Hoyle (2018)) to be included in the current assessment. The relative scaling factors calculated for regions 1–4 are 1.674, 0.623, 0.455 and 1.000 respectively.

For each of the principal longline fisheries, the GLM standardized CPUE index was normalized to the mean of the period for which the region scaling factors were derived (i.e., the GLM index from 1979–1994). The normalized GLM index was then scaled by the respective regional scaling factor to account for the regional differences in the relative level of exploitable longline biomass among regions

A number of important trends are evident in the CPUE indices:

- 1980-1989 the western tropical (region 1b) CPUE increased during the 1980s, then declined until 1995, increased again until 2005, and then decreased again. The low CPUE indices followed the period of exceptionally high catches from the purse seine fishery in region 1b during 2003–2005. The drop in CPUE occurred before the peak in the number of piracy incidents in the western Indian Ocean (2008–2011). After that time, it remained close to the lowest level observed but showed very large seasonal variations.
- The eastern tropical region 4 followed a similar pattern until 1990 but then declined steadily, and by 2016 was also close to the lowest level in the time series. The recent decline in CPUE in this region is consistent with a decline in the proportion of yellowfin in the combined tuna catch from the Japanese longline fleet in the eastern Indian Ocean (see Figure 44 from Hoyle et al 2015). It is unclear whether the change in species proportion is related to a decline in the abundance of yellowfin in the region (relative to the other species) or a regional change in the targeting of the fishing fleet. However, there is an indication that there has been a differential shift towards deeper longline gear (greater HBF) in the eastern Indian Ocean since 2000 and this may indicate a shift in targeting toward bigeye tuna in this region (Hoyle pers. comm. additional JP LL analyses). Such factors may not be adequately accounted for in the standardisation of the yellowfin CPUE data.
- The CPUE indices in western temperate region 2 followed a similar pattern to the western tropical indices, with a decline until the late-1970s followed by an increase until the late 1980s, and subsequently a slow decline with significant variability. However, the two sets of CPUE indices diverge somewhat from about 2007 with the CPUE indices from R2 being maintained at a higher level relative to R1.

- The CPUE indices from region 3 are low compared to the other three regions reflecting the low regional scaling factor. However, the overall trend in the CPUE indices is broadly comparable to the other regions. The eastern temperate region 3 the pattern was similar to the western temperate area before 1979. After 1979 catch rates increased until the mid-2000's, but then declined rapidly and reached their lowest observed levels by 2016.
- There is an exceptionally high peak in CPUE indices 1976–78. Hoyle et al. (2017) showed that this discontinuity exists in Japanese, Taiwanese and Korean data, and in multiple regions in multiple oceans, and for both bigeye and yellowfin tuna. Hoyle et al (2017) suggested this is unlikely to be explained by changes to the population or catchability but may be associated with catch reporting and data management.
- The spike in the CPUE indices around 2012 in the west equatorial region (region 1) was evident for most fishing fleets. Several hypotheses have been proposed on what could have caused CPUE to have increased, including a return to fishing in areas that were most affected by piracy. However, further investigation is required.

3.6 Size data

Describe size data, length bins, catch raising, etc.

3.7 Age data

Describe age-length information, etc.

3.8 Tagging

Tagging information

4 Model description

4.1 Population dynamics

Parametrization of recruitment, growth, etc in SS.

4.2 Fishery dynamics

Selectivity principally.

4.3 Tagged fish

Tag reporting, mixing, etc.

4.4 Likelihood components

Weights, error structure, observation error, etc.

4.5 Parameter estimation and uncertainty

Hessian, max gradient, jitter analysis, likelihood profiles, etc.

4.6 Stock status

Related to MSY, depletion trends, Kobe, etc.

5 Model runs

5.1 Update from the last assessment

Describe stepwise model developtment, etc.

5.2 Sensitivity and structural uncertainty

Different steepness, M, etc, and spatial configurations.

6 Results

6.1 Fits

Describe fits to data.

6.2 Parameter estimates

Describe parameter estimates.

6.3 Time series

Recruitment, SSB, etc.

6.4 Sensitivity

Describe sensitivity analyses.

7 Discussion and conclusions

Discuss. Recommendations for future assessments.

8 Acknowledgements

Write your acknowledgements.

9 Tables

Table 1: Grid size categories in the raw catch and LF datasets.

Grid type	Resolution (latitude × longitude)
1	$30^\circ \times 30^\circ$
2	$10^\circ \times 20^\circ$
3	$10^\circ \times 10^\circ$
4	$20^\circ \times 20^\circ$
5	$1^\circ \times 1^\circ$
6	$5^\circ \times 5^\circ$

Table 2: Fishery classification used in the assessment.

Fishery code	Gear
GI	Gillnet
HD	Handline
LL	Longline
OT	Others
BB	Baitboat
PS FS	Purse seine, free school
PS LS	Purse seine, log school
TR	Troll
LF	Longline (fresh tuna)

Table 3: Fishery definition in the assessment configuration with 4 areas.

Fishery number	Fishery code and region
1	GI 1a
2	HD 1a
3	LL 1a
4	OT 1a
5	BB 1b
6	PS FS 1b
7	LL 1b
8	PS LS 1b
9	TR 1b
10	LL 2
11	LL 3
12	GI 4
13	LL 4
14	OT 4
15	TR 4
16	PS FS 2
17	PS LS 2
18	TR 2
19	PS FS 4
20	PS LS 4
21	LF 4

10 Figures

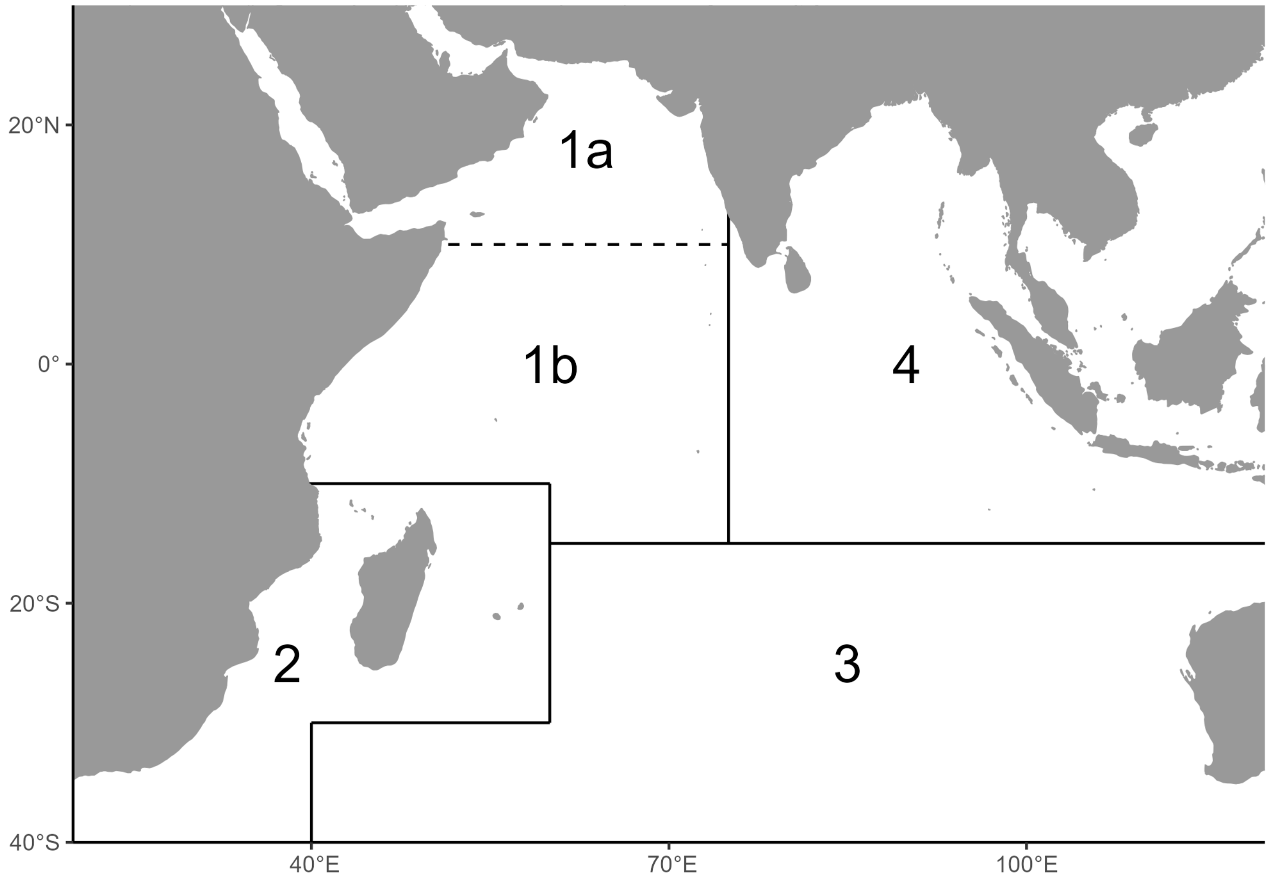

Figure 1: Add your caption here.

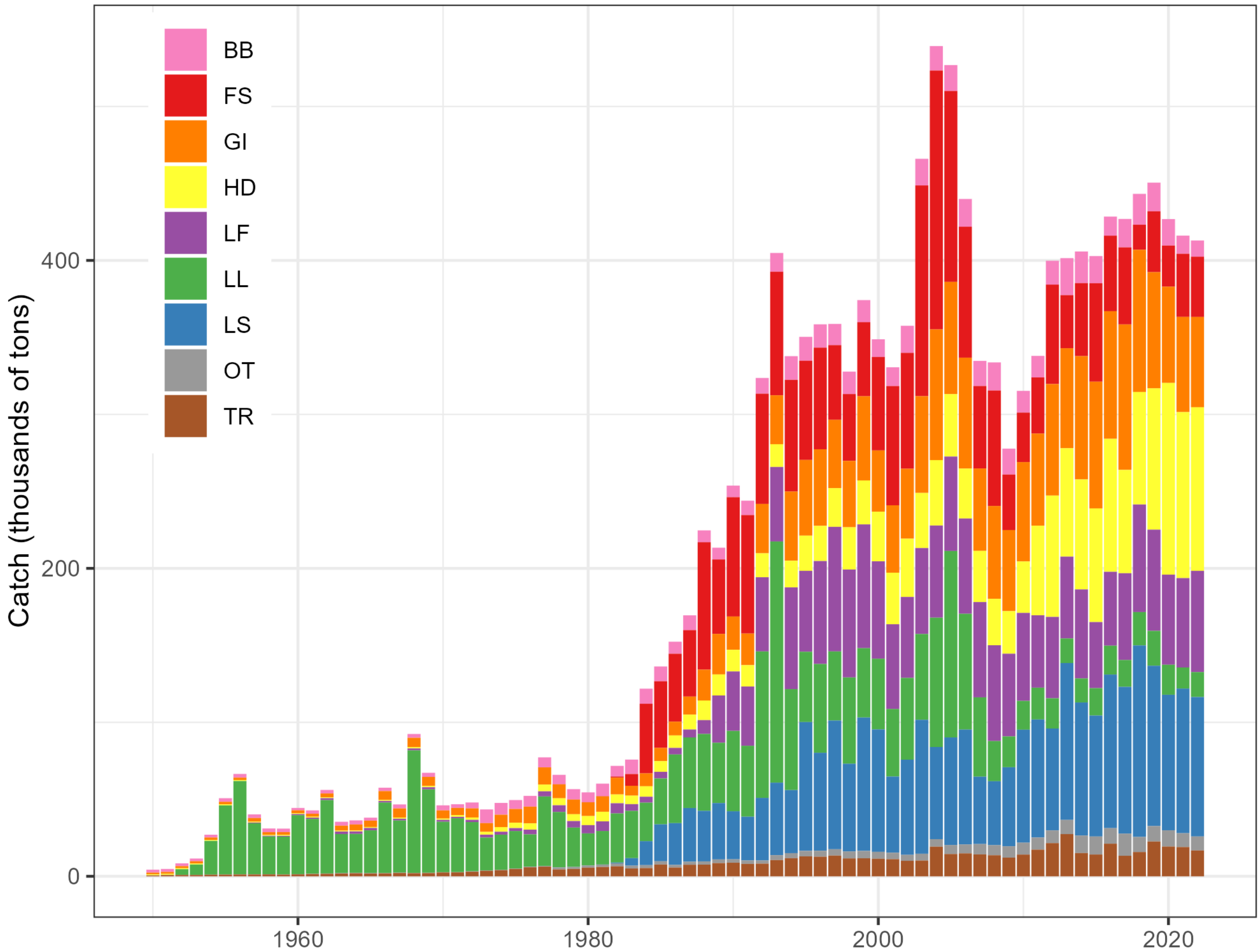

Figure 2: Add your caption here.

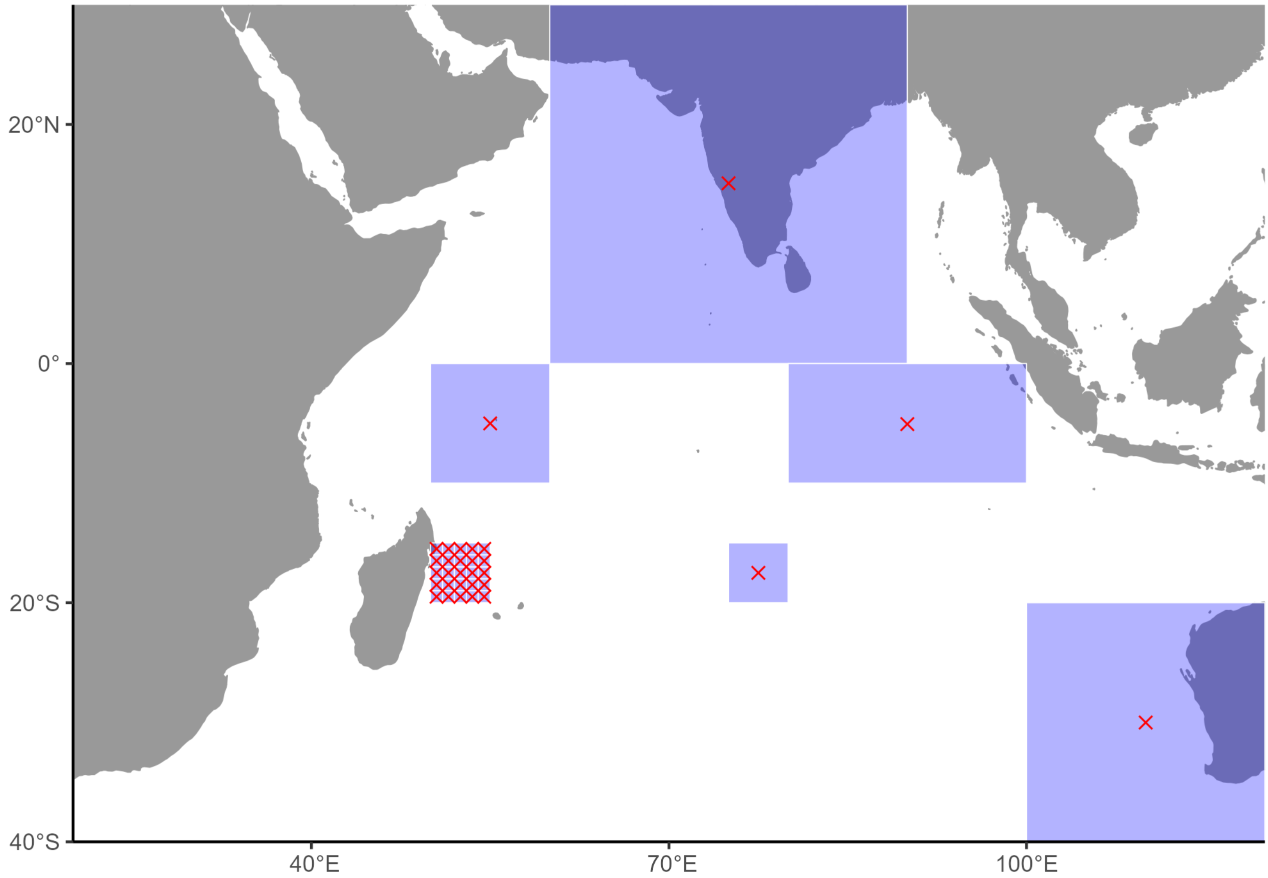

Figure 3: Add your caption here.

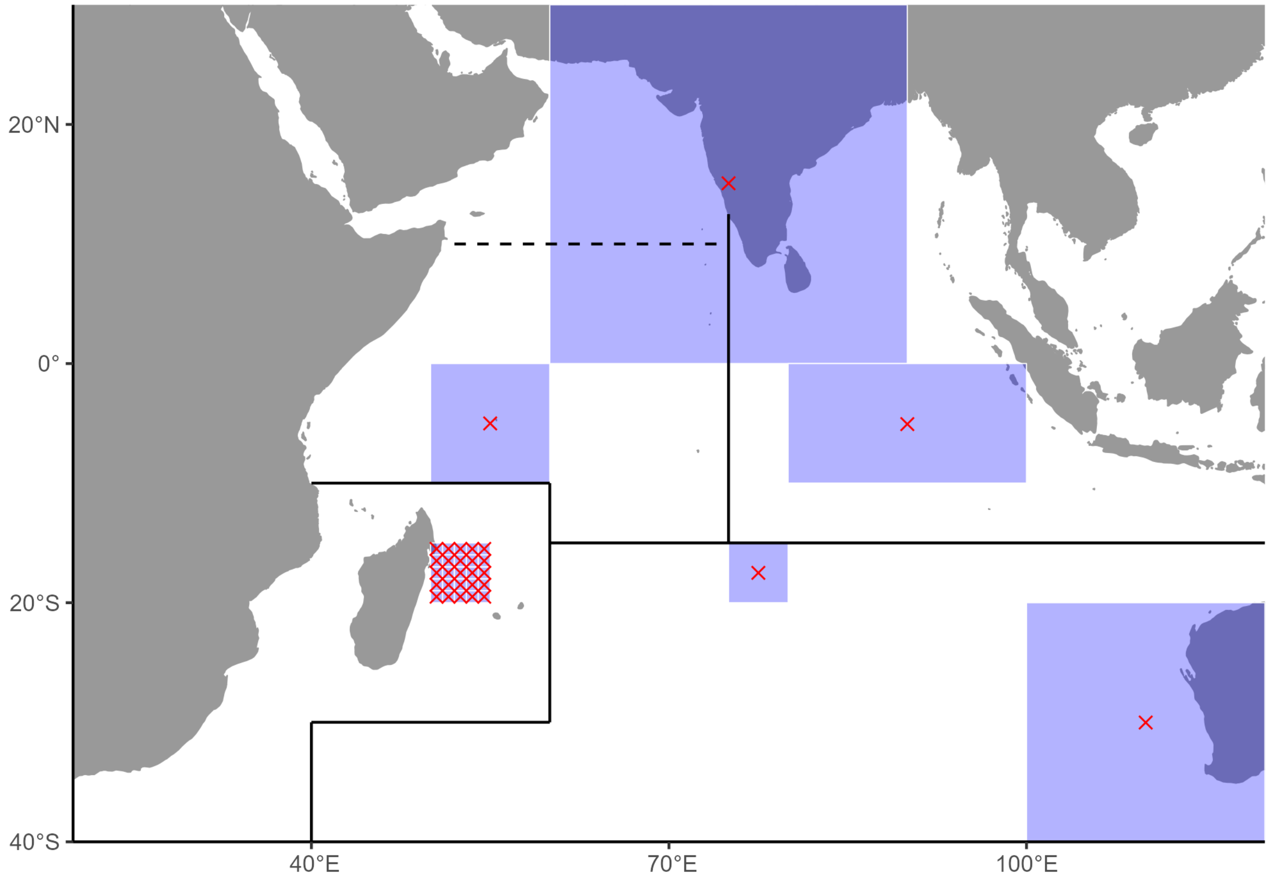

Figure 4: Add your caption here.

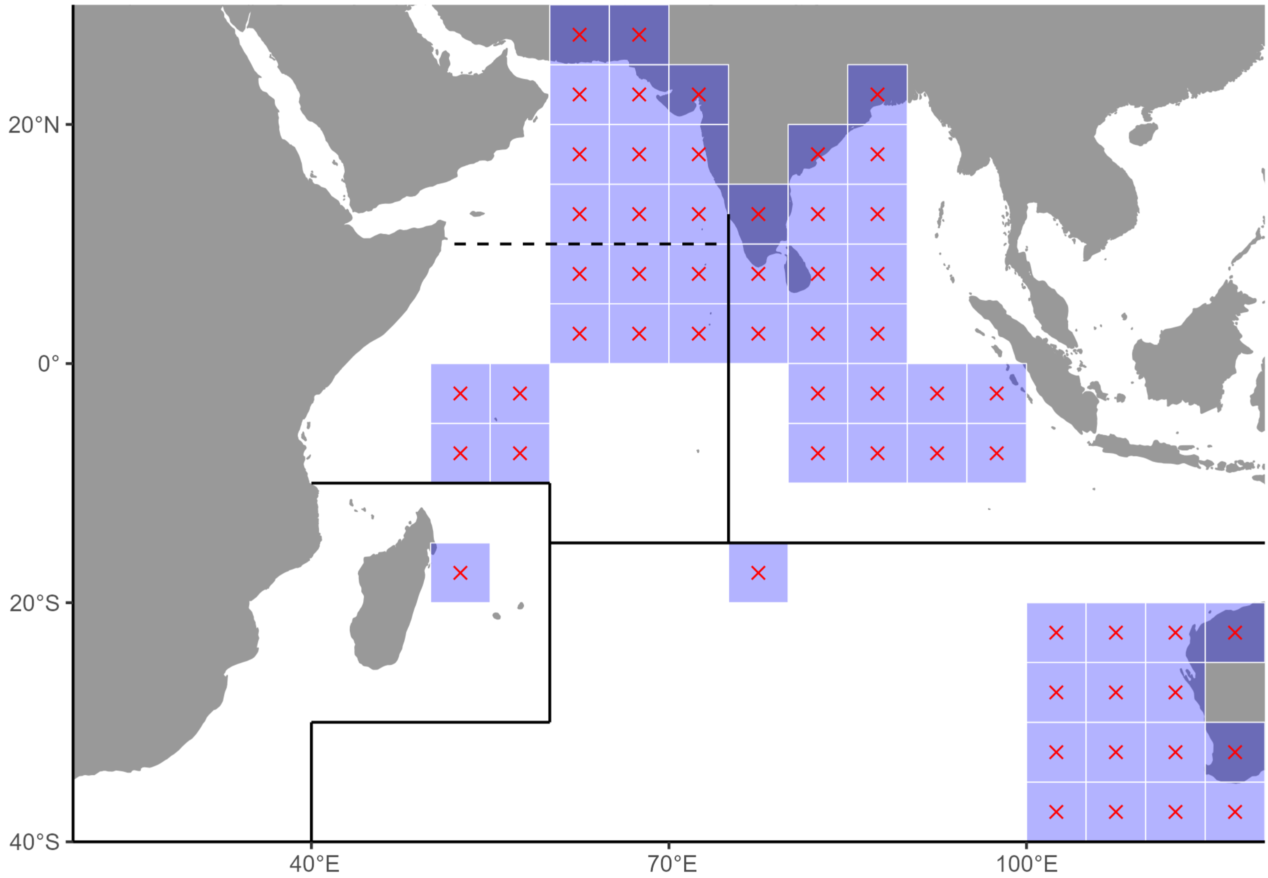

Figure 5: Add your caption here.

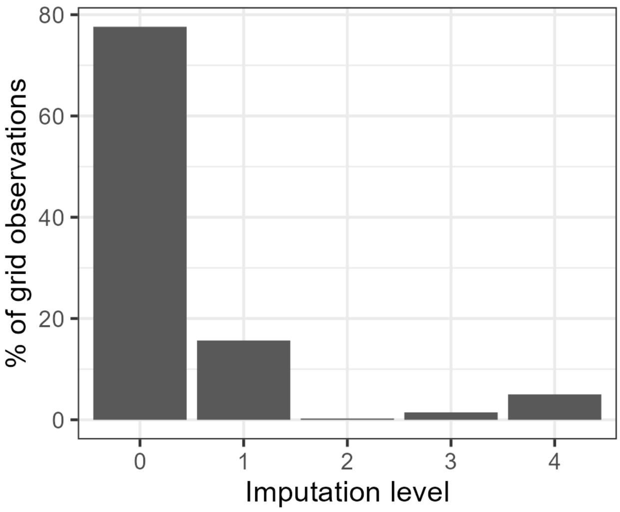

Figure 6: Add your caption here.

11 Appendix

11.1 Acronyms and Abbreviations

Include a table with acronyms (e.g., GLMM, SS, etc.)

11.2 Likelihood profiles

11.3 Retrospective analyses

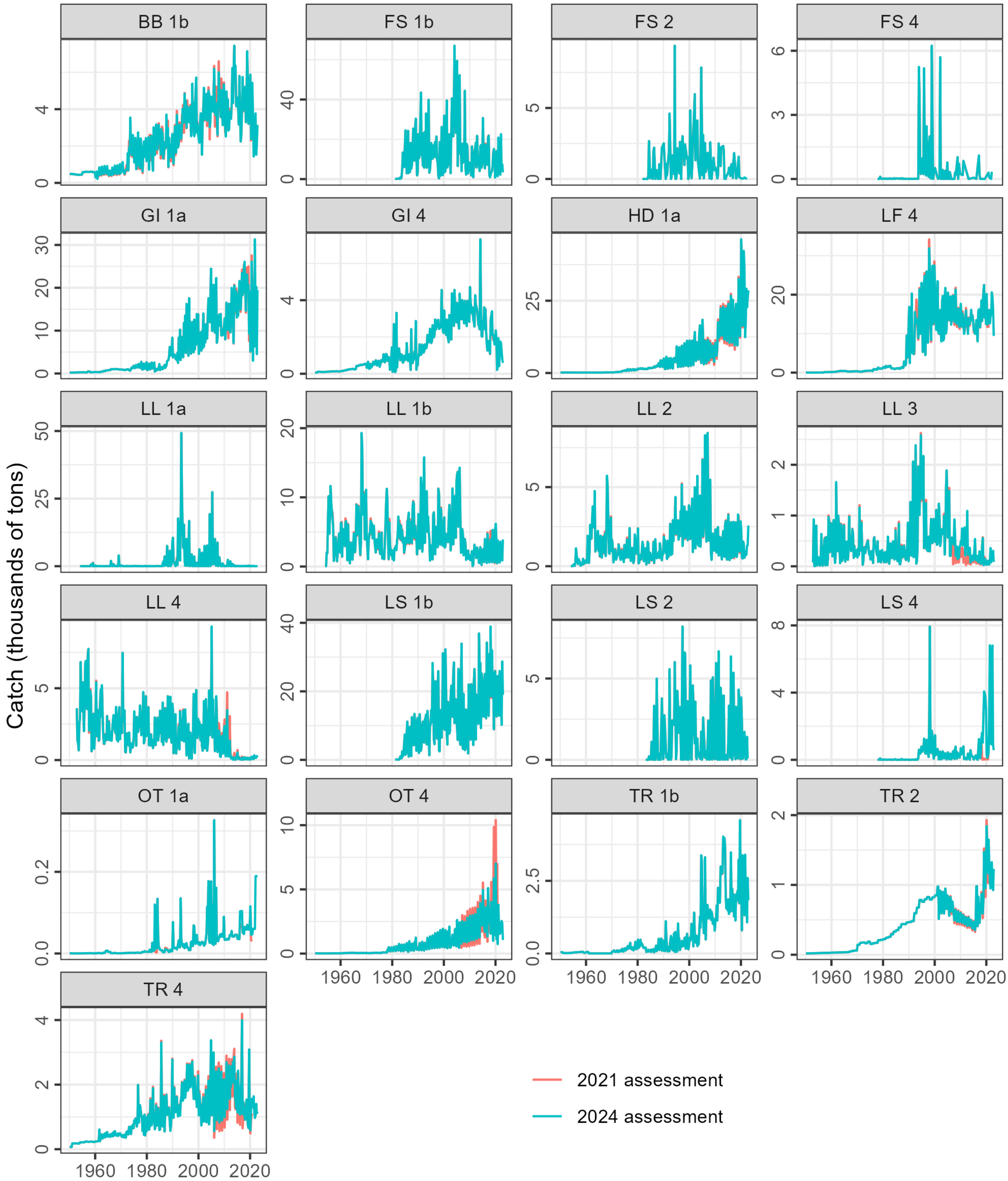

Figure 7: Add your caption here.

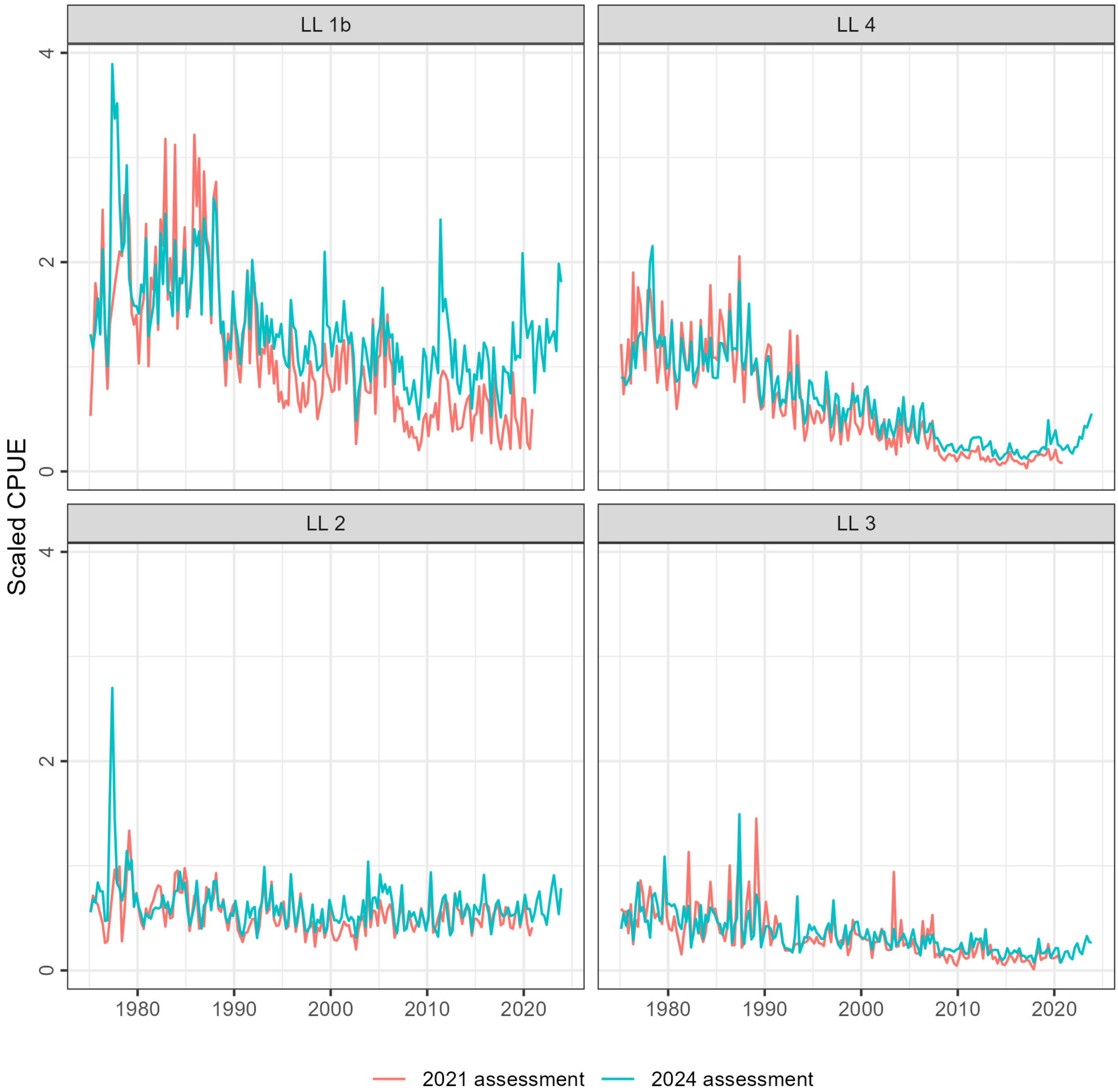

Figure 8: Add your caption here.

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