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# Stock assessment blue shark (*Prionace glauca)* in the Indian Ocean using Stock Synthesis.

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# PREFACE TO THE POST WPEB REVISION (Paper Number IOTC-2015-WPEB11-28_REV-1)

This document incorporates additional work conducted just prior to and during the WEPB 11 meeting in Olhão Portugal. The additional work was undertaken due to the submission of revised CPUE indices, a revision in the catch estimates, and a change in the range of assumed steepness. Note that discussions arising from WPEB asked for modifications to the model based on the recent data submission, this resulted in a set of runs (grid) that was used for stock status advice. **These results are the main results of the stock assessment and are available in Appendix 2.**

## Executive summary

This paper presents the first stock assessment of blue shark in the Indian Ocean. The assessment uses the stock assessment model and computer software known as Stock Synthesis (version 3.24f http://nft.nefsc.noaa.gov/Download.html). The blue shark assessment model is an age structured (30 years), spatially aggregated (1 region) and two sex model. The catch, effort, and size composition of catch, are grouped into 8 fisheries covering the time period from 1971 through 2014. Data collected previous to 1971 are not considered in this analysis.

Blue sharks are most often caught as bycatch in the Indian Ocean tuna fisheries, though some directed mixed species (sharks and tunas/billfish) fisheries do exist. Commercial reporting of landings has been minimal, as has information regarding the targeting and fate of blue sharks encountered in the fisheries. Useful data on catch and effort is mostly limited to recent years, a time series of historical catch has been estimated based on reported effort and observed catch rates.

Multiple data gaps relating to the true state of nature with respect to catch and abundance trends were overcome through the use of integrated stock assessment techniques and the inclusion of alternative data. Multiple models with different combinations of the input datasets and structural model hypotheses were run to assess the plausible range of stock status for blue sharks. The reference case presented here was selected based on the reliability of the data and parameterization and is characterized by the bold values in the table below;.

| GROUP | Variable | Options Run |
|---|---|---|
| **CPUE** | | |
| | | 1. Japan Late |
| | | 2. **Portugal** |
| | | 3. Spain |
| **Length Composition** | | |
| | Sample Size weighting | 1. **Iteratively Re-weighted** |
| | | 2. 0.2 |
| | | 3. 1.0 |
| **Stock Recruitment** | | |
| | Steepness | 1. 0.2 |
| | | 2. **0.3** |
| | | 3. 0.4 |
| | Sigma R (SD on the recruitment deviations) | 1. 0.1 |
| | | 2. **0.3** |
| | | 3. 0.5 |
| **Catch series** | | 1. **IOTC database derived catch** |
| | | 2. Trade based catch |

This reference case model is used as an example for presenting model diagnostics and representative trends, but does not necessarily represent the most appropriate model run to base management advice. The sensitivity of the reference case model to key assumptions (i.e. regarding the stock recruitment relationship, the catch per unit effort time series, data weighting) were explored via sensitivity analyses.

The results of these analyses should also be considered when developing management advice. The axes of uncertainty considered are provided in the table below, reference case options are shown in bold. A full factorial grid of all options was run (this gave a total of 162 model runs), one change sensitivities to the CPUE series and catch estimates are presented in the results, with full results for any run are available on request.

Results for the assessment are compared across different assumptions with reference case parameterization. Estimates of stock status from the reference case and one change CPUE series are $SB_{current}$ /$SB_{MSY}$ =1.2-1.6 and and $F_{current}/F_{MSY}$ = 1.3-2.5_ though the range of uncertainty is extensive. Stock status is reported in relation to MSY based reference points however the authors note that the IOTC has not yet adopted reference points for sharks. Due to the inherent unreliability of recruitment estimates in the terminal year this study defines 'current' as the average of the first four of the last five years (i.e. 2010-2013).

The main conclusions of this assessment are:

1. The stock status is highly dependent on the CPUE series used to fit the model. Among the candidate CPUE models in this assessment no CPUE series runs the through the entire time series.
2. The estimates of catch are highly influential in the model, but mostly in terms of scale, as the current depletion and fishing mortality indicators are approximately equal across both sets of catch estimates.
3. The scale of the assessment is influenced by the CPUE series chosen and by the catch estimates used, estimates of $B_0$ range from approximately 600,000 metric tons to over 5 million metric tons.
4. Among the one change sensitivities and estimates of current stock status with respect for $SB_{current}$ /$SB_{MSY}$ ranged from approximately 0.96-1.63 across the CPUE trends and the catch series which are the main axes of uncertainty considered. This implies a stock that is not likely currently overfished.
5. The stock status implied by the estimates of and $F_{current}/F_{MSY}$ for the reference case and one change sensitivities across the CPUE and catch estimates series was highly divergent with the Spanish series showing almost no impact of fishing on the stock ($F_{current}/F_{MSY}$ =1.7) and while the Japanese and Portuguese show a estimates of and $F_{current}/F_{MSY}$ = 3.07 and 4.63., respectively.

When considering which model(s) to use for the provision of management advice, we recommend that advice be based upon multiple model runs that consider the major axes of uncertainty.

# 1 Introduction

Blue shark (*Prionace glauca*) are a large pelagic species, broadly distributed throughout the Indian Ocean to a southern limit of ~50° S (Figure 1). Indian Ocean blue shark have been incidentally caught by the Japanese longline fleet since the early 1950s. The population was not heavily exploited before targeted fisheries (or bycatch rates increased) in the early 1990s. At this time the Taiwanese long line vessels began taking large numbers, initially in the SW region, followed by the other areas (Figures 1). The European longline fleet (predominantly Spain) started a targeted fishery in the 1990s, while only small numbers are reported in the driftnet fisheries, and purse seine catches are very rare.

# 2 Methods

## Data

There are many different fleets catching blue shark in the Indian Ocean, with vastly different gear types and levels of data quality (Martin et. al. 2015). The 2014 preliminary SS3 assessment used only 8 fleets, and 4 surveys (IOTC–WPEB10 2014) which has been used in 2015 as well. There is enough uncertainty about the selectivity assumptions with respect to time, and the poor size composition data, that we would not expect the size composition data to be very informative about year-class strength. Hence, in most model runs presented here, we down weighted the length-composition data so as to let it inform the selectivity but not alter the model fit to the abundance trend.

## Total catch

Catch estimates by year and fishery are shown in Figure 2 (IOTC-2015-WPEB11-DATA05). It is assumed that the catch in mass figures provided by the IOTC members and cooperating non-contracting parties (CPC's) are the most reliable catch data available. While the total catch data are estimates, they are derived in large part from the industrial fleets in the Indian Ocean and are thought to be more reasonable for blue shark than for the other shark species.

Potential concerns were identified with respect to the catch time series:

- Nominal catch estimates for the Japanese historical series (1964 – 1993) have been estimated using a simple species ratio (in the absence of better information, or more sophisticated approaches such as GLM).
- Catch-and-effort for BSH are highly incomplete: available for a (a.) limited number of years (i.e., from the late-1990s onwards) and (b.) an very limited number of fisheries (mostly Portugal and Taiwan LL, and Japan LL to a lesser extent).
- While breaking the catches by the three assessment areas may be possible in theory (for a subset of the fisheries, for selected years), I would be highly cautious about using a highly incomplete catch-and-effort dataset to disaggregate by area an equally highly incomplete nominal catch series.

An alternative catch series was used based on trade based estimates using the proportion of tuna caught (IOTC–2015–WPEB11–24). This series extends from 1981-2011. To extend this catch series throughout the model domain a ratio (IOTC catch/ trade catch) from the 1980's was used to extend the model prior to 1980. The same method was used for extending the trade estimates to 2012-2014 based on the average ratio from the 2010's.

## 2.1 Relative abundance indices

The standardized CPUE series in 2014 were somewhat different from those previously submitted to the WPEB. Newly estimated CPUE series by Japan from log-books data was analyzed in 2014(Figure 3). The other two series examined were Portugal and Spain. All three are based on incidental bycatch data as the primary focus species is swordfish for the Portuguese and Spanish fleets and tuna for the Japanese fleet (with some directed fisheries towards Swordfish in some areas): Just prior to the meeting data from Taiwan and early series from Japan were submitted, these are included in Figure 3 but due to the lateness of submission the were not included in the analysis.

## 2.2 Size composition data

A major effort was made to organize length-composition data from the main fleets, namely Japan, Taiwan and Portugal. The S. African LL fleet was the primary source for the Fishery 3 (the Other LL fleet). In all, approximately twenty years of length composition data from the LL fleets was organized and used in the analysis.

Some size and sex composition data of catch were available, but in many cases the data were in aggregated form covering several years, or size sampling was incomplete across fisheries. Many of the time series suffered from low sample sizes and inconsistencies across years. For this reason and because of the evidence that there was a conflict between the CPUE and the size data (see results below) we chose to give low weight to the size data in the model – to allow us to estimate selectivity, but not to overwhelm the model. We assumed an annual sample size proportional to the overall sample size, scaled to 1000, for each record and applied a lambda of 0.2 for the reference case and 1 as a sensitivity analysis as:

$ESS_{j,y}$ is the annual effective sample size for the fleet and it is calculated by:

$$ESS_{j,i} = \frac{S_{j,i}}{\sum_j \sum_y s_{j,y}} \times 1000$$

Where $S_{j,y}$ is the exact sample size (numbers of fish) for fleet *j* in year *y*.

This approach is consistent with the recommendations of Francis (2011 and 2014), namely “do not let other data stop the model from fitting abundance data well”.

## 2.3 Software

The analysis was undertaken with Stock synthesis SS V3.234F, 64 bit version (Methot 2000, 2009, executable available from http://nft.nefsc.noaa.gov/SS3.html), running on MS Windows$^{TM}$ 7. Typical function minimization of the fully disaggregated model on a 3.0 GHz personal computer required about 4 minutes. Additional simplifications and aggregations could probably reduce the minimization time further, without significant loss to the stock status inferences. However, given the current exploratory manner in which the model is being used to describe interactions among assumptions, the disaggregation is considered to be useful and the computation speed does not represent a real problem.

## 2.4 General assessment approach

As with previous shark assessments undertaken by other RFMO's the general approach was to identify the key areas that contributed greatest to the uncertainty regarding stock status and then explore the implication of different assumptions on each. In doing this we first identify a 'reference case' model, which is not necessarily the 'best' or 'base case' model but rather a model that we think is reasonable, and use this to present the range of key model diagnostics. Next we identify a range of areas or axes of uncertainty and choose some options for each. For example we consider the steepness of the stock recruitment relationship to be an area of uncertainty and consider three options under it. We then run the set of models that reflect a single change from the reference case and these are our one-change sensitivities. Finally we run a full grid with all the options across all the axes of uncertainty. This is useful to determine if there are particular interactions between model assumptions / data inputs.

## 2.5 Model Assumptions

The most important model assumptions are described in the following sections. Standard population dynamics and statistical terms are described verbally, 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 assumption options that were combined in a balanced 'grid' design (i.e. all possible combinations of the listed assumption options were fit, while the other assumptions remained constant).

## 2.6 Time Period

The model was iterated from 1971-2014 using an annual time-step, however, further analysis of seasonal processes is encouraged.

## 2.7 Biological inputs and assumptions

Blue sharks have a Indian Ocean wide distribution, and genetic evidence of distinct population structure within other oceans (e.g. Pacific) has not been found (Taguchi and Yokawa 2013), and hence assumed homogenous here as well. Conventional tagging studies need to be examined in the Indian Ocean, but currently no such data exist like on the Pacific. In addition to assumptions regarding stock structure, the other critical information on the biology of blue shark necessary for the SS assessment relates to sex-specific growth, natural mortality, maturity and fecundity.

## 2.8 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. For any specific model, it is necessary to assume the number of significant age-classes in the exploited population, with the last age-class being defined as a "plus group", i.e. all fish of the designated age and older. For the results presented here, 30 yearly age-classes have been assumed, as age 30 approximates to the age at the theoretical maximum length of an average fish.

Sex-specific estimates of growth and length-weight parameters from Nakano (1994) were assumed in the assessment (Figure 4) – no attempt was made to estimate growth due to the uninformative nature of the size data to track cohorts through time.

We considered the growth curves from Hsu et al. (2011) as well as specific formulations based on data from the Indian Ocean, in earlier iterations of the assessment, but due to time limitations we did not include these as an element in the final grid. Future assessment may wish to consider alternative growth curves, but their impact needs to be viewed alongside assumptions regarding the descending right-hand limb of the selectivity curves assumed for the fleets in the model.

A CV of 0.25 was used to model variation in length-at-age. All lengths reported from the assessment relate to pre-caudal length (PCL).

## 2.9 Natural mortality

Sets of age and sex-specific natural mortality ogives were considered in the assessment calculated based on the Peterson and Wroblewski (1984) method (Rice and Semba 2014) (Table 3).

## 2.10 Maturity and fecundity

For the purpose of computing the spawning biomass, we assume a logistic maturity schedule based on length with the age-at-50% maturity for females equal to 145cm (Nakano and Seki 2003). There is no information which indicates that sex ratio differs from parity throughout the lifecycle of blue shark. Fecundity was fixed to an average of 25 pups per gestation.

## 2.11 Population and fishery dynamics

The model partitions the population into 30 yearly age-classes in one region (Figure 1). The last age-class comprises a “plus group” in which mortality and other characteristics are assumed to be constant. The population is “monitored” in the model at yearly time steps, extending through a time window of 1971-2014. The main population dynamics processes are as follows:

In this model “recruitment” is the appearance of age-class 1 fish (i.e. fish averaging approximately 50 cm in the population). The results presented in this report were derived using one recruitment episode per year, which is assumed to occur at the start of each year. Annual recruitment deviates from the recruitment relationship were estimated, but constrained reflecting the limited scope for compensation given estimates of fecundity. Deviations from the SRR were estimated in two parts; one the early recruitment deviates for the 5 years prior to the model period before the bulk of the length composition information (1966 -1970) and two being the main recruitment deviates that covered the model period (1971 - 2014).

There is no information which indicates that sex ratio differs from parity throughout the lifecycle of blue shark. In this assessment the term spawning biomass (SB) is a relative measure of spawning potential (the mature female population) and is a unit less term of reference. It is comparable to other iterations of itself, but not to total biomass.

## 2.12 Initial population state

It is not assumed that the blue shark population was at an unfished state of equilibrium at the start of the model (1971) as longline fishing occurred in the region for a significant number of years (at least from the 1950s onwards). Stock Synthesis has several approaches to start from a fished state and two of these were considered during this assessment. One approach is to estimate an initial equilibrium fishing mortality, which would result in a stable age distribution, impacted by fishing, which would match the observed age distribution at the start of the time series. However our model lacked length information from the first two thirds of the model which made estimating this parameter difficult, often leading to heavily depleted populations at the beginning of the model. Therefore the initial catch was set to approximately 100% of the average of the first five years of the model, to represent a plausible estimate for the initial depletion.

The population age structure and overall size in the first year is determined as a function of the estimate of the first years recruitment ($R_1$) offset from virgin recruitment ($R_0$), the initial 'equilibrium' fishing mortality discussed above, and the initial recruitment deviations. As the size data were found to be uninformative about initial depletion and recruitment variation only a small number (five) of initial recruitment deviates were estimated.

### 2.13 Selectivity Curves

Selectivity is fishery-specific and was assumed to be time-invariant. A double-half normal functional form was assumed for all selectivity curves except the miscellaneous fishery which was set to a logistic. An offset on the peak and scale was estimated for sex-specific differences in selectivity that were evident in the data. The selectivity function location and scale were estimated for fleets 3, 4, 6,7 and 8 and with the ascending and descending functions were fixed to a best fit when estimated independently, only the location parameter was estimated for fleet 5 as the model failed to converge if the scale was also estimated.

### 2.14 Parameter estimation and uncertainty

Model parameters were estimated by maximizing 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 maximization was performed by an efficient optimization using exact numerical derivatives with respect to the model parameters (Fournier et al. 2012). Estimation was conducted in a series of phases, the first of which used arbitrary starting values for most parameters. The control file documenting the phased procedure, initial starting values and model assumptions are available from the lead author (joelrice@uw.edu).

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.

### 2.15 Assessment Strategy

As noted above, our strategy was to determine some main axes of uncertainty and these have been described in the preceding sections, a graphical description of the data availability is shown in Figure 5. A summary table of the model options considered is provided Table 2. In total 162 model runs were undertaken in the full grid. This reflects the broader range of options available under the more complex SS assessment framework (in terms of both model assumptions and data inputs). One advantage of this approach is that the model runs are available for the working party to decide on the model(s) that it wishes to use for the provision of management advice.

From this set of 162 runs we selected our reference case model. The reference case model selected used: Portuguese index of abundance, age specific natural mortality, length composition weighting = iteratively re-weighted, steepness =0.3, sigma R of 0.3 and catches as estimated by the IOTC (IOTC-2015-WPEB11-DATA03 Rev_1).

### 2.16 Retrospective Analysis

To analyse the model structure with respect to bias, a retrospective analysis (Cadrin and Vaughn, 1997) was conducted by sequentially deleting annual data from the model, starting with the last year. Consistent misestimation of the spawning biomass is generally considered evidence of bias within the structuring of the model.

### 2.17 R0 Profile

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. We use the MLE of R0 and the estimate of R0 corresponding to the minimum value of specific data components to evaluate the impact of each data set. Virgin recruitment (R0) is an ideal scaling parameter because it is proportional to the unfished biomass. Profiles were run with the Ln(R0) parameter 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.

## 3 Results

In this section we focus on the basis for selection of the reference 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 one-change sensitivity analyses.

### 3.1 Reference case model

The reference case model choice is described in section 2.15. The choice of model parameters and data inputs reflected the best plausible combination data.

Estimated parameters and model performance

We found strong differences in the sex-specific selectivity curves for many of the fisheries which reinforce the observations of biologists for areas of sex-segregation during the life history of blue sharks (Figure 6). With the exception of the Japanese longline fishery; all fisheries where sex specific selectivity could be estimated resulted in a lower peak selectivity (therefore catchability) for females.

The overall fit to the length data was generally good (Figures 7 and 8). 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. When attempting to estimate selectivity curves for fisheries with sex specific patterns the model often did not converge, therefore the sex specific offsets were fixed. Pearson residuals of the fit to the length compositions were small – on the order of 2 to -2 and did not show any temporal trend (Figure 9).

The fit to the CPUE indices was generally good for the reference case model (Figure 10). The fit to the CPUE series was within the confidence intervals for all years however in the later years the predicted values decline faster than the point estimates of the index. This clearly shows the impact of the dramatic increase in estimated catch in the recent years.

Retrospective analysis (Figure 18) showed variability in each of the models fit using only one CPUE. No structural bias was obvious in based on the retrospective analysis because the estimation of spawning biomass did not show a clear trend. For all retrospective plots the first two years (2013 and 2012 ) show estimates of spawning biomass in concert with the full model, while the years 2011 and 2010 are consistently lower.

As part of an analysis of model structure retrospective analysis (sequentially deleting 1 year of data from the end of the model and re-running) was run using the Portuguese, Japanese late and Spanish CPUE series and the IOTC database catches. Due to late revision the Taiwanese CPUE series was not used for a retrospective analysis. While the retrospective analysis showed some change in scale for the for the estimates of spawning biomass, especially with the deletion of 3 or more years of data, there was no systematic bias in the direction of the change across the three CPUE series analysed (Figure 18). The estimates of spawning depletion remain very similar across all the retrospective model runs considered indicating that the changes in estimates of spawning biomass are based on the total catch (Figure 18 right hand column).

Further analysis of model structure was investigated via an age-structured production model (ASPM) run within the SS3 framework. In essence this modelling technique allows the assessment to be informed by the length compositions as to the population structure but fits only the catch and CPUE, thus allowing the analysis of the overall impact on the population scale of fitting to the length compositions.

The age structured production model run with the reference weight and equal weights (yellow and red lines Figure 19) was quite similar in scale to the ASPM reference case model using the Portuguese CPUE series and estimating recruitment deviations (dark blue line Figure 19). The result of the giving no weight to the length composition (light blue line Figure 19) shows a slight increase in the number of annual recruits as well as a corresponding increase in the spawning biomass, most notably in the early years of the model where there is neither CPUE series or length composition to inform the model. The trends and scale of the ASPM and the ASPM reference model (dark blue line Figure 19) are similar throughout the data rich part of the model domain (the last 20 years) indicating that the model is properly structured.

Additional investigation of model structure was undertaken via the use of profile likelihood on the global scaling parameter (R0). The two data components that were profiled were the length composition (Figure 20) and CPUE series (Figure 20).The likelihood profiles over R0 show a consistent trend towards smaller values (appx 7-8) for ln(R0) (Figure 20 A,B, &C).

Overall, the model fit to data, length compositions and indices was good. Estimation of the R0 parameter and the virgin spawning biomass was fairly consistent based on the retrospective analysis (Figure 21), though with the removal of 5 years of data the model either resulted in wide density estimation or failed to converge.

### Estimated stock status and other quantities

The reference case model estimates that the total biomass of the stock was at 97% of the unfished level at the start of the model period (Table 4 and Figure 11) and steadily decreased to an estimate of ) for $SB_{CURRENT}/S_{B0}$ =50-75% based on the IOTC catches () for $SB_{CURRENT}/S_{B0=}$ 44%-68% for the trade based catches). Recruitment is fairly well estimated throughout the model time period (Figures 12 and 13), with recent recruitment estimated to be lower than then 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 1990's and early 2000's due to the increase in catch (Figure 14).

SS provides estimates of the MSY-related quantities and these and other quantities of interest for management are provided in Table 4. We note that the IOTC has not yet adopted target or limit reference points for any shark species, so a broad suite of MSY-related quantities are presented.

In the reference case the estimated MSY is approximately 6000 mt and this is predicted to occur at 46% of the unfished biomass (Figure 15), which is similar to the standard Schaefer production model (0.5). Current catches are estimated to be well in excess of MSY.

The stock is declining due to an increase in F, F in the final year is greater than $F_{MSY}$, with estimates of $F_{CURRENT}/F_{MSY}$ ranging from 1.67 to 4.9 depending on the CPUE and catch series selected. Based on recent conditions (current) the spawning stock biomass is estimated to be $SB_{CURRENT}/S_{MSY}$ =0.96-1.63 depending on the CPUE and catch series. By the standard terminology, this would indicate that the stock is experiencing overfishing and on the cusp of being overfished.. If current trends in fishing conditions continue, the stock will become overfished. Estimates of stock status from the entire grid (Figure 17) indicate that across the axes of uncertainty considered the majority of the runs indicate that the stock is currently not overfished however overfishing is occurring.

# 4 Conclusion

Results for the assessment are compared across different assumptions with reference case parameterization resulting in estimates of $SB_{current}/SB_{MSY}$ =1.08% and $F_{current}/F_{MSY}$ =4.6 though the range of uncertainty is extensive. Stock status is reported in relation to MSY based reference points however the authors note that the IOTC has not yet adopted reference points for sharks. Due to the inherent unreliability of recruitment estimates in the terminal year this study defines 'current' as the average of the first four of the last five years (i.e. 2010-2013).

The main conclusions of this assessment are:

- The stock status is highly dependent on the CPUE series used to fit the model. Among the candidate CPUE models in this assessment no CPUE series runs the through the entire time series.
- The scale of the assessment is influenced partially by the CPUE series chosen, estimates of $B_0$ range from approximately 600,000 metric tons to over 1 million metric tons. The choice of catch series also heavily influencing the scale by an order of 3-4 million tons.
- Among the one change sensitivities and estimates of current stock status with respect for $SB_{current}/SB_{MSY}$ ranged from approximately 0.9 to 1.6 across the CPUE and catch trends which was the main axis of uncertainty. This implies a stock that is likely not currently overfished.
- The stock status implied by the estimates of and $F_{current}/F_{MSY}$ for the reference case and one change sensitivities across the CPUE series and catch series all showed values of $F_{current}/F_{MSY}$ >1.
- Relative to *MSY*, the reference case and the majority of models run with input parameter values considered most probable, support the conclusion that the Indian Ocean blue shark is not overfished ($SB_{2014}>SB_{MSY}$) and but overfishing is likely occurring ($F_{2014}>F_{MSY}$).

- While the results of the sensitivity runs varied depending upon the input assumptions, a few axes of uncertainty were most influential on the results, including CPUE series and catch series.

When considering which model(s) to use for the provision of management advice, we recommend that advice be based upon multiple model runs that consider the major axes of uncertainty.

The main drivers of this assessment are the trend in the catch and CPUE series. In particular the large increase in recent years of catch has different interpretations – within the model- based on whether the CPUE series is slightly increasing (Japanese late) , decreasing (Portuguese), or relatively stable (Spanish).

Recommended work products that would improve future analysis are

- Develop appropriate length inputs for all fleet.
- Further investigation of CPUE series and their representativeness.
- Develop region specific biological inputs..
- Further work on developing catch histories.

## 5 Acknowledgements

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# 7 Tables

**Table 1. Fishery definitions for the Indian Ocean Assessment**

| Fleet/ Survey Number and Short Name | Gear (s) | Selectivity |
|---|---|---|
| F1 MISC | Costal longline, trolling and artisanal fisheries | Fixed logistic |
| F2 GILL | Gillnet Fleets | Mirrored F5 |
| F3 OTHER_LL | All longline other than Japan, TWN, China, Korea, Portugal and Spain. | Estimated |
| F4 JPN_LL | Japanese longline | Estimated |
| F5 KOR_LL | Korean longline | Estimated |
| F6 PRT_LL | Taiwanese longline | Estimated |
| F7 TWN_LL | Portuguese longline | Estimated |
| F8 ESP_LL | Spanish longline | Estimated |
| S1 JPN_EARLY | Japan early years survey | NA |
| S2 JPN_LATE | Japan late years survey | NA |
| S3 POR | Portugal Survey | NA |
| S4 ESP | Spain Survey | NA |

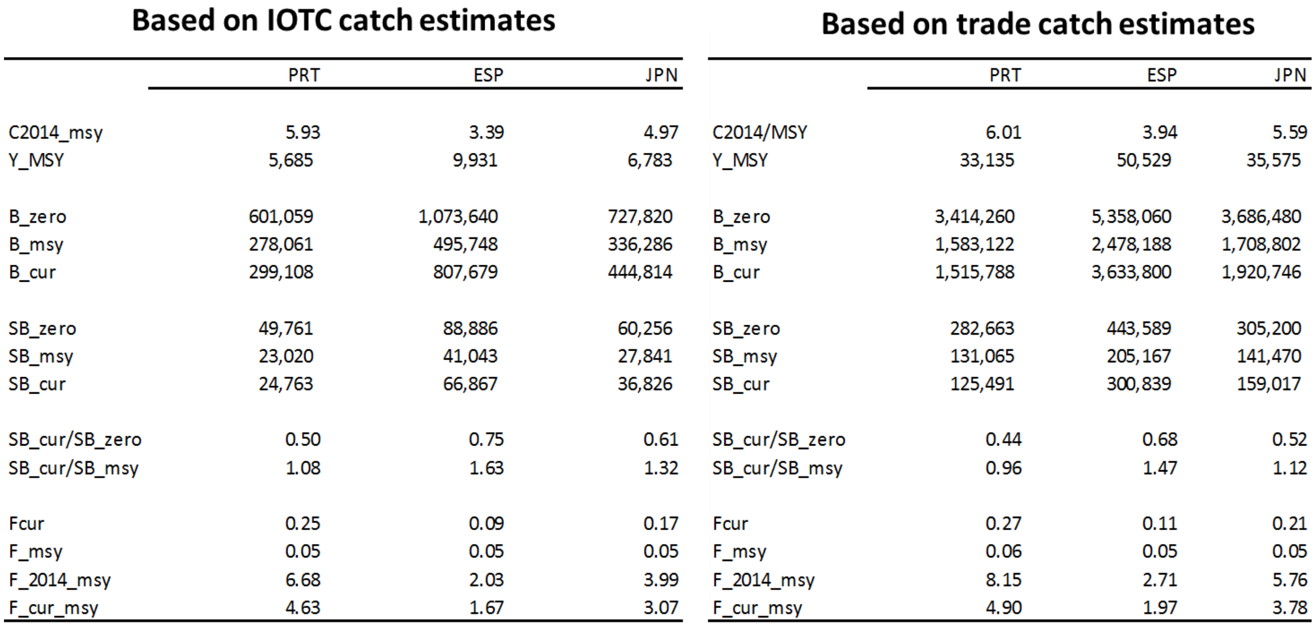
**Table 2. Summary of SS3 specification options for the Indian Ocean assessment models. Other assumptions were constant for all models. The options below were applied in a balanced design (all possible combinations, such that a total 162 models were fit for the IO).**

| GROUP | Variable | Options Run |
|---|---|---|
| **CPUE** | | |
| | | 1. Japan Late |
| | | 2. **Portugal** |
| | | 3. Spain |
| **Length Composition** | | |
| | Sample Size weighting | 1. **Iteratively Re-weighted** |
| | | 2. 0.2 |
| | | 3. 1.0 |
| **Stock Recruitment** | | |
| | Steepness | 1. 0.2 |
| | | 2. **0.3** |
| | | 3. 0.4 |
| | Sigma R (SD on the recruitment deviations) | 1. 0.1 |
| | | 2. **0.3** |
| | | 3. 0.5 |
| **Catch series** | | 1. **IOTC database derived catch** |
| | | 2. Trade based catch |

**Table 3: Estimates of age-specific natural mortality used in the assessment. The reference case used those based on the approach of Peterson and Wroblewski (1984) method and the Nakano data (Rice and Semba 2014).**

| | Natural Mortality | |
|---|---|---|
| Age | Male | Female |
| 0 | 0.564 | 0.535 |
| 1 | 0.3 | 0.309 |
| 2 | 0.22 | 0.233 |
| 3 | 0.18 | 0.194 |
| 4 | 0.156 | 0.171 |
| 5 | 0.14 | 0.155 |
| 6 | 0.128 | 0.144 |
| 7 | 0.12 | 0.135 |
| 8 | 0.114 | 0.129 |
| 9 | 0.109 | 0.124 |
| 10 | 0.105 | 0.12 |
| 11 | 0.101 | 0.117 |
| 12 | 0.099 | 0.114 |
| 13 | 0.096 | 0.112 |
| 14 | 0.095 | 0.11 |
| 15 | 0.093 | 0.109 |
| 16 | 0.092 | 0.107 |
| 17 | 0.09 | 0.106 |
| 18 | 0.089 | 0.105 |
| 19 | 0.089 | 0.105 |
| 20 | 0.088 | 0.104 |
| 21 | 0.087 | 0.103 |
| 22 | 0.087 | 0.103 |
| 23 | 0.086 | 0.103 |
| 24 | 0.086 | 0.102 |
| 25 | 0.085 | 0.102 |
| 26 | 0.085 | 0.102 |
| 27 | 0.085 | 0.101 |
| 28 | 0.085 | 0.101 |
| 29 | 0.084 | 0.101 |
| 30 | 0.084 | 0.101 |

**Table 4: Estimates of key management quantities for the reference case model and one change sensitivities.**



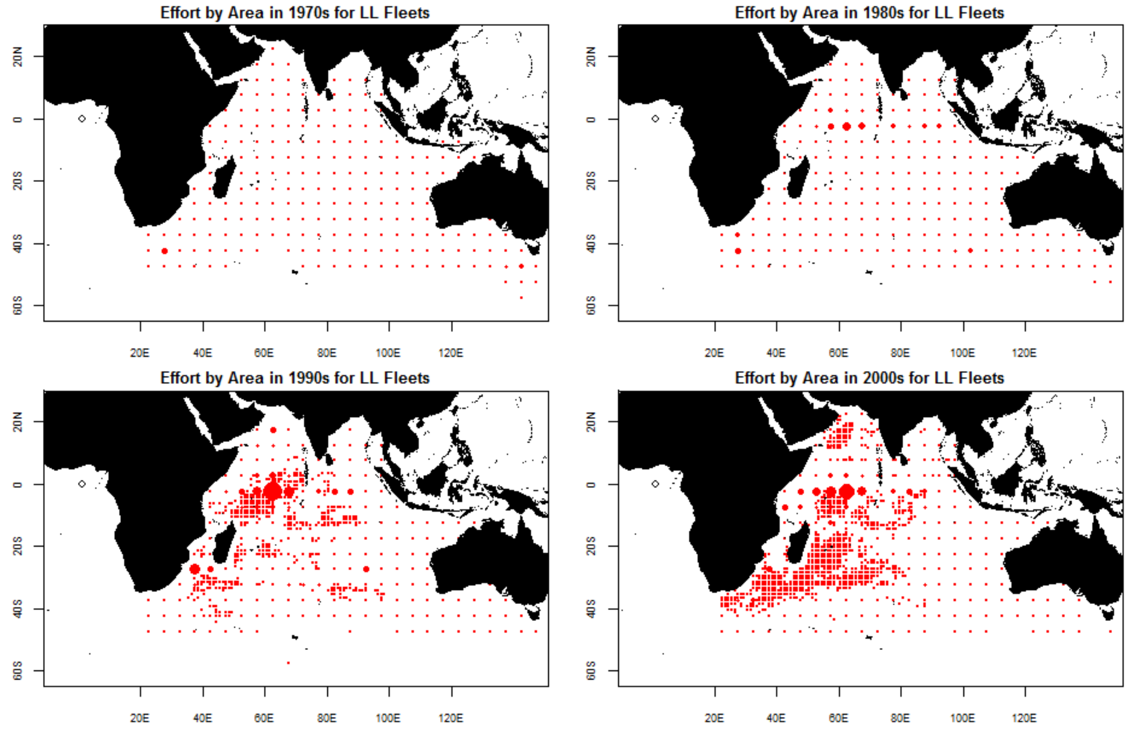
**Based on IOTC catch estimates**

|  | PRT | ESP | JPN |
|---|---|---|---|
| C2014_msy | 5.93 | 3.39 | 4.97 |
| Y_MSY | 5,685 | 9,931 | 6,783 |
| B_zero | 601,059 | 1,073,640 | 727,820 |
| B_msy | 278,061 | 495,748 | 336,286 |
| B_cur | 299,108 | 807,679 | 444,814 |
| SB_zero | 49,761 | 88,886 | 60,256 |
| SB_msy | 23,020 | 41,043 | 27,841 |
| SB_cur | 24,763 | 66,867 | 36,826 |
| SB_cur/SB_zero | 0.50 | 0.75 | 0.61 |
| SB_cur/SB_msy | 1.08 | 1.63 | 1.32 |
| Fcur | 0.25 | 0.09 | 0.17 |
| F_msy | 0.05 | 0.05 | 0.05 |
| F_2014_msy | 6.68 | 2.03 | 3.99 |
| F_cur_msy | 4.63 | 1.67 | 3.07 |

**Based on trade catch estimates**

|  | PRT | ESP | JPN |
|---|---|---|---|
| C2014/MSY | 6.01 | 3.94 | 5.59 |
| Y_MSY | 33,135 | 50,529 | 35,575 |
| B_zero | 3,414,260 | 5,358,060 | 3,686,480 |
| B_msy | 1,583,122 | 2,478,188 | 1,708,802 |
| B_cur | 1,515,788 | 3,633,800 | 1,920,746 |
| SB_zero | 282,663 | 443,589 | 305,200 |
| SB_msy | 131,065 | 205,167 | 141,470 |
| SB_cur | 125,491 | 300,839 | 159,017 |
| SB_cur/SB_zero | 0.44 | 0.68 | 0.52 |
| SB_cur/SB_msy | 0.96 | 1.47 | 1.12 |
| Fcur | 0.27 | 0.11 | 0.21 |
| F_msy | 0.06 | 0.05 | 0.05 |
| F_2014_msy | 8.15 | 2.71 | 5.76 |
| F_cur_msy | 4.90 | 1.97 | 3.78 |

# 8 Figures



Effort by Area in 1970s for LL Fleets

Effort by Area in 1980s for LL Fleets

Effort by Area in 1990s for LL Fleets

Effort by Area in 2000s for LL Fleets

**Figure 1. Study area and effort by decade. The red dots are proportional to the longline effort in each 5x5 degree cell.**

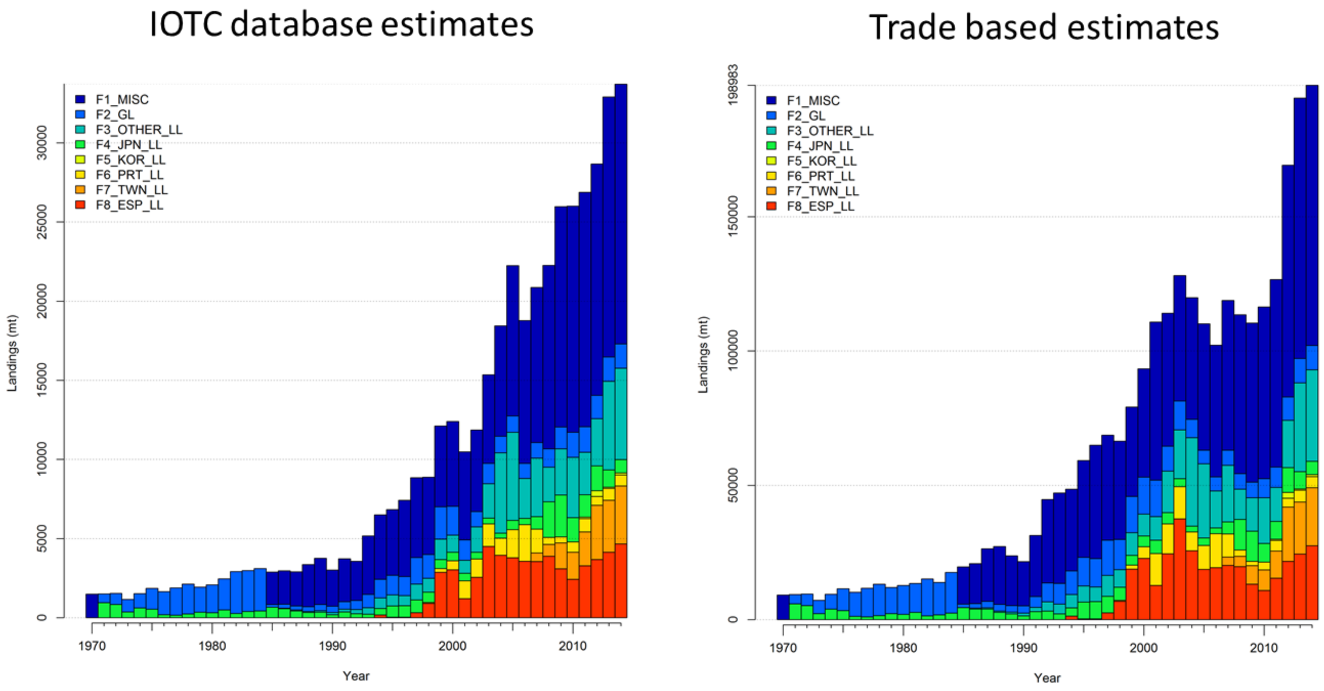


**Figure 2 Estimated total blue shark catch in mass by fishery over time for the whole Indian Ocean based on the IOTC database (left hand panel) and based on trade based methods (right hand panel). Note the difference in scale on the y-axis.**

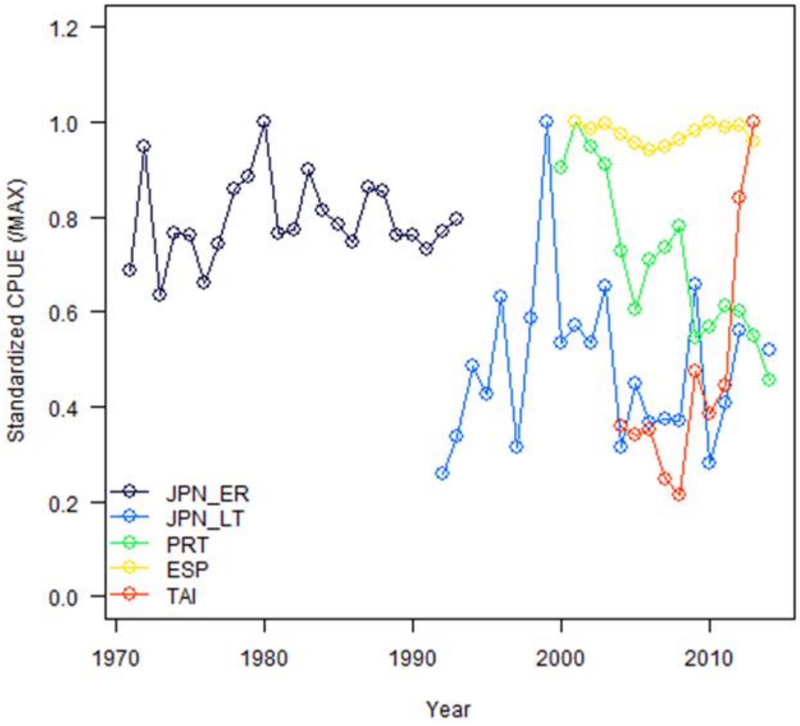


**Figure 3. Standardized CPUE by area for Japanese, Portuguese, Taiwanese and Spanish longline fleets based on papers submitted to WPEB2015. All series have been rescaled so that they are visually comparable for relevant periods of overlap. Note that this re-scaling does not reflect the relative weighting across areas that is applied to the Japanese fleet.**

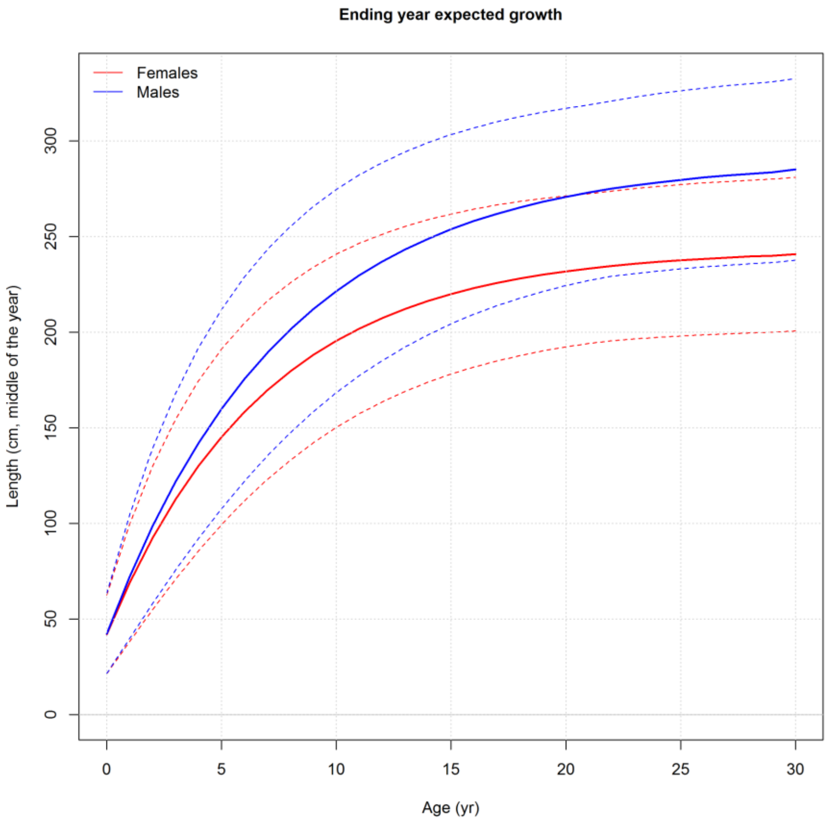


**Figure 4. : Sex-specific growth curves (from Nakano 1994) assumed in for the assessment of blue sharks in the north Pacific.**

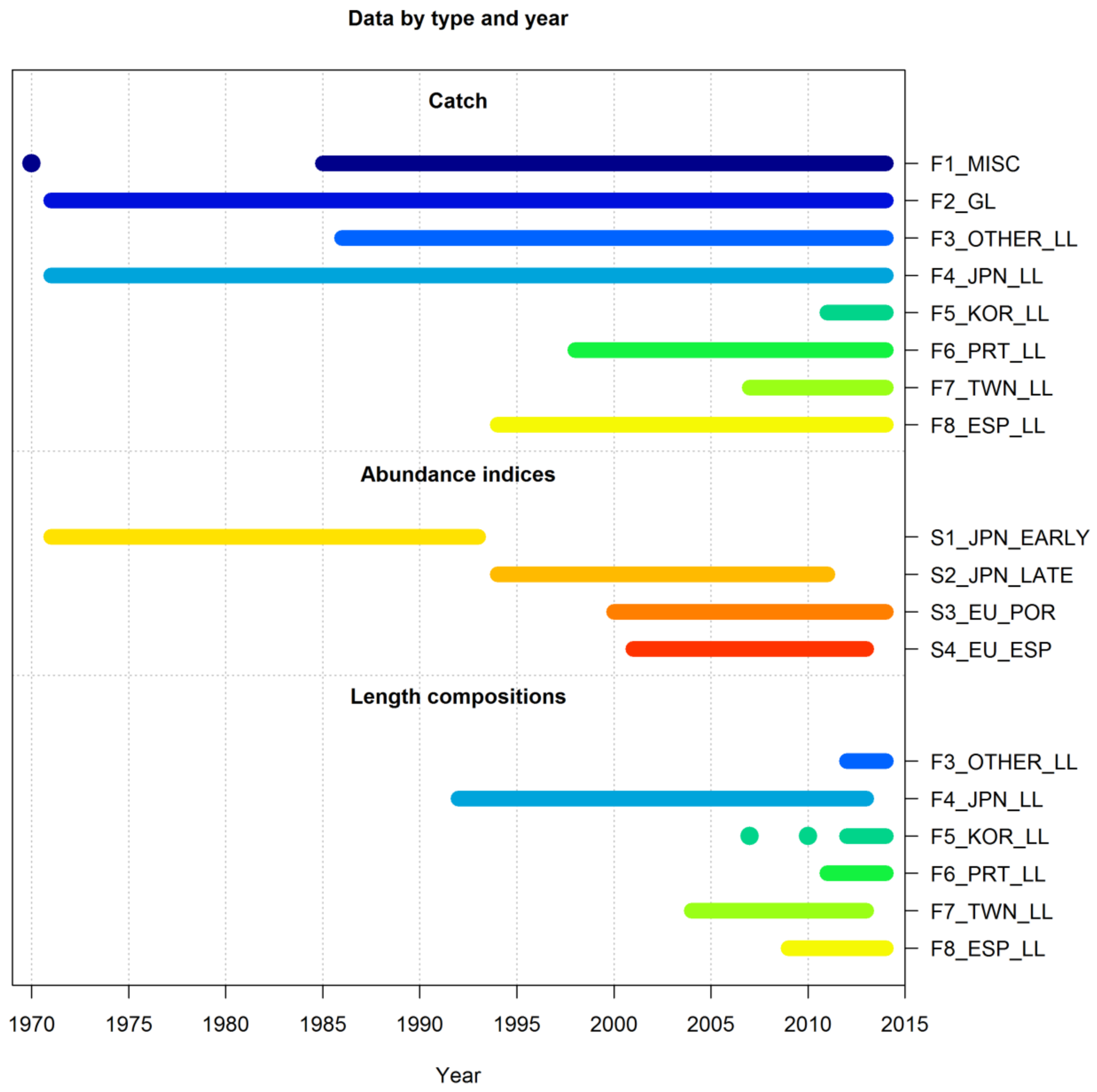


**Figure 5: Temporal data coverage for the reference case model for the assessment of blue sharks in the north Pacific.**

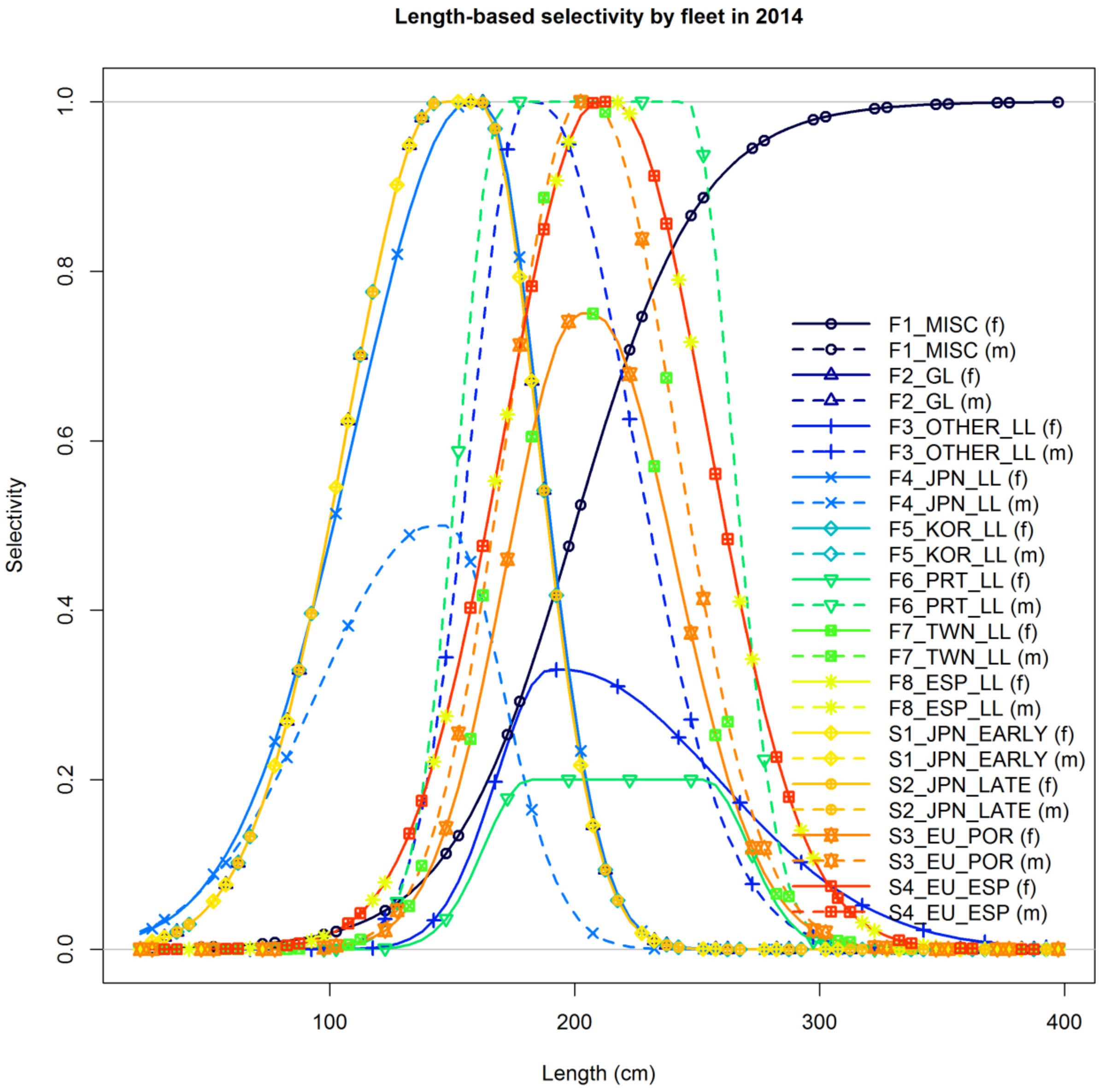


**Figure 6: Selectivity curves estimated for female and male from the reference case model for the assessment of blue sharks in the Indian Ocean.**

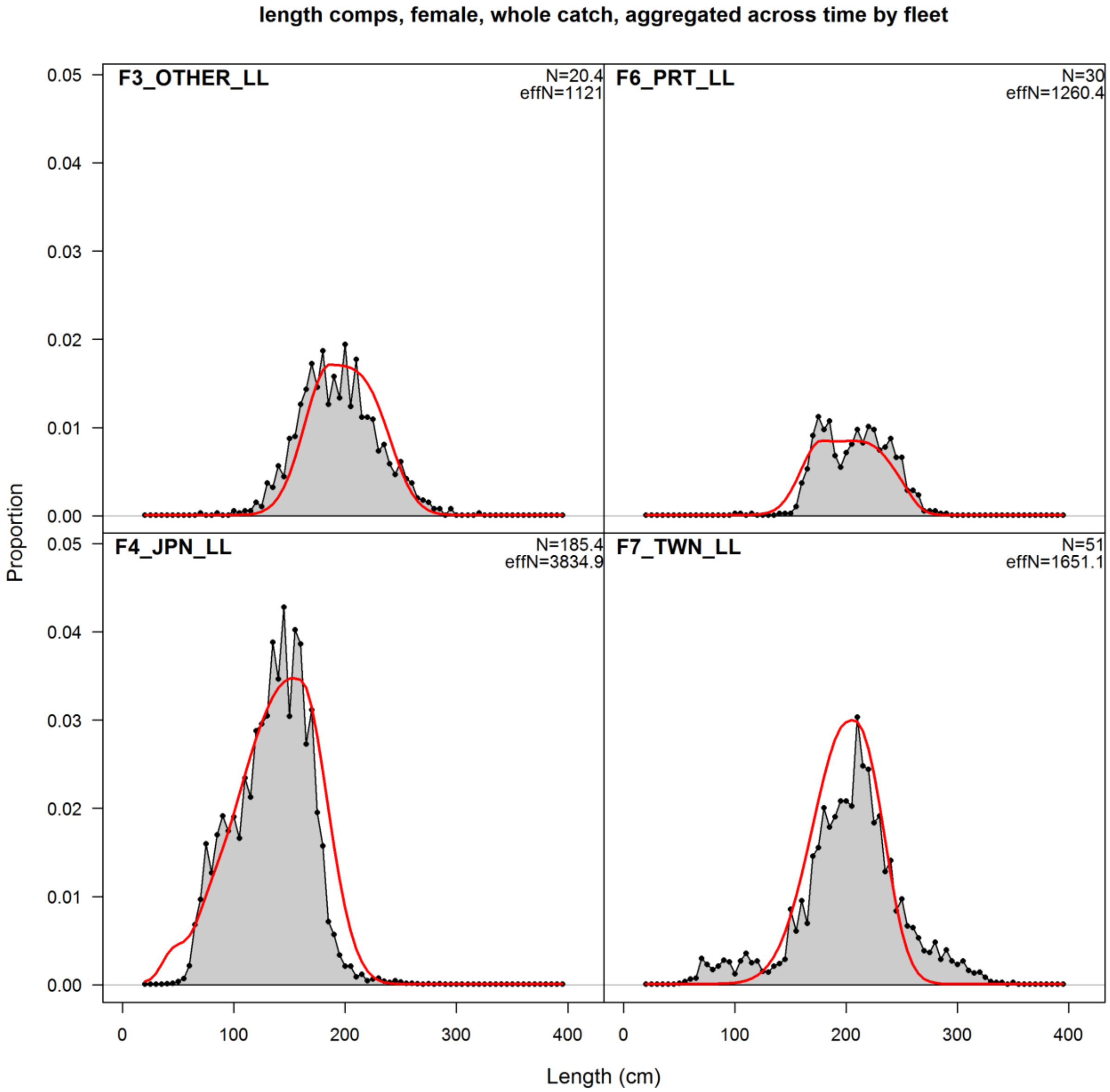


**Figure 7 Fit to the female length frequency data for the reference case model for the assessment of blue sharks in the Indian Ocean.**

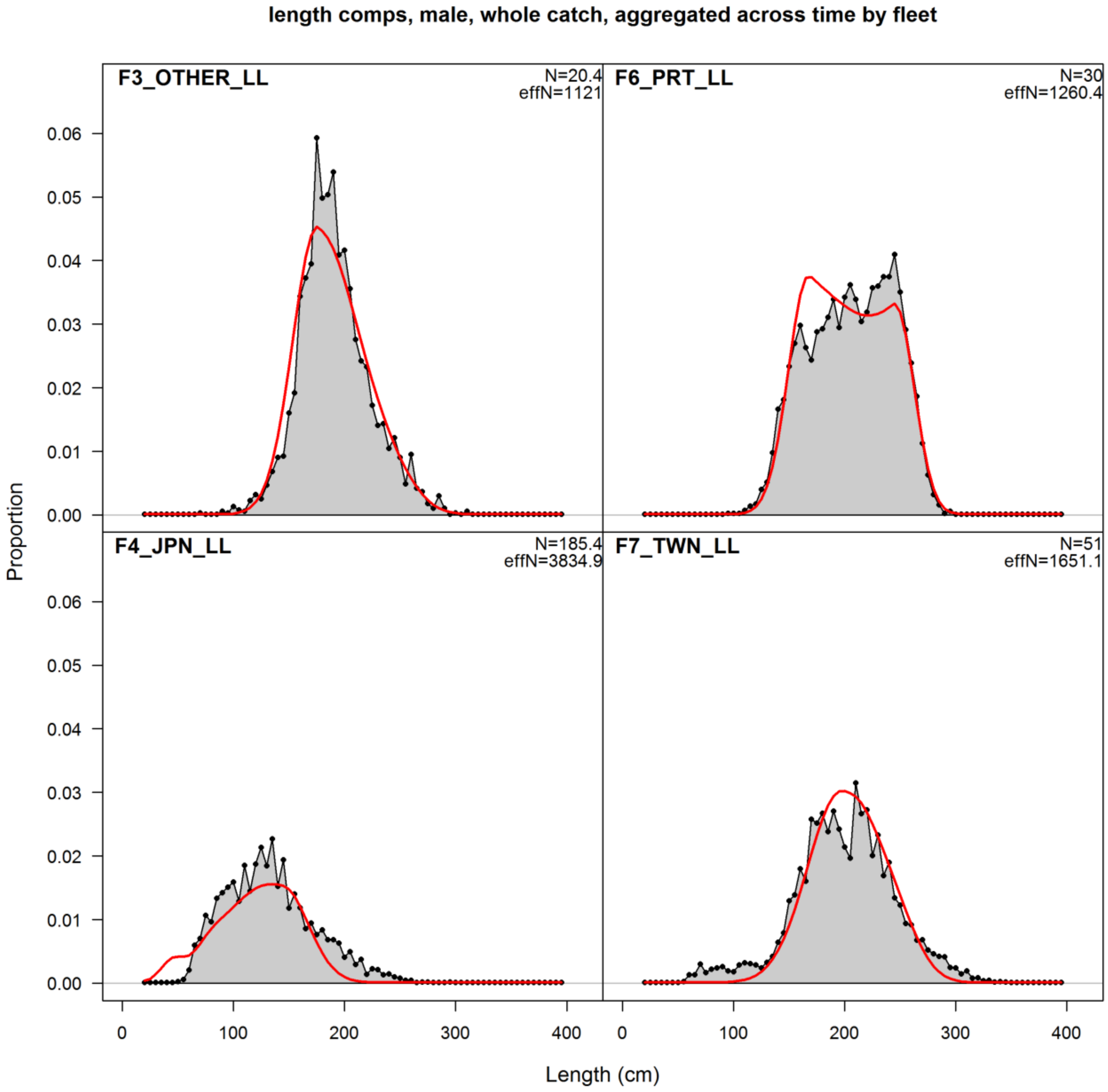


**Figure 8  Fit to the male length frequency data for the reference case model for the assessment of blue sharks in the Indian Ocean.**

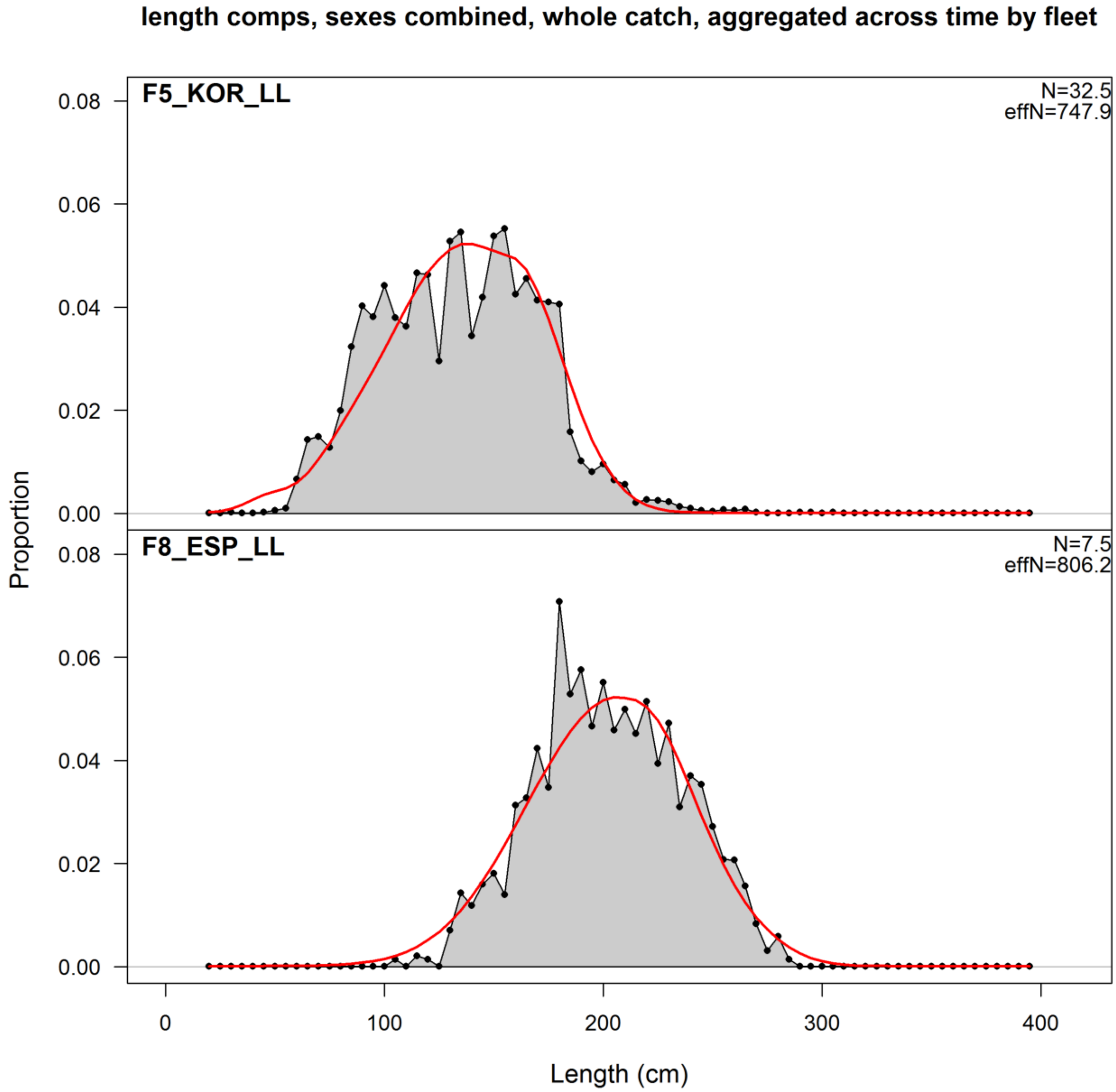


**Figure 8a. Fit to the length frequency data for the reference case model for the assessment of blue sharks in the Indian Ocean, combined sex.**

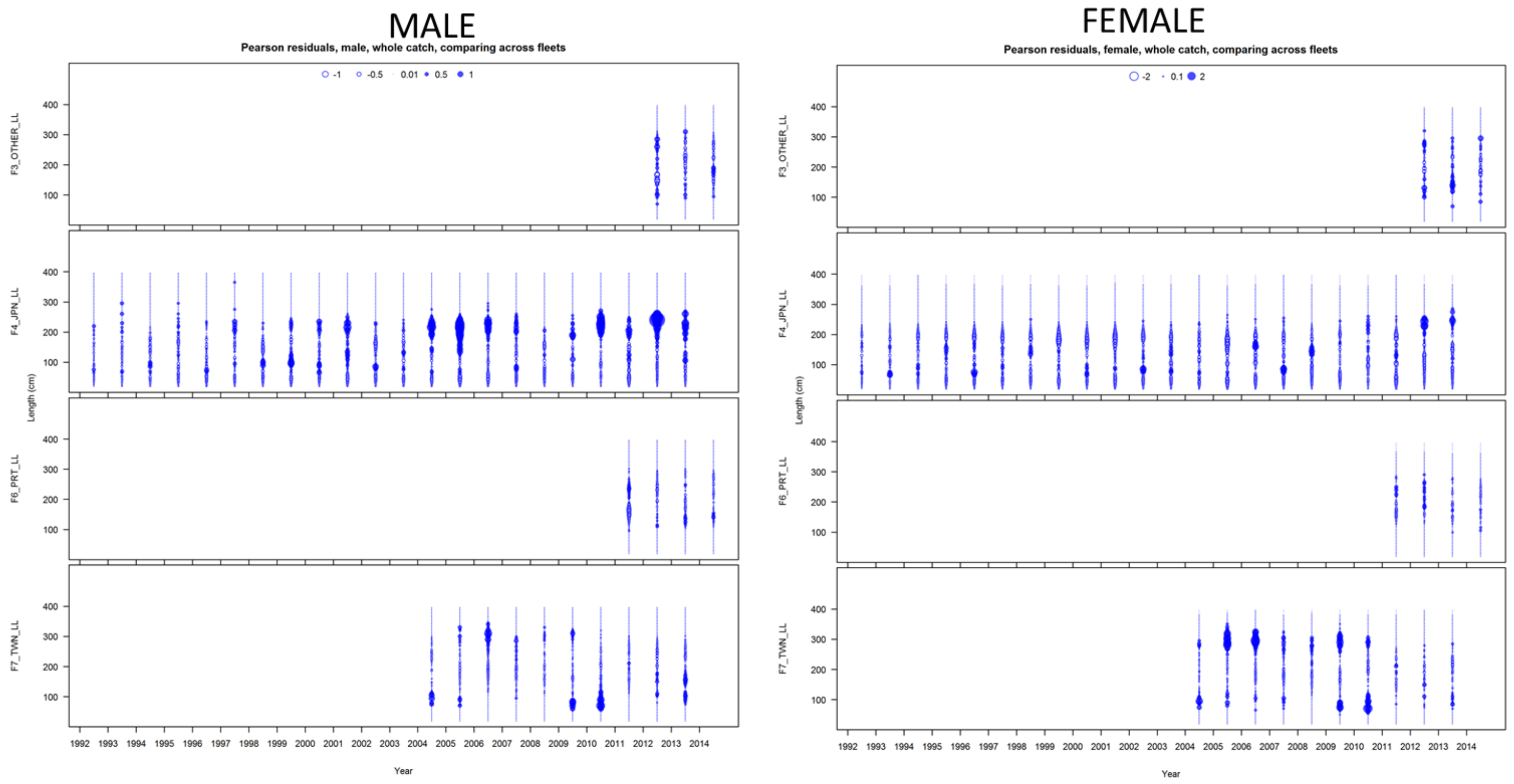


**Figure 9 Pearson residuals, comparing across fleets (males left, females right). Closed bubbles are positive residuals and open bubbles are negative residuals, bubble sizes are scaled to maximum within each panel. Thus, comparisons across panels should focus on patterns, not bubble sizes**.

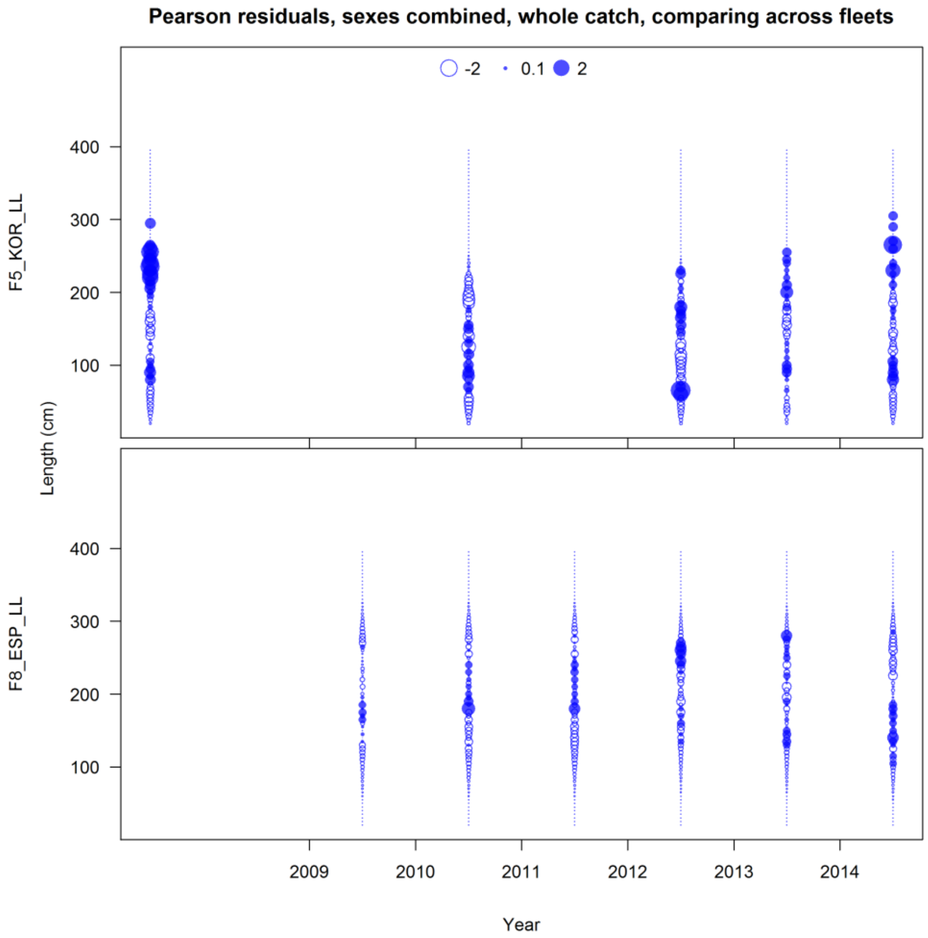


**Figure 9a. Pearson residuals, comparing across fleets (sexes combined). Closed bubbles are positive residuals and open bubbles are negative residuals, bubble sizes are scaled to maximum within each panel. Thus, comparisons across panels should focus on patterns, not bubble sizes.**

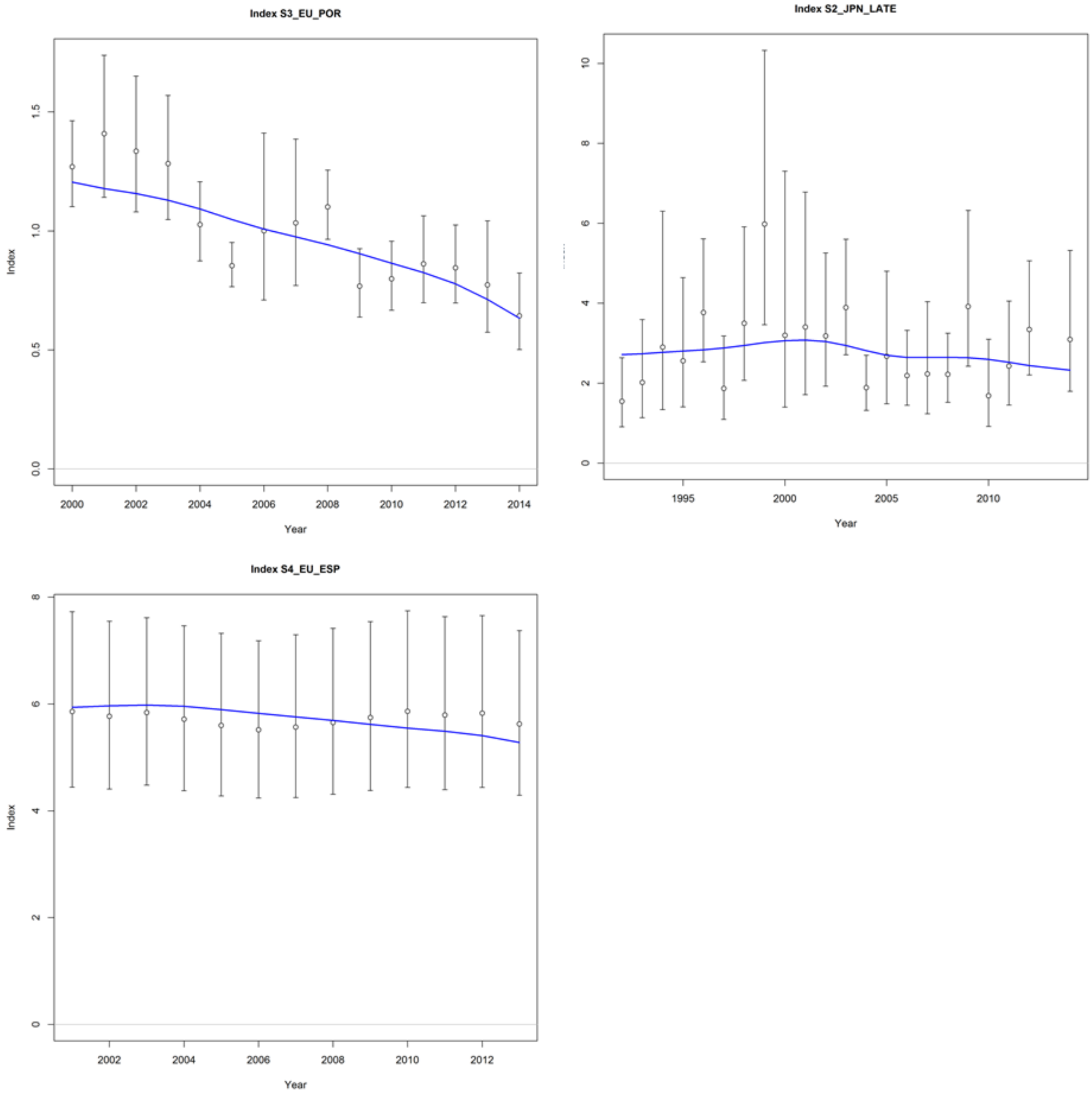


**Figure 10: Fit to the Portuguese CPUE time series for the reference case model (top left) and fit to the Japanese late series (top right) and fit to the Spanish CPUE series (bottom) for the assessment of blue sharks in the Indian Ocean. All fits represent individual model fits to the respective CPUE series individually.**

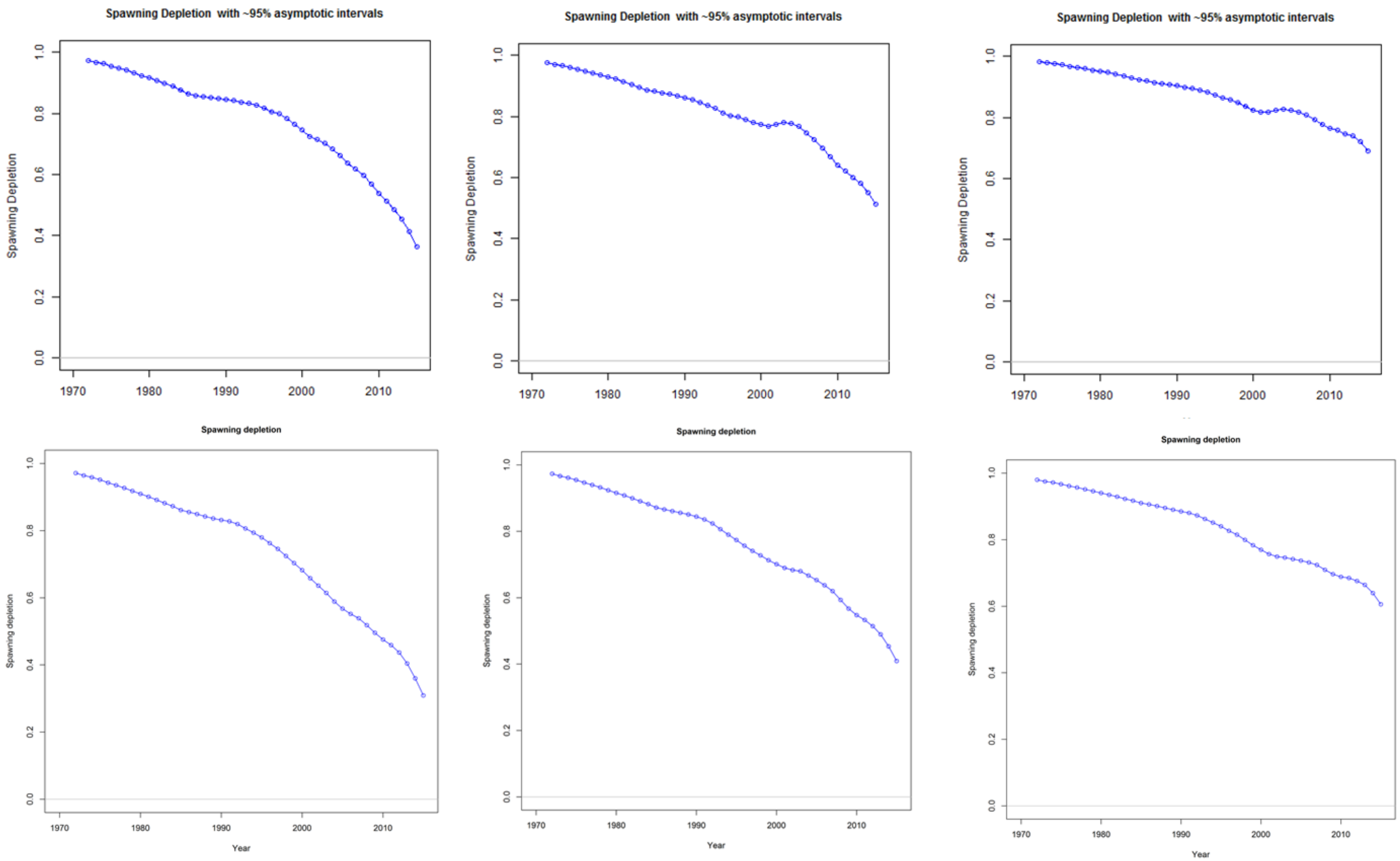


**Figure 11: Spawning depletion for the reference case parameterization of sigma R and steepness based on the IOTC catch estimates (top row) and the trade based catch estimates (bottom row) based on individual models fit to the Portuguese CPUE (left column) the Japanese late series (middle column) and Spanish CPUE (right hand column).**

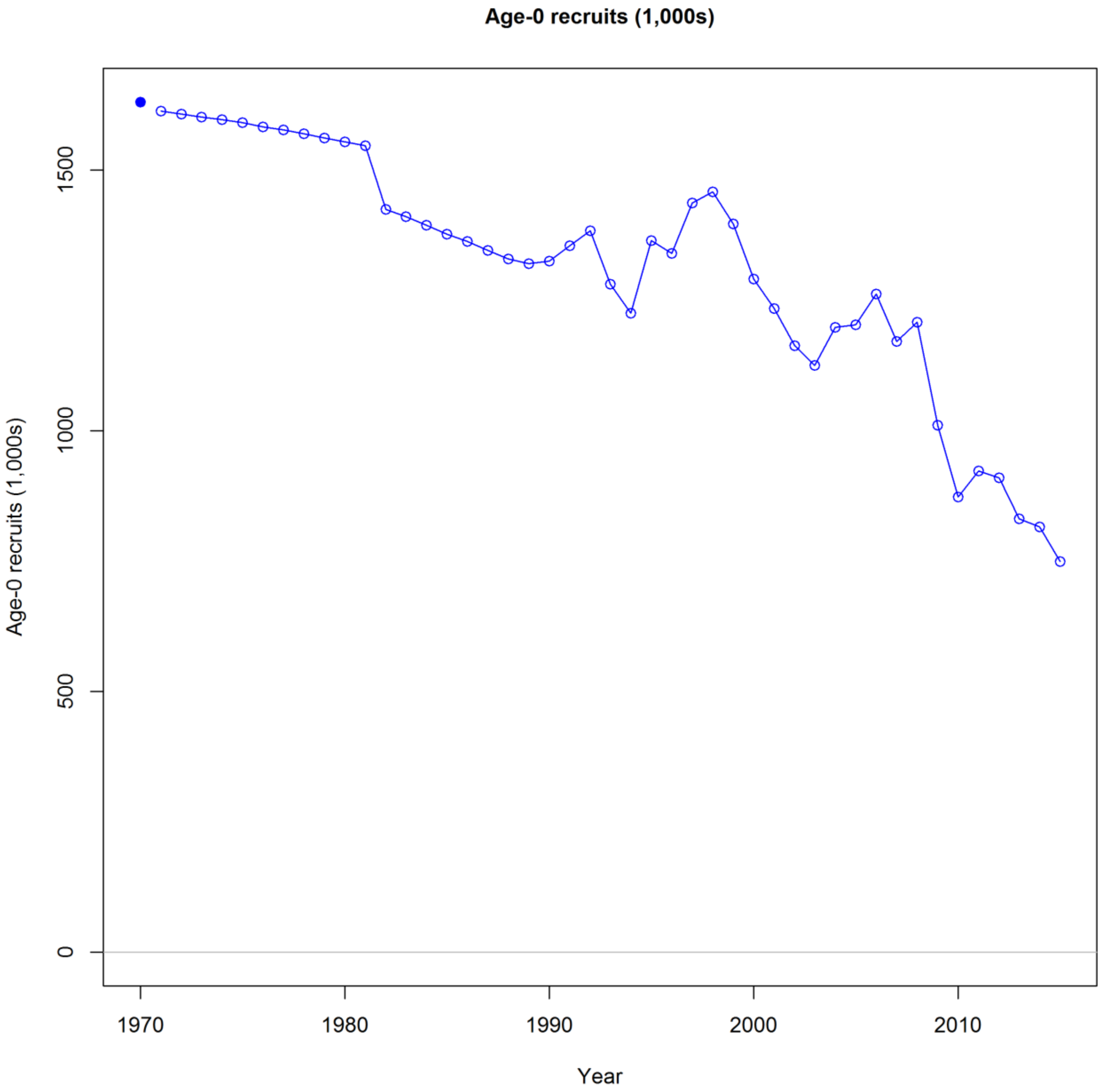


**Figure 12 .Estimated recruitment including the estimate of virgin recruitment (filled circle at the start of the time series) for the reference case model for the assessment of blue sharks in the Indian Ocean.**

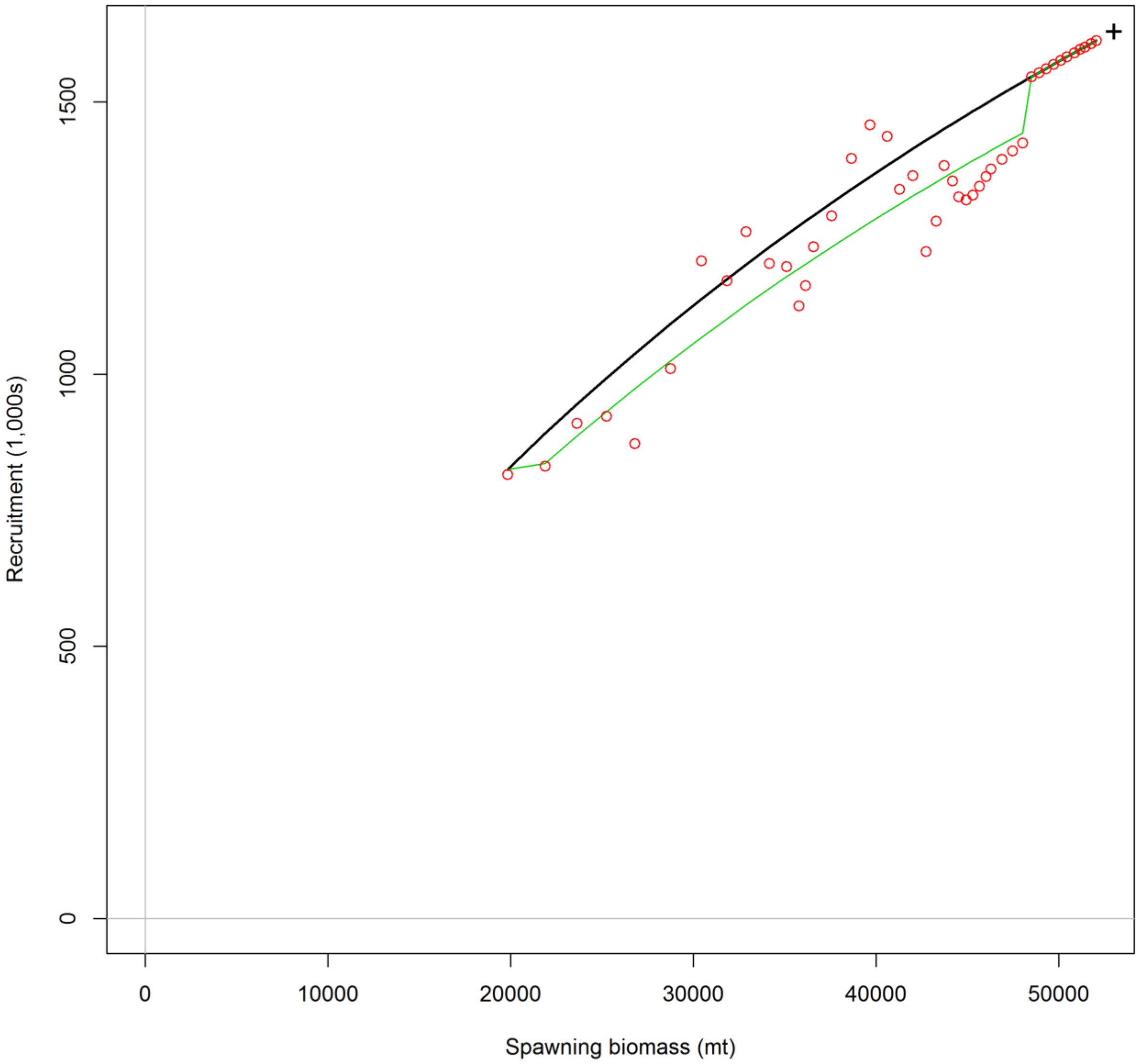


**Figure 13  Stock recruitment curve used in the assessment and time series of estimates (red points).**

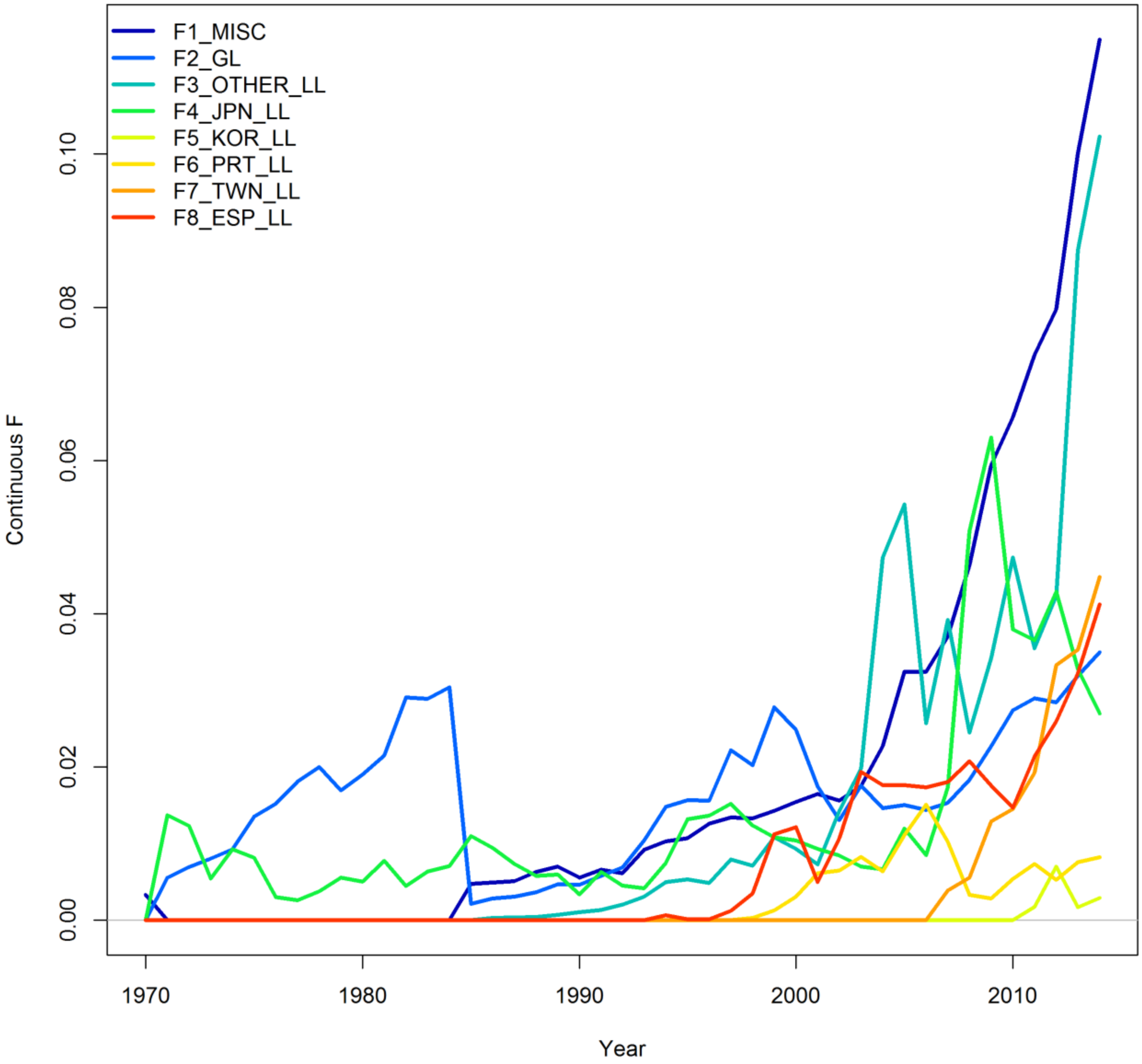


**Figure 14 Estimated fishing mortality for each fleet in the assessment**.

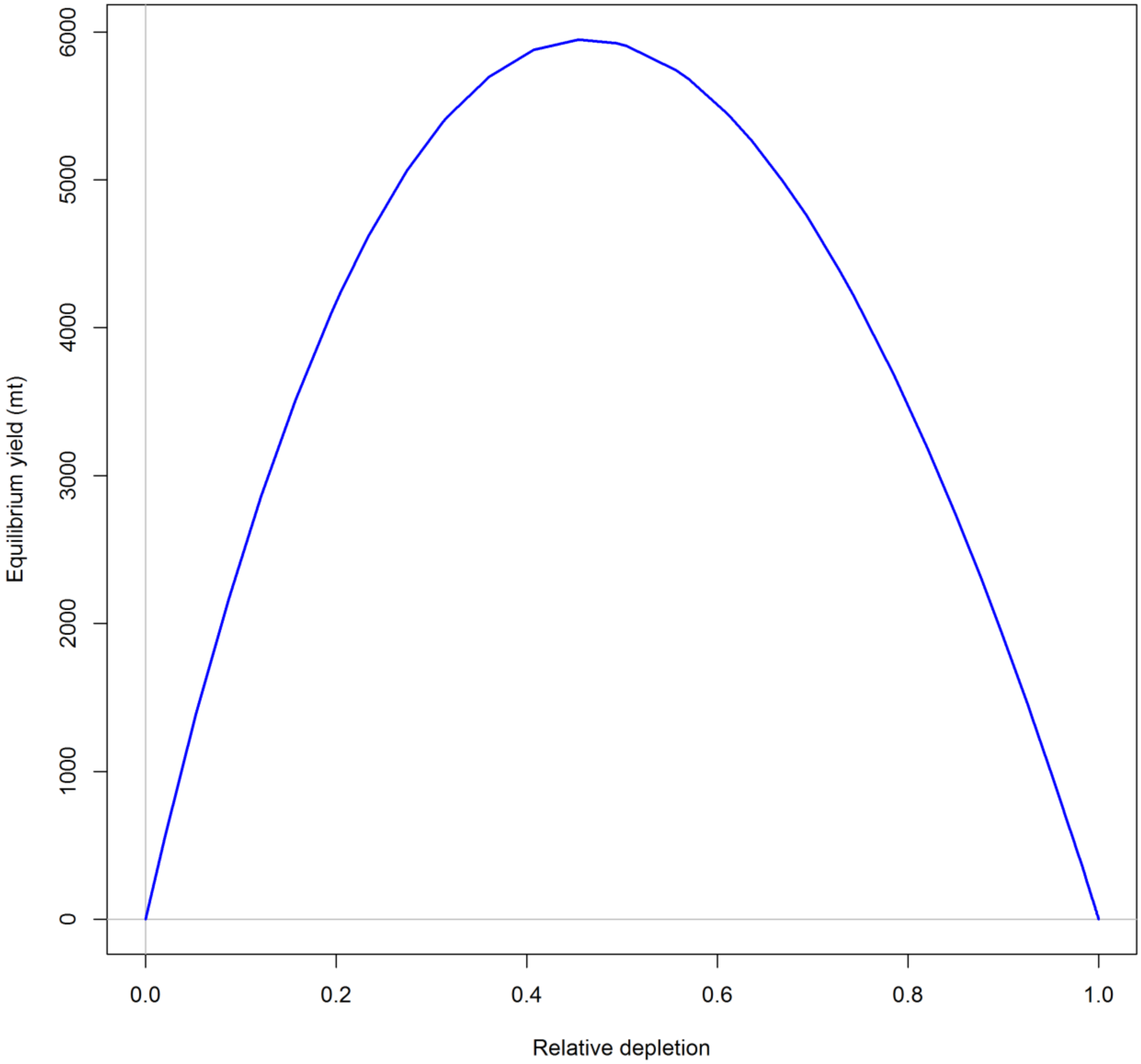


**Figure 15. Equilibrium yield curve for the reference case model for the assessment of blue sharks in the Indian Ocean.**

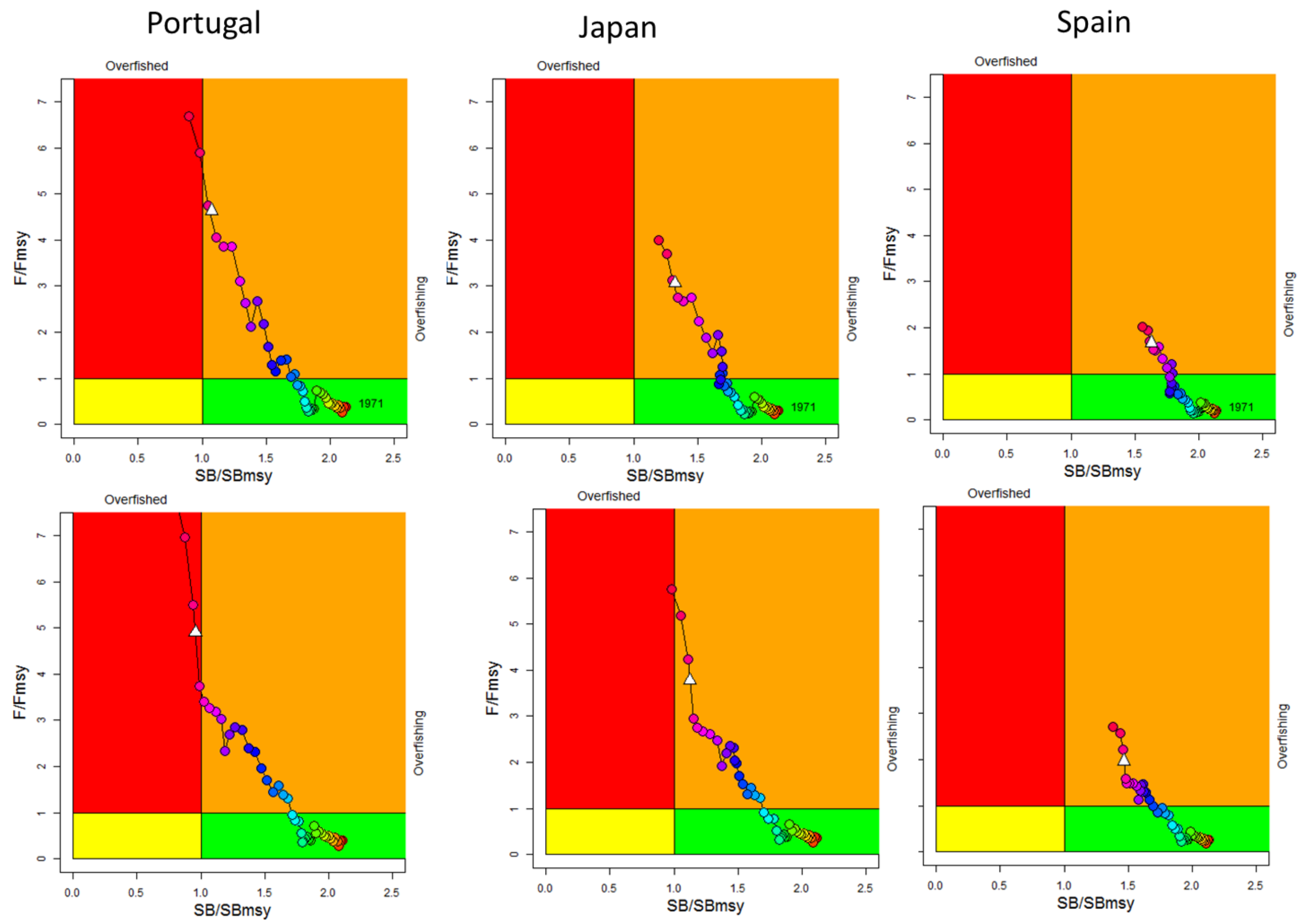
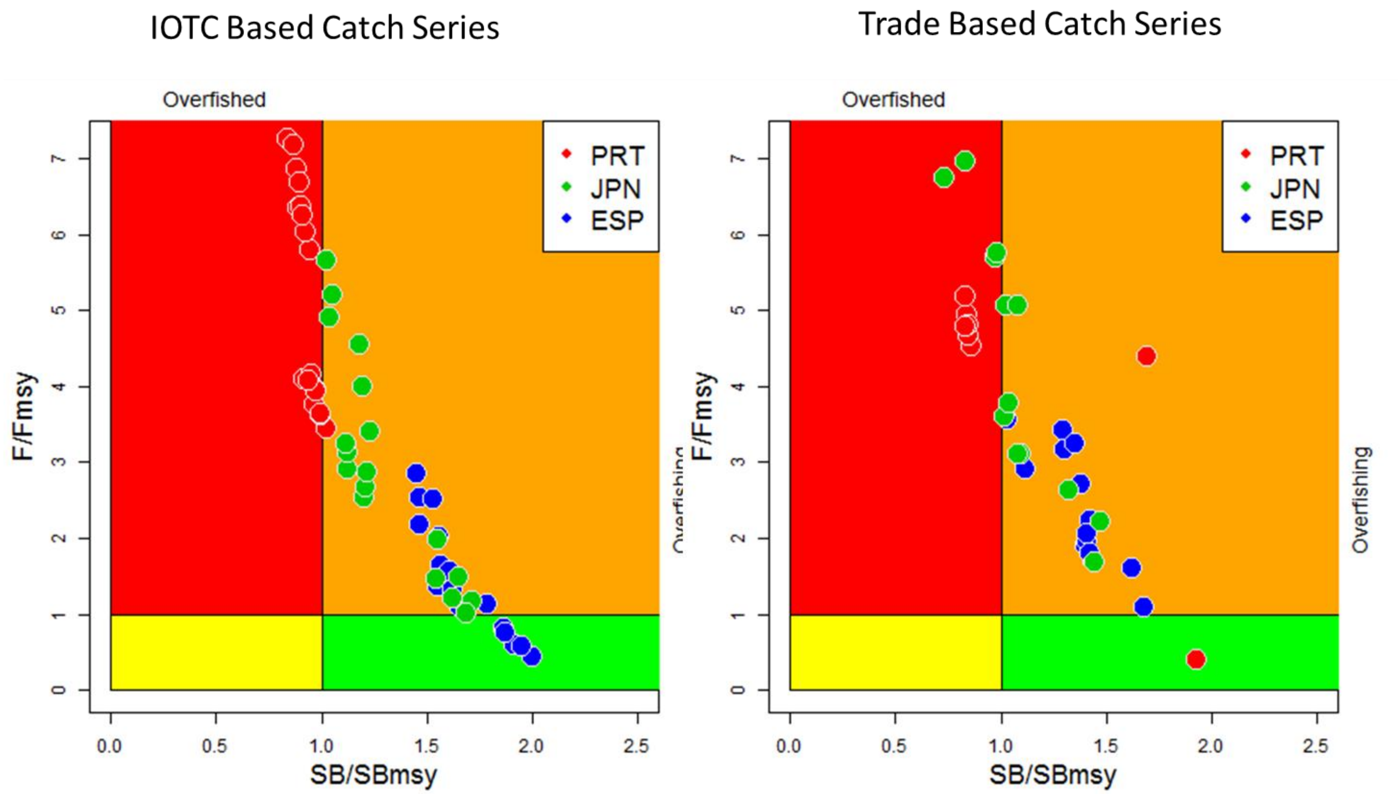


**Figure 16. Kobe plot showing the time series of $SB/SB_{MSY}$ and $F/F_{MSY}$ and the current (average of 2010-2013) value(white triangle), the initial year (1971) is labelled. The top row is based on the IOTC catch estimates and the bottom row the model un with the trade based catch estimates. The first column is for the model run with only the Portuguese CPUE and the middle and right hand with only the Japanese and Spanish CPUE series, respectively.**


IOTC Based Catch Series

Trade Based Catch Series

**Figure 17. Kobe Plot for the full grid of runs note that many are over plotted as the point estimates were quite close. The left hand panel is based on the IOTC database catch estimates and the right hand panel on the trade based catch estimates.**

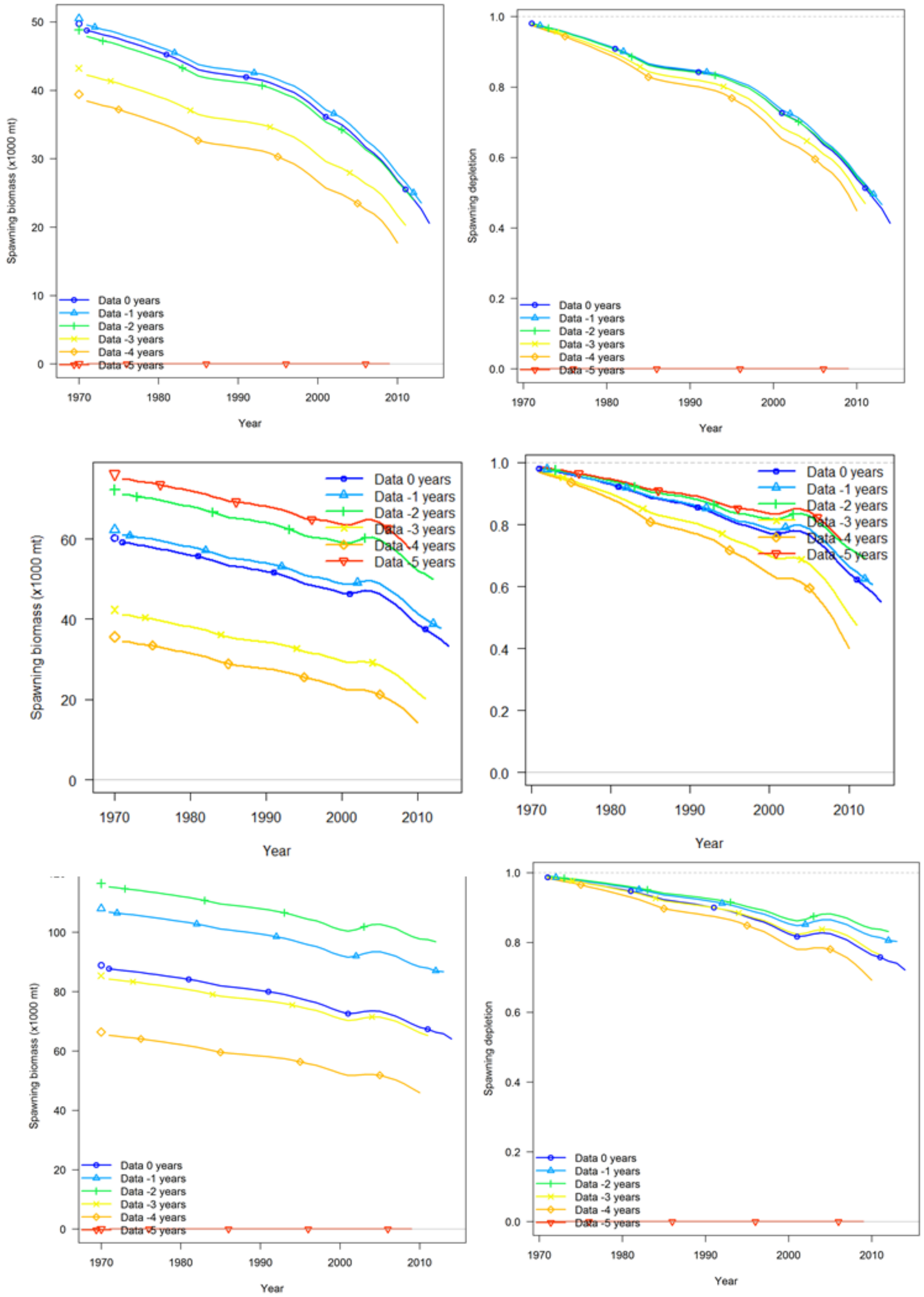


**Figure 18 Spawning biomass (left hand column) and estimates of spawning depletion(right hand column) for retrospective models run with the Portuguese CPUE series only (top row), the Japanese CPUE series only (middle row) and the Spanish CPUE series only (bottom row). All runs used the IOTC catch estimates. Note that the model failed to converge due to a short time series for the Spanish and Portuguese CPUE series when 5 years of data were deleted.**

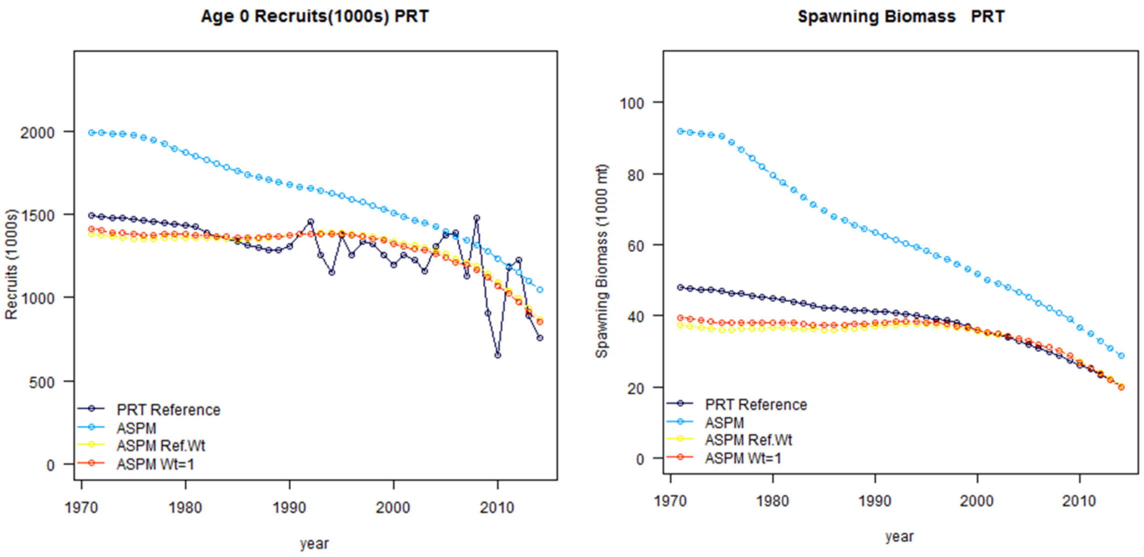


**Figure 19 Age structured production model based on a model using the Portuguese CPUE and the IOTC based catch estimates.**

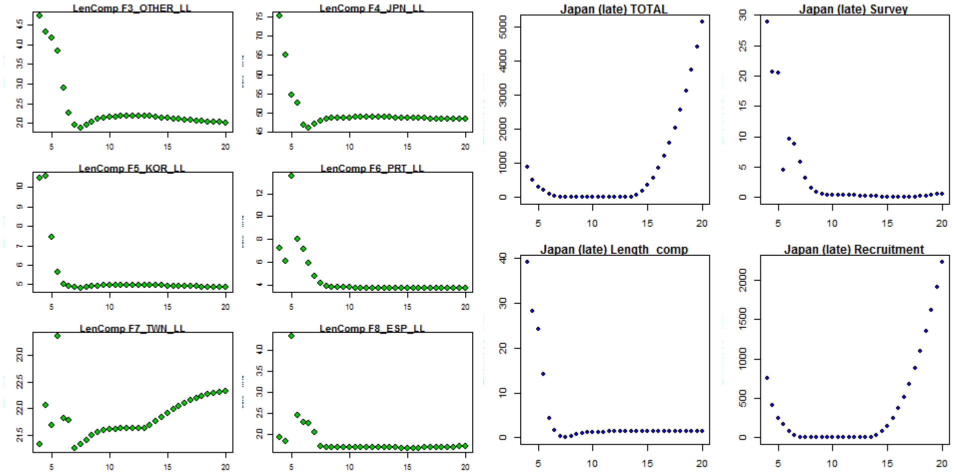


**Figure 20 (A) R0 Profile for runs using only the Spanish CPUE series.**

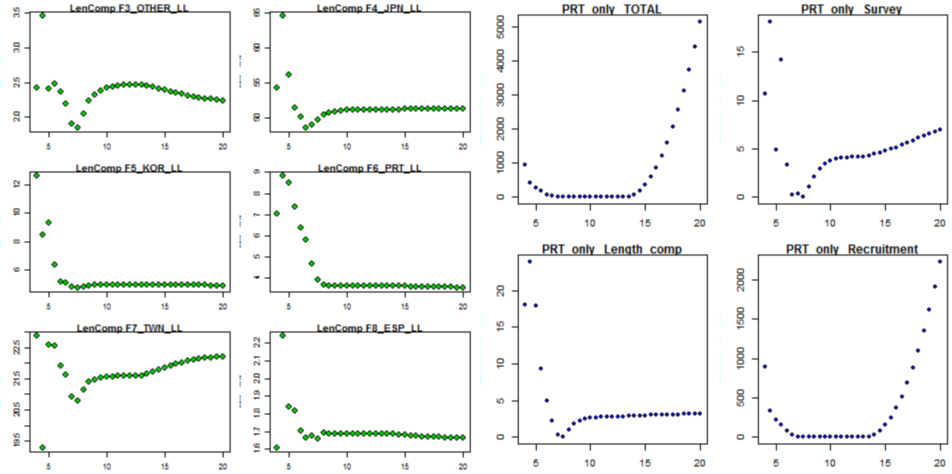


Figure 20 (B)  R0 Profile for runs using only the Portuguese CPUE series.

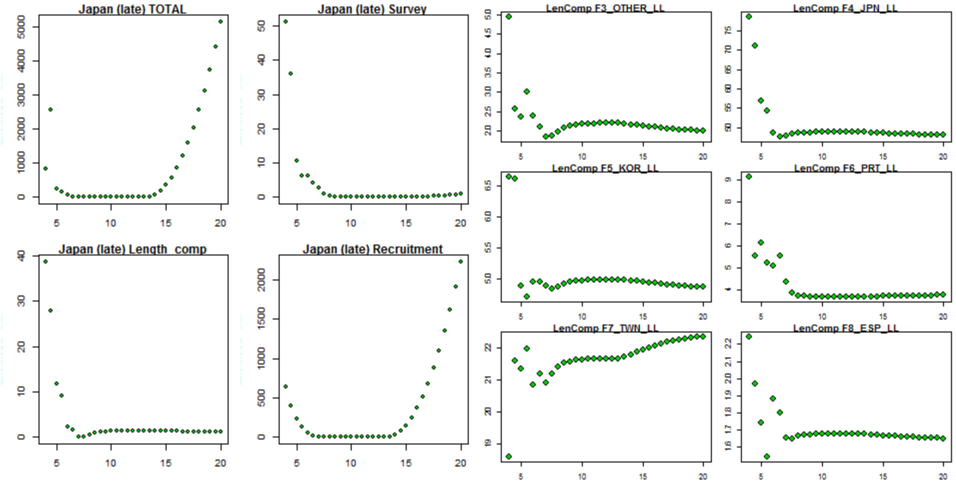


**Figure 20 (C) R0 Profile for runs using only the Japanese CPUE series.**

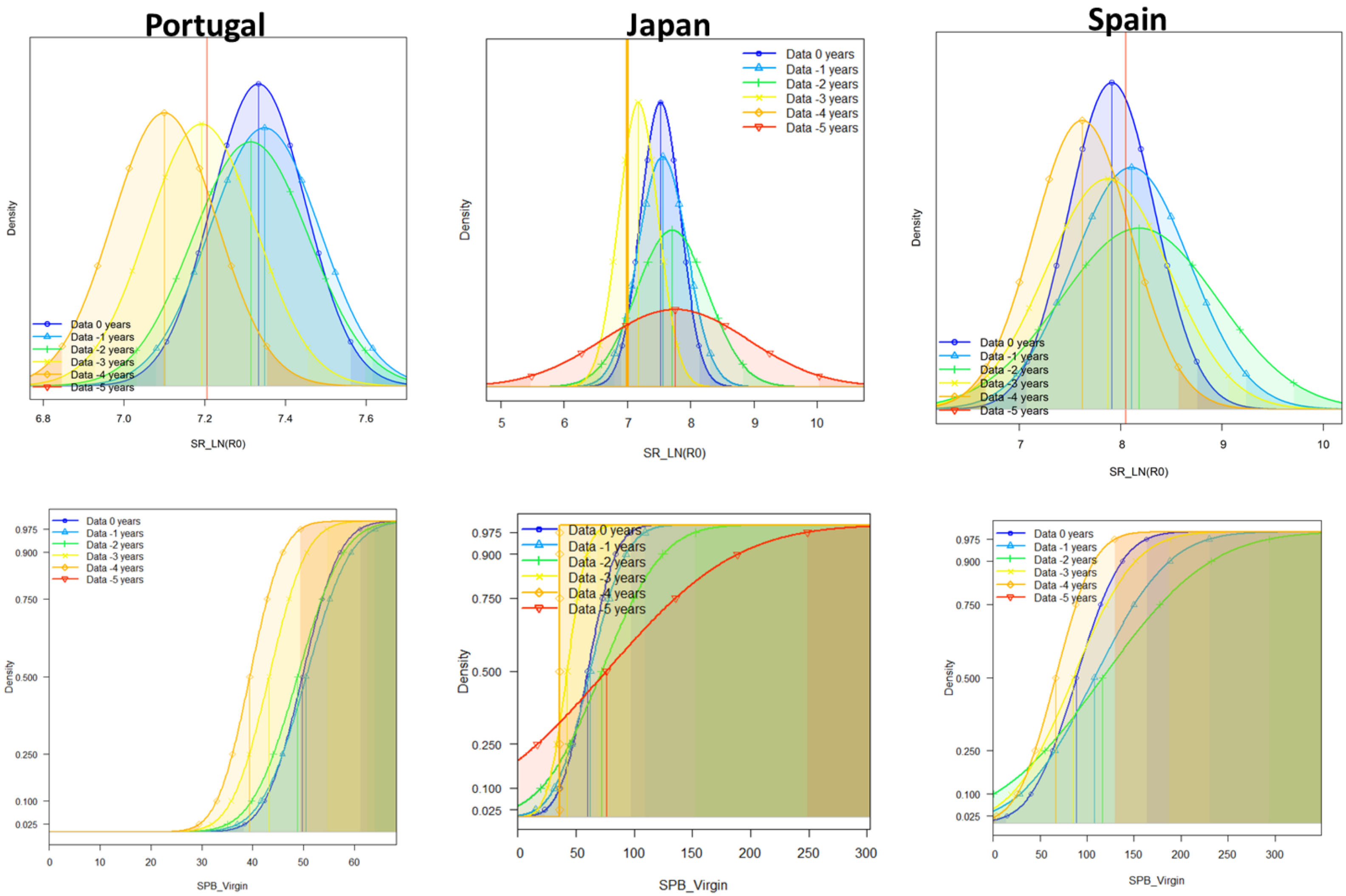


**Figure 21. Estimated densities of the LN(R0) parameter (top row) and estimates of the unexploited biomass (bottom row). Based on retrospective models run with the Portuguese CPUE series only (left column), the Japanese CPUE series only (middle column) and the Spanish CPUE series only (right column). All runs used the IOTC catch estimates. Note that the model failed to converge due to a short time series for the Spanish and Portuguese CPUE series when 5 years of data were deleted.**

**APPENDIX 1**

CTL FILE

```
#V3.24f
#_data_and_control_files: DATA.SS // CONTROL.SS
#_SS-V3.24f-safe-Win64;
1  #_N_Growth_Patterns
1 #_N_Morphs_Within_GrowthPattern
#_Cond 1 #_Morph_between/within_stdev_ratio (no read if N_morphs=1)
#_Cond  1 #vector_Morphdist_(-1_in_first_val_gives_normal_approx)
#
#_Cond 0  #  N recruitment designs goes here if N_GP*nseas*area>1
#_Cond 0  #  placeholder for recruitment interaction request
#_Cond 1 1 1  # example recruitment design element for GP=1, seas=1, area=1
#
#_Cond 0 # N_movement_definitions goes here if N_areas > 1
#_Cond 1.0 # first age that moves (real age at begin of season, not integer) also cond on
do_migration>0
#_Cond 1 1 1 2 4 10 # example move definition for seas=1, morph=1, source=1 dest=2, age1=4,
age2=10
#
0 #_Nblock_Patterns
#_Cond 0 #_blocks_per_pattern
# begin and end years of blocks
#
0.5 #_fracfemale
3 #_natM_type:_0=1Parm;
1=N_breakpoints;_2=Lorenzen;_3=agespecific;_4=agespec_withseasinterpolate
 #_Age_natmort_by gender x growthpattern
 0.366 0.245 0.195 0.168 0.151 0.139 0.13 0.124 0.119 0.115 0.112 0.11 0.108 0.106 0.105
0.104 0.103 0.102 0.102 0.101 0.101 0.1 0.1 0.1 0.099 0.099 0.099 0.099 0.099 0.099 0.099
 0.359 0.245 0.195 0.166 0.147 0.134 0.125 0.118 0.112 0.108 0.104 0.101 0.099 0.097 0.095
0.094 0.092 0.091 0.09 0.09 0.089 0.088 0.088 0.087 0.087 0.087 0.086 0.086 0.086 0.086 0.085
2 # GrowthModel: 1=vonBert with L1&L2; 2=Richards with L1&L2; 3=age_speciific_K; 4=not
implemented
0.5 #_Growth_Age_for_L1
22 #_Growth_Age_for_L2 (999 to use as Linf)
0 #_SD_add_to_LAA (set to 0.1 for SS2 V1.x compatibility)
0 #_CV_Growth_Pattern:  0 CV=f(LAA); 1 CV=F(A); 2 SD=F(LAA); 3 SD=F(A); 4 logSD=F(A)
1 #_maturity_option:  1=length logistic; 2=age logistic; 3=read age-maturity matrix by
growth_pattern; 4=read age-fecundity; 5=read fec and wt from wtatage.ss
#_placeholder for empirical age-maturity by growth pattern
5 #_First_Mature_Age
```

```
2 #_fecundity option:(1)eggs=Wt*(a+b*Wt);(2)eggs=a*L^b;(3)eggs=a*Wt^b; (4)eggs=a+b*L;
(5)eggs=a+b*W
0 #_hermaphroditism option:  0=none; 1=age-specific fxn
3 #_parameter_offset_approach (1=none, 2= M, G, CV_G as offset from female-GP1, 3=like SS2
V1.x)
1 #_env/block/dev_adjust_method (1=standard; 2=logistic transform keeps in base parm
bounds; 3=standard w/ no bound check)
#
#_growth_parms
#_LO HI INIT PRIOR PR_type SD PHASE env-var use_dev dev_minyr dev_maxyr dev_stddev
Block Block_Fxn
 10 120 42 45 0 10 -4 0 0 0 0 0.5 0 0 # L_at_Amin_Fem_GP_1
 40 410 234 400 0 10 -2 0 0 0 0 0.5 0 0 # L_at_Amax_Fem_GP_1
 0.1 0.25 0.144 0.15 0 0.8 -4 0 0 0 0 0.5 0 0 # VonBert_K_Fem_GP_1
 -10 10 1 1 0 0.8 -4 0 0 0 0 0.5 0 0 # Richards_Fem_GP_1
 0.01 1 0.25 0.0834877 0 0.8 -3 0 0 0 0 0.5 0 0 # CV_young_Fem_GP_1
 -3 3 -1.07881 0 0 0.8 -3 0 0 0 0 0.5 0 0 # CV_old_Fem_GP_1
 -3 3 0.00875604 0 0 0.8 -3 0 0 0 0 0.5 0 0 # L_at_Amin_Mal_GP_1
 -3 3 0.157941 0 0 0.8 -2 0 0 0 0 0.5 0 0 # L_at_Amax_Mal_GP_1
 -3 3 -0.110001 0 0 0.8 -3 0 0 0 0 0.5 0 0 # VonBert_K_Mal_GP_1
 -3 3 0 0 0 0.8 -3 0 0 0 0 0.5 0 0 # Richards_Mal_GP_1
 -3 3 0 0 0 0.8 -3 0 0 0 0 0.5 0 0 # CV_young_Mal_GP_1
 -3 3 -1.07881 0 0 0.8 -3 0 0 0 0 0.5 0 0 # CV_old_Mal_GP_1
 -3 3 5.388e-006 5.388e-006 0 0.8 -3 0 0 0 0 0.5 0 0 # Wtlen_1_Fem
 -3 3.5 3.102 3.102 0 0.8 -3 0 0 0 0 0.5 0 0 # Wtlen_2_Fem
 -3 300 145 55 0 0.8 -3 0 0 0 0 0.5 0 0 # Mat50%_Fem
 -3 3 -0.138 -0.138 0 0.8 -3 0 0 0 0 0.5 0 0 # Mat_slope_Fem
 -3 36 25 28 0 0.8 -3 0 0 0 0 0.5 0 0 # Eggs_scalar_Fem
 -3 3 0 0 0 0.8 -3 0 0 0 0 0.5 0 0 # Eggs_exp_len_Fem
 -3 3 3.293e-006 3.293e-006 0 0.8 -3 0 0 0 0 0.5 0 0 # Wtlen_1_Mal
 -3 3.5 3.225 3.225 0 0.8 -3 0 0 0 0 0.5 0 0 # Wtlen_2_Mal
 -4 4 0 0 -1 99 -3 0 0 0 0 0.5 0 0 # RecrDist_GP_1
 -4 4 0 0 -1 99 -3 0 0 0 0 0.5 0 0 # RecrDist_Area_1
 -4 4 4 0 -1 99 -3 0 0 0 0 0.5 0 0 # RecrDist_Seas_1
 1 1 1 1 -1 99 -3 0 0 0 0 0.5 0 0 # CohortGrowDev
#
#_Cond 0  #custom_MG-env_setup (0/1)
#_Cond -2 2 0 0 -1 99 -2 #_placeholder when no MG-environ parameters
#
#_Cond 0  #custom_MG-block_setup (0/1)
#_Cond -2 2 0 0 -1 99 -2 #_placeholder when no MG-block parameters
#_Cond No MG parm trends
#
#_seasonal_effects_on_biology_parms
```

```
 0 0 0 0 0 0 0 0 0 0 #_femwtlen1,femwtlen2,mat1,mat2,fec1,fec2,Malewtlen1,malewtlen2,L1,K
#_Cond -2 2 0 0 -1 99 -2 #_placeholder when no seasonal MG parameters
#
#_Cond -4 #_MGparm_Dev_Phase
#
#_Spawner-Recruitment
3 #_SR_function: 2=Ricker; 3=std_B-H; 4=SCAA; 5=Hockey; 6=B-H_flattop; 7=survival_3Parm
#_LO HI INIT PRIOR PR_type SD PHASE
 7 18 7.39649 15 -1 10 3 # SR_LN(R0)
 0.1 0.3 0.3 0.35 0 10 -2 # SR_BH_steep
 0 2 0.4 0.3 0 0.8 -3 # SR_sigmaR
 -5 5 0 0 0 1 -3 # SR_envlink
 -5 5 -0.000261953 0 0 1 1 # SR_R1_offset
 0 0 0 0 -1 99 -1 # SR_autocorr
0 #_SR_env_link
0 #_SR_env_target_0=none;1=devs;_2=R0;_3=steepness
2 #do_recdev:  0=none; 1=devvector; 2=simple deviations
1992 # first year of main recr_devs; early devs can preceed this era
2014 # last year of main recr_devs; forecast devs start in following year
2 #_recdev phase
1 # (0/1) to read 13 advanced options
 -10 #_recdev_early_start (0=none; neg value makes relative to recdev_start)
 1 #_recdev_early_phase
 0 #_forecast_recruitment phase (incl. late recr) (0 value resets to maxphase+1)
 1 #_lambda for Fcast_recr_like occurring before endyr+1
 -1 #_last_early_yr_nobias_adj_in_MPD
 2011 #_first_yr_fullbias_adj_in_MPD
 2013 #_last_yr_fullbias_adj_in_MPD
 2014 #_first_recent_yr_nobias_adj_in_MPD
 0.8 #_max_bias_adj_in_MPD (-1 to override ramp and set biasadj=1.0 for all estimated
recdevs)
 0 #_period of cycles in recruitment (N parms read below)
 -15 #min rec_dev
 15 #max rec_dev
 0 #_read_recdevs
#_end of advanced SR options
#
#
#Fishing Mortality info
0.02 # F ballpark for tuning early phases
2010 # F ballpark year (neg value to disable)
3 # F_Method:  1=Pope; 2=instan. F; 3=hybrid (hybrid is recommended)
5 # max F or harvest rate, depends on F_Method
# no additional F input needed for Fmethod 1
```

```
# if Fmethod=2; read overall start F value; overall phase; N detailed inputs to read
# if Fmethod=3; read N iterations for tuning for Fmethod 3
4  # N iterations for tuning F in hybrid method (recommend 3 to 7)
#
#_initial_F_parms
#_LO HI INIT PRIOR PR_type SD PHASE
 1e-005 0.1 0.00330448 0.001 0 1 1 # InitF_1F1_MISC
 0.1 5 0 0.01 0 99 -1 # InitF_2F2_GL
 0.1 5 0 0.01 0 99 -1 # InitF_3F3_OTHER_LL
 0.1 5 0 0.01 0 99 -1 # InitF_4F4_JPN_LL
 0.1 5 0 0.01 0 99 -1 # InitF_5F5_KOR_LL
 0.1 5 0 0.01 0 99 -1 # InitF_6F6_PRT_LL
 0.1 5 0 0.01 0 99 -1 # InitF_7F7_TWN_LL
 0.1 5 0 0.01 0 99 -1 # InitF_8F8_ESP_LL
#
#_Q_setup
 # Q_type options:  <0=mirror, 0=float_nobiasadj, 1=float_biasadj, 2=parm_nobiasadj,
3=parm_w_random_dev, 4=parm_w_randwalk, 5=mean_unbiased_float_assign_to_parm
#_for_env-var:_enter_index_of_the_env-var_to_be_linked
#_Den-dep  env-var  extra_se  Q_type
 0 0 0 0 # 1 F1_MISC
 0 0 0 0 # 2 F2_GL
 0 0 0 0 # 3 F3_OTHER_LL
 0 0 0 0 # 4 F4_JPN_LL
 0 0 0 0 # 5 F5_KOR_LL
 0 0 0 0 # 6 F6_PRT_LL
 0 0 0 0 # 7 F7_TWN_LL
 0 0 0 0 # 8 F8_ESP_LL
 0 0 0 0 # 9 S1_JPN_EARLY
 0 0 0 0 # 10 S2_JPN_LATE
 0 0 0 0 # 11 S3_EU_POR
 0 0 0 0 # 12 S4_EU_ESP
#
#_Cond 0 #_If q has random component, then 0=read one parm for each fleet with random q;
1=read a parm for each year of index
#_Q_parms(if_any)
#
#_size_selex_types
#discard_options:_0=none;_1=define_retention;_2=retention&mortality;_3=all_discarded_dea
d
#_Pattern Discard Male Special
 1 0 0 0 # 1 F1_MISC
 5 0 0 5 # 2 F2_GL
 24 0 4 0 # 3 F3_OTHER_LL
```

```
 24 0 3 0 # 4 F4_JPN_LL
 24 0 0 0 # 5 F5_KOR_LL
 24 0 4 0 # 6 F6_PRT_LL
 24 0 4 0 # 7 F7_TWN_LL
 24 0 0 0 # 8 F8_ESP_LL
 5 0 0 5 # 9 S1_JPN_EARLY
 5 0 0 5 # 10 S2_JPN_LATE
 5 0 0 7 # 11 S3_EU_POR
 5 0 0 8 # 12 S4_EU_ESP
#
#_age_selex_types
#_Pattern ___ Male Special
 11 0 0 0 # 1 F1_MISC
 11 0 0 0 # 2 F2_GL
 11 0 0 0 # 3 F3_OTHER_LL
 11 0 0 0 # 4 F4_JPN_LL
 11 0 0 0 # 5 F5_KOR_LL
 11 0 0 0 # 6 F6_PRT_LL
 11 0 0 0 # 7 F7_TWN_LL
 11 0 0 0 # 8 F8_ESP_LL
 11 0 0 0 # 9 S1_JPN_EARLY
 11 0 0 0 # 10 S2_JPN_LATE
 11 0 0 0 # 11 S3_EU_POR
 11 0 0 0 # 12 S4_EU_ESP
#_LO HI INIT PRIOR PR_type SD PHASE env-var use_dev dev_minyr dev_maxyr dev_stddev
Block Block_Fxn
 1 300 200 100 0 0.1 -2 0 0 0 0 0.5 0 0 # SizeSel_1P_1_F1_MISC
 1 339 75 100 0 0.1 -3 0 0 0 0 0.5 0 0 # SizeSel_1P_2_F1_MISC
 1 300 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_2P_1_F2_GL
 1 339 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_2P_2_F2_GL
 180 200 180.089 190 -1 0 1 0 0 0 0 0.5 0 0 # SizeSel_3P_1_F3_OTHER_LL
 -10 -9 -9.50516 -9.5 -1 0 2 0 0 0 0 0.5 0 0 # SizeSel_3P_2_F3_OTHER_LL
 -15 15 6.90381 0 -1 0 -4 0 0 0 0 0.5 0 0 # SizeSel_3P_3_F3_OTHER_LL
 -15 15 8 0 -1 0 -5 0 0 0 0 0.5 0 0 # SizeSel_3P_4_F3_OTHER_LL
 -999 -999 -999 0 -1 0 -2 0 0 0 0 0.5 0 0 # SizeSel_3P_5_F3_OTHER_LL
 -999 -999 -999 0 -1 5 -2 0 0 0 0 0.5 0 0 # SizeSel_3P_6_F3_OTHER_LL
 -20 200 10 125 -1 50 -4 0 0 0 0 0 0 0 # SzSel_3Fem_Peak_F3_OTHER_LL
 -15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel_3Fem_Ascend_F3_OTHER_LL
 -15 15 1 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel_3Fem_Descend_F3_OTHER_LL
 -15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel_3Fem_Final_F3_OTHER_LL
 -15 15 0.33 4 -1 50 -5 0 0 0 0 0 0 0 # SzSel_3Fem_Scale_F3_OTHER_LL
 145 165 157.583 150 -1 0 1 0 0 0 0 0.5 0 0 # SizeSel_4P_1_F4_JPN_LL
 -10 -9 -9.67096 -9.5 -1 0 2 0 0 0 0 0.5 0 0 # SizeSel_4P_2_F4_JPN_LL
 -15 15 8.42507 0 -1 0 -4 0 0 0 0 0.5 0 0 # SizeSel_4P_3_F4_JPN_LL
```

```
-15 15 7 0 -1 0 -5 0 0 0 0 0.5 0 0 # SizeSel_4P_4_F4_JPN_LL
-999 -999 -999 0 -1 0 -2 0 0 0 0 0.5 0 0 # SizeSel_4P_5_F4_JPN_LL
-999 -999 -999 0 -1 5 -2 0 0 0 0 0.5 0 0 # SizeSel_4P_6_F4_JPN_LL
-20 200 -15 125 -1 50 -4 0 0 0 0 0 0 0 # SzSel_4Male_Peak_F4_JPN_LL
-15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel_4Male_Ascend_F4_JPN_LL
-15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel_4Male_Descend_F4_JPN_LL
-15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel_4Male_Final_F4_JPN_LL
-15 15 0.5 4 -1 50 -5 0 0 0 0 0 0 0 # SzSel_4Male_Scale_F4_JPN_LL
145 165 145.021 150 -1 0 1 0 0 0 0 0.5 0 0 # SizeSel_5P_1_F5_KOR_LL
-15 15 -3 0 -1 0 -2 0 0 0 0 0.5 0 0 # SizeSel_5P_2_F5_KOR_LL
-15 15 8 0 -1 0 -4 0 0 0 0 0.5 0 0 # SizeSel_5P_3_F5_KOR_LL
-15 15 7 0 -1 0 -5 0 0 0 0 0.5 0 0 # SizeSel_5P_4_F5_KOR_LL
-999 -999 -999 0 -1 0 -2 0 0 0 0 0.5 0 0 # SizeSel_5P_5_F5_KOR_LL
-999 -999 -999 0 -1 5 -2 0 0 0 0 0.5 0 0 # SizeSel_5P_6_F5_KOR_LL
155 175 171.305 165 -1 0 1 0 0 0 0 0.5 0 0 # SizeSel_6P_1_F6_PRT_LL
-1 1 -0.750989 -0.4 -1 0 3 0 0 0 0 0.5 0 0 # SizeSel_6P_2_F6_PRT_LL
-15 15 6.5 0 -1 0 -5 0 0 0 0 0.5 0 0 # SizeSel_6P_3_F6_PRT_LL
-15 15 6.5 0 -1 0 -5 0 0 0 0 0.5 0 0 # SizeSel_6P_4_F6_PRT_LL
-999 -999 -999 0 -1 0 -2 0 0 0 0 0.5 0 0 # SizeSel_6P_5_F6_PRT_LL
-999 -999 -999 0 -1 5 -2 0 0 0 0 0.5 0 0 # SizeSel_6P_6_F6_PRT_LL
-20 200 10 125 -1 50 -4 0 0 0 0 0 0 0 # SzSel_6Fem_Peak_F6_PRT_LL
-15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel_6Fem_Ascend_F6_PRT_LL
-15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel_6Fem_Descend_F6_PRT_LL
-15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel_6Fem_Final_F6_PRT_LL
-15 15 0.2 4 -1 50 -5 0 0 0 0 0 0 0 # SzSel_6Fem_Scale_F6_PRT_LL
195 215 202.231 209 -1 0 1 0 0 0 0 0.5 0 0 # SizeSel_7P_1_F7_TWN_LL
-10 -9 -9.3001 -9.5 -1 0 2 0 0 0 0 0.5 0 0 # SizeSel_7P_2_F7_TWN_LL
-15 15 7.5 0 -1 0 -4 0 0 0 0 0.5 0 0 # SizeSel_7P_3_F7_TWN_LL
-15 15 7.75 0 -1 0 -5 0 0 0 0 0.5 0 0 # SizeSel_7P_4_F7_TWN_LL
-999 -999 -999 0 -1 0 -2 0 0 0 0 0.5 0 0 # SizeSel_7P_5_F7_TWN_LL
-999 -999 -999 0 -1 5 -2 0 0 0 0 0.5 0 0 # SizeSel_7P_6_F7_TWN_LL
-20 200 0 125 -1 50 -4 0 0 0 0 0 0 0 # SzSel_7Fem_Peak_F7_TWN_LL
-15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel_7Fem_Ascend_F7_TWN_LL
-15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel_7Fem_Descend_F7_TWN_LL
-15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel_7Fem_Final_F7_TWN_LL
-15 15 0.75 4 -1 50 -5 0 0 0 0 0 0 0 # SzSel_7Fem_Scale_F7_TWN_LL
200 225 209.556 215 -1 0 1 0 0 0 0 0.5 0 0 # SizeSel_8P_1_F8_ESP_LL
-5 1 -4.82622 -3 -1 0 2 0 0 0 0 0.5 0 0 # SizeSel_8P_2_F8_ESP_LL
-15 15 8 0 -1 0 -4 0 0 0 0 0.5 0 0 # SizeSel_8P_3_F8_ESP_LL
-15 15 8 0 -1 0 -5 0 0 0 0 0.5 0 0 # SizeSel_8P_4_F8_ESP_LL
-999 -999 -999 0 -1 0 -2 0 0 0 0 0.5 0 0 # SizeSel_8P_5_F8_ESP_LL
-999 -999 -999 0 -1 5 -2 0 0 0 0 0.5 0 0 # SizeSel_8P_6_F8_ESP_LL
1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_9P_1_S1_JPN_EARLY
1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_9P_2_S1_JPN_EARLY
```

```
 1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_10P_1_S2_JPN_LATE
 1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_10P_2_S2_JPN_LATE
 1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_11P_1_S3_EU_POR
 1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_11P_2_S3_EU_POR
 1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_12P_1_S4_EU_ESP
 1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_12P_2_S4_EU_ESP
 1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_1P_1_F1_MISC
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_1P_2_F1_MISC
 1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_2P_1_F2_GL
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_2P_2_F2_GL
 1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_3P_1_F3_OTHER_LL
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_3P_2_F3_OTHER_LL
 1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_4P_1_F4_JPN_LL
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_4P_2_F4_JPN_LL
 1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_5P_1_F5_KOR_LL
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_5P_2_F5_KOR_LL
 1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_6P_1_F6_PRT_LL
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_6P_2_F6_PRT_LL
 1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_7P_1_F7_TWN_LL
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_7P_2_F7_TWN_LL
 1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_8P_1_F8_ESP_LL
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_8P_2_F8_ESP_LL
 1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_9P_1_S1_JPN_EARLY
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_9P_2_S1_JPN_EARLY
 1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_10P_1_S2_JPN_LATE
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_10P_2_S2_JPN_LATE
 1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_11P_1_S3_EU_POR
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_11P_2_S3_EU_POR
 1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_12P_1_S4_EU_ESP
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_12P_2_S4_EU_ESP
#_Cond 0 #_custom_sel-env_setup (0/1)
#_Cond -2 2 0 0 -1 99 -2 #_placeholder when no enviro fxns
#_Cond 0 #_custom_sel-blk_setup (0/1)
#_Cond -2 2 0 0 -1 99 -2 #_placeholder when no block usage
#_Cond No selex parm trends
#_Cond -4 # placeholder for selparm_Dev_Phase
#_Cond 0 #_env/block/dev_adjust_method (1=standard; 2=logistic trans to keep in base parm bounds; 3=standard w/ no bound check)
#
# Tag loss and Tag reporting parameters go next
0  # TG_custom:  0=no read; 1=read if tags exist
#_Cond -6 6 1 1 2 0.01 -4 0 0 0 0 0 0 0  #_placeholder if no parameters
#
1 #_Variance_adjustments_to_input_values
```

```
#_fleet: 1 2 3 4 5 6 7 8 9 10 11 12
  0 0 0 0 0 0 0 0 0 0 0 0 #_add_to_survey_CV
  0 0 0 0 0 0 0 0 0 0 0 0 #_add_to_discard_stddev
  0 0 0 0 0 0 0 0 0 0 0 0 #_add_to_bodywt_CV
  1 1 0.2 0.2 0.2 0.2 0.2 0.2 1 1 1 1 #_mult_by_lencomp_N
  1 1 1 1 1 1 1 1 1 1 1 1 #_mult_by_agecomp_N
  1 1 1 1 1 1 1 1 1 1 1 1 #_mult_by_size-at-age_N
#
1 #_maxlambdaphase
1 #_sd_offset
#
23 # number of changes to make to default Lambdas (default value is 1.0)
# Like_comp codes:  1=surv; 2=disc; 3=mnwt; 4=length; 5=age; 6=SizeFreq; 7=sizeage; 8=catch;
# 9=init_equ_catch; 10=recrdev; 11=parm_prior; 12=parm_dev; 13=CrashPen; 14=Morphcomp;
15=Tag-comp; 16=Tag-negbin
#like_comp fleet/survey  phase  value  sizefreq_method
 1 1 1 0 1
 1 2 1 0 1
 1 3 1 0 1
 1 4 1 0 1
 1 5 1 0 1
 1 6 1 0 1
 1 7 1 0 1
 1 8 1 0 1
 1 9 1 0 1
 1 10 1 0 1
 1 11 1 1 1
 1 12 1 0 1
 4 1 1 0 0
 4 2 1 0 0
 4 3 1 1 0
 4 4 1 1 0
 4 5 1 1 0
 4 6 1 1 0
 4 7 1 1 0
 4 8 1 1 0
 4 9 1 0 0
 4 10 1 0 0
 9 1 1 1 0
#
# lambdas (for info only; columns are phases)
#  0 #_CPUE/survey:_1
#  0 #_CPUE/survey:_2
#  0 #_CPUE/survey:_3
```

```
#  0 #_CPUE/survey:_4
#  0 #_CPUE/survey:_5
#  0 #_CPUE/survey:_6
#  0 #_CPUE/survey:_7
#  0 #_CPUE/survey:_8
#  0 #_CPUE/survey:_9
#  0 #_CPUE/survey:_10
#  1 #_CPUE/survey:_11
#  0 #_CPUE/survey:_12
#  0 #_lencomp:_1
#  0 #_lencomp:_2
#  1 #_lencomp:_3
#  1 #_lencomp:_4
#  1 #_lencomp:_5
#  1 #_lencomp:_6
#  1 #_lencomp:_7
#  1 #_lencomp:_8
#  0 #_lencomp:_9
#  0 #_lencomp:_10
#  0 #_lencomp:_11
#  0 #_lencomp:_12
#  1 #_init_equ_catch
#  1 #_recruitments
#  1 #_parameter-priors
#  1 #_parameter-dev-vectors
#  1 #_crashPenLambda
0 # (0/1) read specs for more stddev reporting
 # 0 1 -1 5 1 5 1 -1 5 # placeholder for selex type, len/age, year, N selex bins, Growth pattern, N growth ages, NatAge_area(-1 for all), NatAge_yr, N Natages
 # placeholder for vector of selex bins to be reported
 # placeholder for vector of growth ages to be reported
 # placeholder for vector of NatAges ages to be reported
999
```

# APPENDIX 2 Revisions made to stock assessment immediately prior and during WEPB 11.

## Updated stock assessment of blue shark (*Prionace glauca)* in the Indian Ocean using Stock Synthesis.

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# A2.1 Introduction

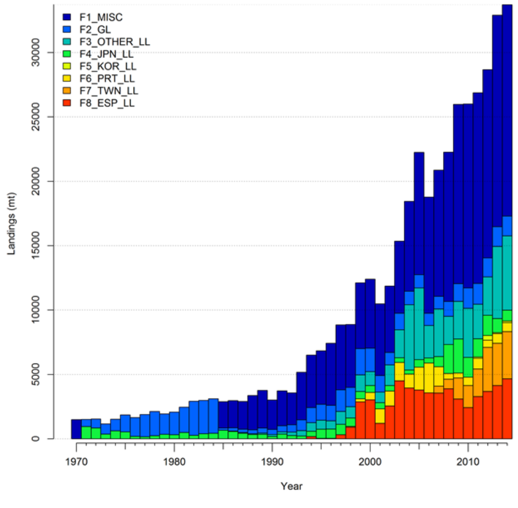
This appendix documents revisions to the paper IOTC-20150WPEB11-28 that occurred immediately prior to and during the working party. The final models used for developing stock status advice are documented.

## A2.2 Revision of the Assessment Methodology

As before the assessment scope covers the entire Indian Ocean from the years 1971-2014 (Figure 1 above). The assessment uses stock synthesis 3.24f, is age and sex structured with 8 fleets and 5 surveys representing individual CPUE series. This is a change from the previous document with the addition of an early series (1971-1993) from Japanese longline fisheries and a revised Taiwanese series that spans the years 2004-2013. As before two catch series are used based on the IOTC catch estimates and a revised estimate based on the trade based estimates(Figure A2.1).

A revision was made to the ratio estimator for the trade based estimates, years 2012-2014. As before (main text of this document) an alternative catch series was estimated based on trade based estimates using the proportion of tuna caught (IOTC–2015–WPEB11–24). The original trade based estimate extends from 1981-2011. To extend this catch series throughout the model domain a ratio (IOTC catch/ trade catch) from the first the 1980’s was used to extend the model prior to 1980. The years 2012-2014 were calculated by calculating the ratio of reported catch of tropical tuna and swordfish catch in 2012 (and 2013, 2014) to the average from 2008-2011. It was assumed that this ratio would be representative of the estimated BSH catch from the same time periods, hence these ratios were applied to the average of trade based blue shark catch estimates from 2008-2011 to estimate the catch for 2012-2014 (Figure A2.1).

IOTC



TRADE

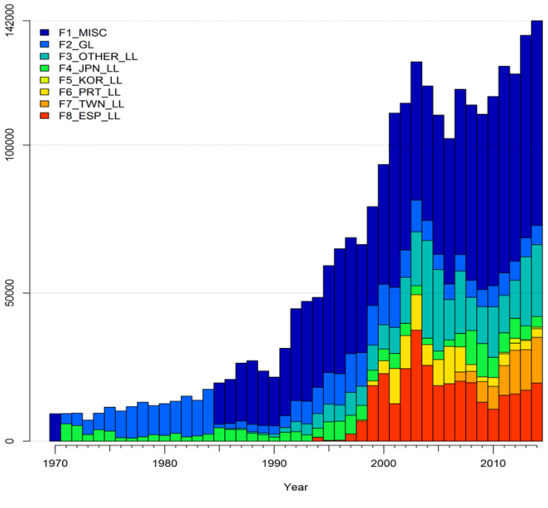


**Figure A2.1 Comparison of catch series used in the revised assessment. Note the difference in scale on the y-axis.**

The biological parameters were unchanged from the previous analysis (Table 2, Table 3, Figure 4). As before the selectivity partially estimated for the fleets with length composition with the exception of the Fleet 5 (Korean longline) which was fixed due to convergence problems. As previously the initial equilibrium catch was fixed at approximately 100% of the first 5 years of catch (depending on the catch time series used) and was given the same selectivity as for Fleet 4, the Japanese longline fleet. The corresponding initial fishing mortality (and depletion) were then estimated. The assessment methodology was to determine the major axes of uncertainty within the assessment and then compare the stock status and range of uncertainty considered based on the suite of models run. This re vised analysis considered first 162 runs as described in the following table

**TABLE A2.1 Initial alternative model formations**

| GROUP | Variable | Options Run |
|---|---|---|
| **CPUE** | | |
| | | 2. Japan Late |
| | | 3. **Portugal** |
| | | 4. Spain |
| **Length Composition** | | |
| | Sample Size weighting | 1. **Iteratively Re-weighted** |
| | | 2. 0.2 |
| | | 3. 1.0 |
| **Stock Recruitment** | | |
| | Steepness | 1. 0.2 |
| | | 2. **0.3** |
| | | 3. 0.4 |
| | Sigma R (SD on the recruitment deviations) | 1. 0.1 |
| | | 2. **0.3** |
| | | 3. 0.5 |
| **Catch series** | | 1. **IOTC database derived catch** |
| | | 2. Trade based catch |

After consultation with the working party the, submission by Japan and Taiwan of new CPUE series and recalculation of the trade based catch estimates from the years 2012-2014 the following set of 42 models were decided upon;

TABLE A2.2 Final alternative model formations

| GROUP | Variable | Options Run |
|---|---|---|
| **CPUE** | | 1. Japan Early and Late<br>2. Japan Late<br>3. Portugal<br>4. Spain<br>5. Taiwan<br>6. All CPUE series<br>7. All later CPUE series (post 1993) |
| **Stock Recruitment** | Steepness | 1. 0,3<br>2. 0.5<br>3. 0.7 |
| **Catch series** | | 1. IOTC database derived catch<br>2. Trade based catch |

Where the "All" and "All_late" refer to models using all the CPUE series and all of the later CPUE series. These were run primarily as a diagnostic to compare the results with the surplus production models also presented at the working party.

## RESULTS

As in the report above in this section we focus on the results based on a singular model as the key results and model diagnostics are similar across all models. We then comment on any important differences in both outputs and model diagnostics for the one-change sensitivity analyses. Model diagnostics, where possible are shown across the major axes of uncertainty. For the purposes of diagnosing model fit we select the model with the Portuguese CPUE, steepness of 0.5 and catch based on the IOTC database.

### Model Fit and Diagnostics

The model fit well to the index of abundance and length composition (Figure A2.2). Pearson residuals (Figure A2.3) are small, on the order of 1-2 maximum, and show no significant pattern through time.

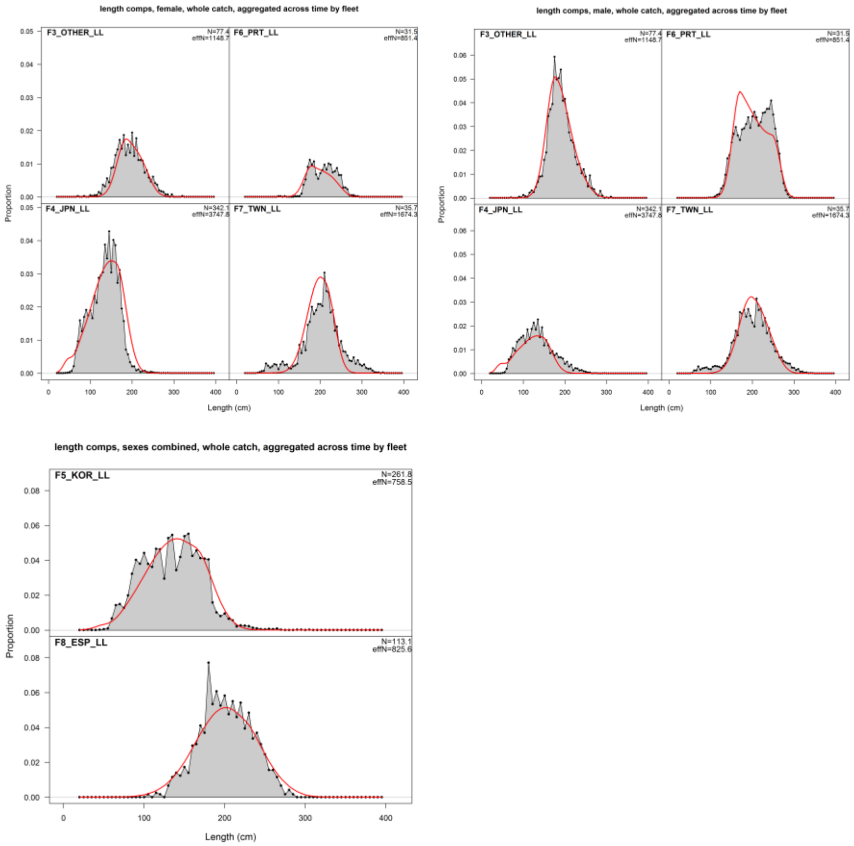


**Figure A2.2 Model fit to the female (top left), male( top right) and sex aggregated length compositions(bottom left panels).**

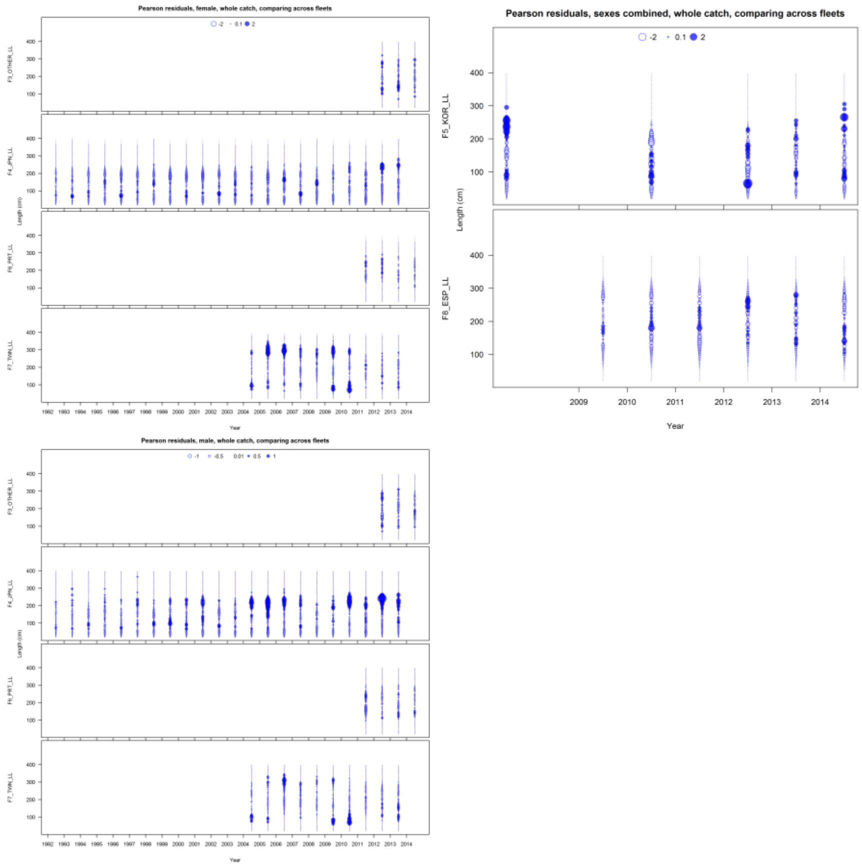


**Figure A2.3 Pearson residuals, comparing across fleets (females top left, males bottom left and sexes combined top right). Closed bubbles are positive residuals and open bubbles are negative residuals, bubble sizes are scaled to maximum within each panel. Thus, comparisons across panels should focus on patterns, not bubble sizes.**

The model fit well to the single index of abundance (Figure A2.4), though given the constraints of the biology and the coverage of the CPUE series with respect to the model time frame some misfit is evident in the early years. No evidence of a systematic trend was found in the fits to the estimated recruitment deviates (Figure A2.4),.

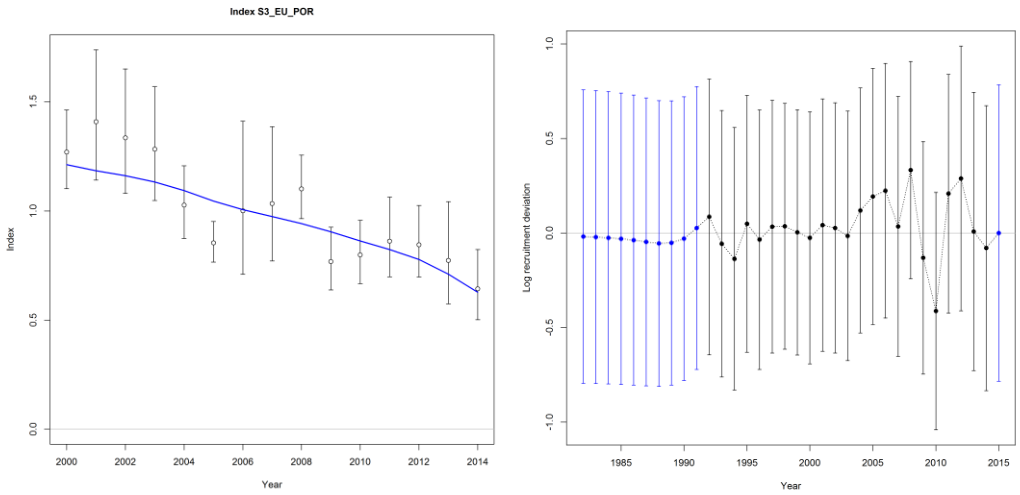


**Figure A2.4 Model fit to the Portuguese CPUE series (left hand panel) and the estimated recruitment deviates (right hand panel) .**

Overall the model results were quite similar, differing mainly due to the catch series assumed (Figure A2.5)

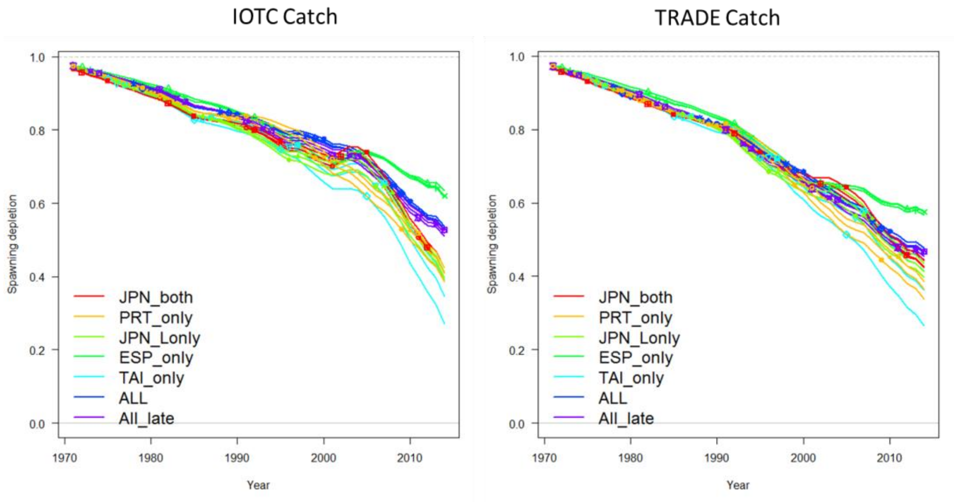


**Figure A2.5 Spawning Depletion by catch series assumed by CPUE series fitted, individual lines represent alternative values of steepness assumed.**

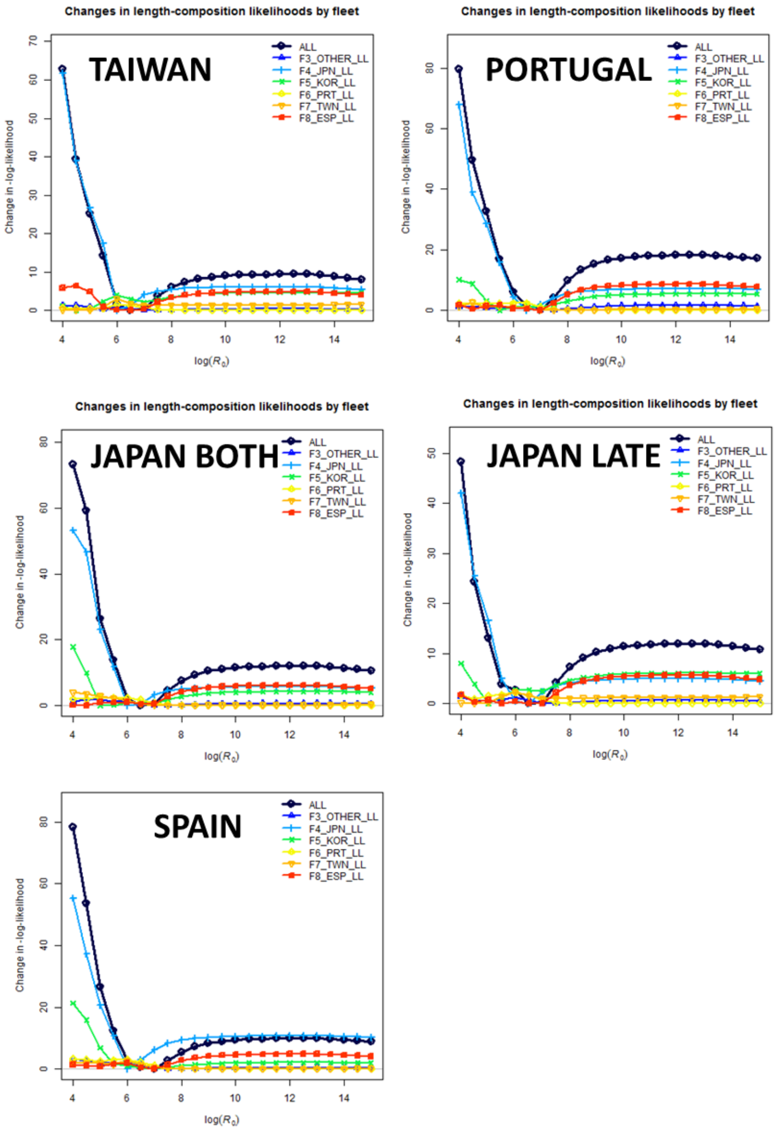


**Figure A2.8 Likelihood profiles over the length composition by fleet when fit to different CPUE series (indicated in bold in each panel).**

The likelihood profiles over the length compositions indicated that to a large extent the only fleet that had significant information in it was Fleet 4 (light blue line Figure A2.8 Japanese longline). To a certain extent the other fleets, most notably the Korean longline fleet (Fleet 5 light green line Figure A2.8) contributed information to the population scale, but overall information from the length composition was driven by the Japanese length data.

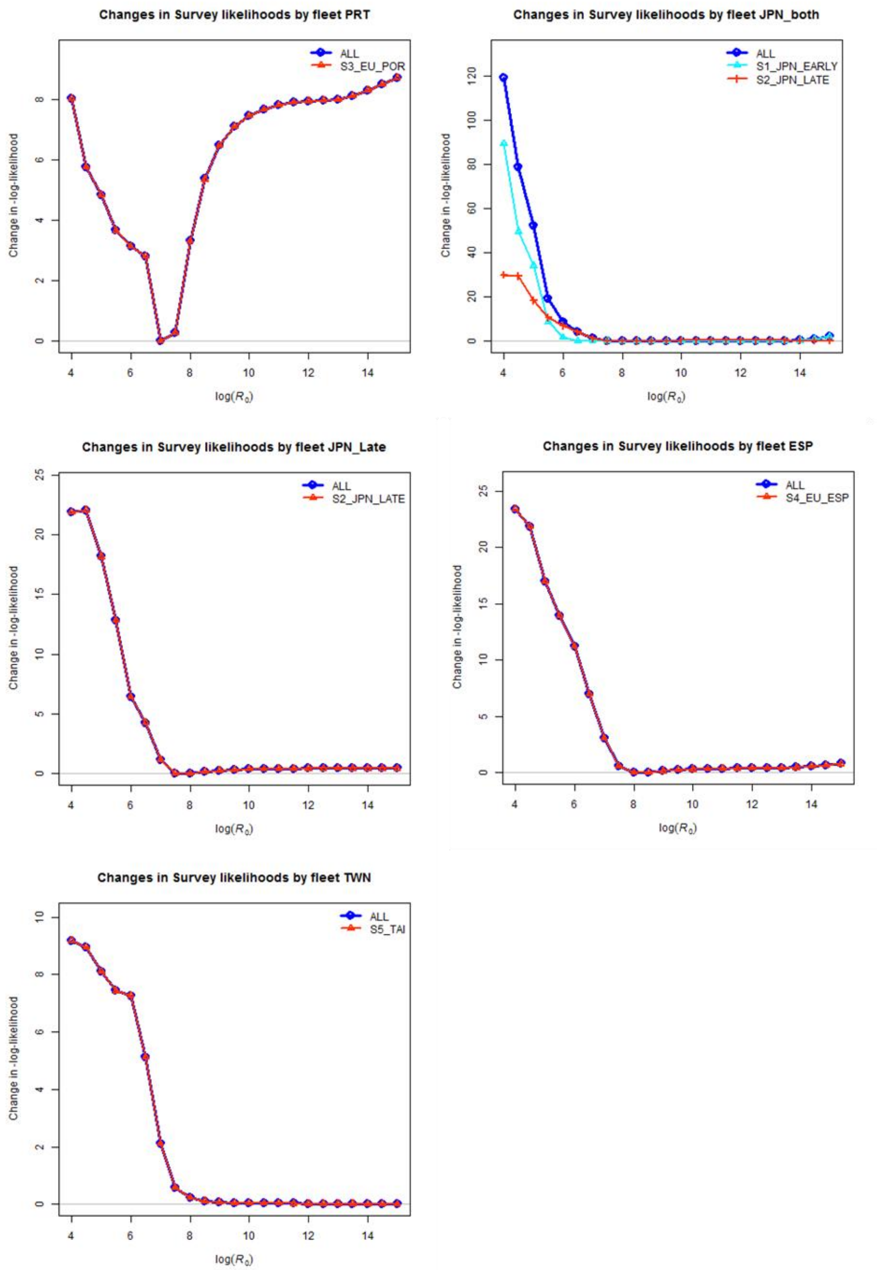


**Figure A2.9 Likelihood profiles over the CPUE series by survey when fit to different CPUE series (indicated in the title of each panel).**

The likelihood profiles conducted while running each of the CPUE series independently (and the Japanese early and late series together) indicated that most of the CPUE series have relatively little information in them regarding the scale of the population (Figure A2.9). The only CPUE series that has information is the Portuguese CPUE series (top left panel Figure A2.9).

Stock status across the axes of uncertainty indicated that the stock was likely above $SB_{MSY}$ but that $F/F_{MSY}$ was likely greater than 1 (Figure A2.10, Tables A2.2 and A2.3).

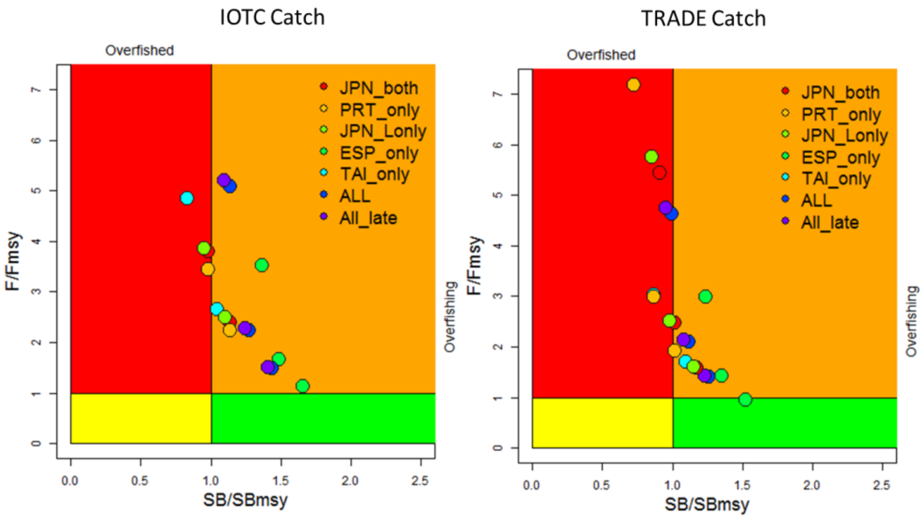


**Figure A2.10 Stock status by assumed catch series (IOTC database estimates on the left) and CPUE series fitted to the model.**

## Conclusions

The model results depend heavily on the CPUE series selected and the assumed catch series. Most models showed the stock was likely above $SB_{MSY}$ but that $F/F_{MSY}$ was likely greater than 1. Alternative runs show a broad range of uncertainty, largely with respect to the F values. The ASPM and retrospective analysis shows that the model is appropriately structured, the likelihood profile analysis indicates that the Japanese length composition and Portuguese CPUE series are driving the analysis.

There are several limitations of this analysis, of which the lack of a single CPUE series that extends through the time series is one of the main ones. Additionally the available CPUE series show different trends. One of the most influential data components, the catch, is largely exhibits a steep trend from the mid 1980's to the mid 2000's. This increase is reflected in the spawning biomass trajectories and the depletion estimates given the expectation (based on historical effort) that the population was lightly exploited prior to 1970. Catch of blue sharks has only recently been reported to species in the Indian Ocean, and is likely underreported as many unidentified sharks are still. The resulting level of uncertainty with regards to the catch is high, as demonstrated by the difference in an order of magnitude between the two catch histories used in this assessment. Both estimates show an increase in estimated catch between the 1980s and 2010, which corresponds to an increase in pelagic longline effort in the Indian Ocean. The magnitude and steepness of the overall catch curve are influential an unknown.

Available information on blue shark in the Indian Ocean has been improving in recent years, however many data gaps exist. It is important to note that due to data limitations it was impossible to assess the area on a scale finer than one region although the extent of population mixing on a basin scale is unclear. Given the extent of the fisheries that commonly catch blue sharks in the Indian Ocean and the observed size frequency it is likely that in some areas they are fished in their nursery grounds. Because of their life history characteristics – they are relatively long lived (20–25 years), mature relatively late (at 4–6 years), and have relativity few offspring (25–50 pups every year), the blue shark is vulnerable to overfishing. However, blue shark assessments in the Atlantic and Pacific oceans seem to indicate that blue shark stocks can sustain relatively high fishing pressure. On the weight-of-evidence available in 2015, the stock status is uncertain. A precautionary approach to the management of blue shark should be considered by ensuring that future catches do not exceed current catches or some other appropriate limit on any bycatch and directed fisheries.

Specific areas of work that would improve future assessments include;

1) Estimation of catch data series that is representative of the Indian Ocean, by fleet where possible.
2) Assessing if spatial patterns exist on length comps in the analysis and splitting the fisheries by areas.
3) Resolving differences in CPUE series across areas, and use some weighting factors on which series is the most representative of what is happening in the Indian Ocean fishery.
4) Assessing a single or multi-stock structure, and incorporating it in the assessments.
5) Analyse seasonality with in the selectivity of the fishery and with respect the size an sex structure of the population.
6) Development of sex specific biological parameters based on wide scale analysis of the population in the Indian Ocean.

**Table A2.2 Estimates of management quantities by CPUE series based on trade based catch estimates and an assumed steepness of 0.5.**

| | PRT | ESP | JPN_late | JPN_both | TWN | All | All -Late |
|---|---|---|---|---|---|---|---|
| C2014_msy | 2.50 | 2.06 | 2.46 | 2.50 | 2.53 | 2.37 | 2.34 |
| Y_MSY | 56882 | 69026 | 57693 | 56758 | 56097 | 59841 | 60794 |
| B_zero | 2,615,650 | 3,210,900 | 2,671,190 | 2,632,040 | 2,597,680 | 2,760,520 | 2,799,540 |
| B_msy | 1,097,999 | 1,344,020 | 1,119,013 | 1,102,219 | 1,088,179 | 1,158,024 | 1,174,884 |
| B_cur | 1,102,279 | 1,872,102 | 1,219,315 | 1,237,550 | 1,081,910 | 1,367,191 | 1,347,646 |
| SB_zero | 216,547 | 265,827 | 221,145 | 217,904 | 215,060 | 228,541 | 231,771 |
| SB_msy | 90,902 | 111,270 | 92,642 | 91,252 | 90,090 | 95,872 | 97,267 |
| SB_cur | 91,257 | 154,989 | 100,946 | 102,455 | 89,570 | 113,188 | 111,570 |
| SB_cur/SB_zero | 0.42 | 0.58 | 0.46 | 0.47 | 0.42 | 0.50 | 0.48 |
| SB_cur/SB_msy | 1.00 | 1.39 | 1.09 | 1.12 | 0.99 | 1.18 | 1.15 |
| Fcur | 0.31 | 0.17 | 0.28 | 0.27 | 0.31 | 0.24 | 0.25 |
| F_msy | 0.15 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.15 |
| F_2014_msy | 2.98 | 1.42 | 2.52 | 2.47 | 3.02 | 2.09 | 2.13 |
| F_cur_msy | 2.15 | 1.20 | 1.91 | 1.88 | 2.18 | 1.67 | 1.69 |

**Table A2.3 Estimates of management quantities by CPUE series based on IOTC database catch estimates and an assumed steepness of 0.5.**

| | PRT | ESP | JPN_late | JPN_both | TWN | All | All -Late |
|---|---|---|---|---|---|---|---|
| C2014_msy | 14.04 | 11.24 | 14.90 | 15.13 | 15.47 | 12.71 | 12.56 |
| Y_MSY | 10113 | 12629 | 9530 | 9383 | 9180 | 11173 | 11303 |
| B_zero | 478,700 | 599,112 | 449,935 | 443,601 | 432,215 | 533,780 | 539,201 |
| B_msy | 199,262 | 249,329 | 187,372 | 184,678 | 180,131 | 221,676 | 224,007 |
| B_cur | 233,618 | 392,045 | 218,038 | 220,514 | 192,809 | 306,873 | 302,738 |
| SB_zero | 39,631 | 49,600 | 37,250 | 36,725 | 35,783 | 44,191 | 44,640 |
| SB_msy | 16,497 | 20,642 | 15,512 | 15,289 | 14,913 | 18,352 | 18,545 |
| SB_cur | 19,341 | 32,457 | 18,051 | 18,256 | 15,963 | 25,406 | 25,063 |
| SB_cur/SB_zero | 0.49 | 0.65 | 0.48 | 0.50 | 0.45 | 0.57 | 0.56 |
| SB_cur/SB_msy | 1.17 | 1.57 | 1.16 | 1.19 | 1.07 | 1.38 | 1.35 |
| Fcur | 0.33 | 0.19 | 0.35 | 0.35 | 0.41 | 0.24 | 0.24 |
| F_msy | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 |
| F_2014_msy | 3.44 | 1.67 | 3.86 | 3.79 | 4.84 | 2.23 | 2.27 |
| F_cur_msy | 2.27 | 1.30 | 2.47 | 2.44 | 2.86 | 1.66 | 1.68 |