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Stock assessment of blue sharks in the north Pacific Ocean using Stock Synthesis

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From the draft ISC Shark Working Group report provided electronically 17 July 2013

"6.0 SS MODELING OF NORTH PACIFIC BLUE SHARK

Members of the ISC SHARKWG and SPC had previously agreed to collaborate on an age-structured model of north Pacific blue shark using Stock Synthesis (SS) (reference report from May 2013). The purpose of the SS modeling efforts was to help the WG understand the effects of the age and sex structure on stock assessment results because the BSP model used in the current assessment does not account for these effects.

The WG discussed the executive summary and key figures and tables for the base case age-structured SS3 model of north Pacific blue shark (ISC/13/SHARKWG-3/INFO-01). However, the WG was unable to review the collaborative SS3 model and its results because a full report detailing the SS model was not provided to the WG by the previously agreed upon deadline nor by the start of the meeting. In addition, the executive summary did not contain enough technical detail for the WG to understand and review the scientific and technical aspects of the model. Therefore, the WG was also unable to endorse the SS3 model for developing conservation and management advice. Furthermore, the WG requests that presentation of the SS3 model results to the WCPFC be postponed until SC 10 so that the WG has an opportunity to adequately review the model. The WG welcomes further collaborative refinement of the modeling and submission of the full assessment report for review at a future WG meeting.

The WG recognized that a draft of the detailed assessment report for the WCPFC was received on 9 July 2013. However, the paper was not accepted as a submission for this meeting because it was received too late to be taken up by the WG, in particular given the need to thoroughly review the technical details of the assessment. The WG agreed to review the paper on the SS model (or a revised version, if submitted) at the next WG meeting tentatively scheduled for January 2014."

Executive summary

This paper presents an age-based statistical catch-at-length stock assessment of blue shark in the North Pacific Ocean (NPO). The assessment uses the stock assessment model and computer software known as Stock Synthesis (version 3.24F http://nft.nefsc.noaa.gov/Download.html).

This is one of the two stock assessment approaches being applied to blue sharks in the NPO. The ISC Shark WG has agreed to use a Bayesian Surplus Production (BSP) model for the main stock assessment and the age-based statistical catch-at-length length stock assessment presented here to help support results from the BSP. This paper should be read with the full assessment report of the ISC Shark WG which provides greater details of the data sources and how they were derived as well as pertinent summaries of biological knowledge.

The primary reasons to use Stock Synthesis was to take advantage of the Low Fecundity Spawner Recruitment relationship (LFSR) functionality. In the assessment we examined many alternative parameterisations of this relationship which provided similar productivity assumptions to the BSP (i.e., BMSY/B0 ~ 0.5). Also we were able to incorporate the strong sex-specific patterns that are seen in many of the data sets.

This is an integrated stock assessment using estimated catch, standardized catch per unit effort time series, observed catch at length, and published life history information. The blue shark model is an age (30 years) structured spatially aggregated (1 region) and two sex model. The catch, effort, and size composition of catch are grouped into 18 fisheries covering the time period from 1976 through 2011.

Blue sharks are often caught as bycatch in the Pacific tuna fisheries, though significant directed and mixed species (sharks and tunas/billfish) fisheries do exist. Commercial reporting of blue shark landings has been minimal, and information regarding the targeting, and fate of sharks encountered in the fisheries is limited. Observer data on catch and effort is mostly confined to areas near the Hawaiian Islands (US jurisdiction) and the island states north of the equator. Although the observer data suffers from poor coverage in key areas such as the eastern Pacific Ocean and North West Pacific, logbook and other fishery dependent data exists.

Due to gaps in the data and varied estimates of life history parameters multiple models that reflected different assumptions were run with alternative data/parameters. These multiple models with different combinations of the input datasets and structural model hypotheses were used to assess the plausible range of stock status for blue shark. The reference case presented here was chosen based on input from the ISC and attempts to approximate the overall productivity assumptions used in the BSP. It represents the set of LFSR parameters which gave the best fit given the other assumptions decided for the reference case. The reference case model is used as an example for presenting model diagnostics. The most appropriate model run(s) upon which to base management advice will be determined by the WCPFC Scientific Committee considering the recommendations from the ISC Plenary.

The reference case model and alternative model assumptions are provided in the table below. A full factorial grid of all options was run (this gave a total of 192 model runs) – and full results for any run are available on request.

Axis of uncertainty	Reference case assumption	Alternative assumptions
CPUE series	Japanese early and late CPUE series	Japanese early and HW deep set Japanese early and Japan RTV
Age-specific natural mortality approach	Chen and Watanabe (low)	Peterson and Wroblewski (hi)
Sample size for length frequency data	Scalar of 0.2	Scalar of 0.5 (upweight)
Sfrac of the LFSR	0.35	0.05, 0.13, 0.2
Beta of the LFSR	2	1,3,4

We recognize that there are other sources of model and data uncertainty that could be examined, but believe we have captured the major sources of uncertainty here relative to the BSP.

We have reported stock status in relation to MSY based reference points, but note that WCPFC has not yet made decisions regarding limit (or target) reference points for sharks.

The key conclusions of the SS stock assessment for blue sharks in the NPO are as follows:

1. For the reference case model current catches are two thirds of the MSY level (MSY=50,330 t), current biomass is 84.6% of BMSY and 90% in the last year of the model, and fishing mortality is 77.6% of FMSY level. The stock could be said to be in an overfished state, but the stock is rebuilding under current catches as fishing mortality is declining. However there is considerable uncertainty around the estimates of current depletion and fishing mortality from the model. The 95% confidence limits for spawning depletion in the final year are 17.5%-152% of BMSY and fishing mortality at 20%-136% of FMSY.
2. We found many significant sex-specific differences in selectivity and catchability which emphasises the importance of including these processes in the assessment.
3. Looking at the key sources of uncertainty, one off changes from the reference case lead to the following conclusions:
    a. The alternative late CPUE series had the greatest influence on the assessment conclusions. Under the Hawaiian deep set series the biomass was continually declining over the modelling period, MSY was lower, depletion was much greater with the stock 60% below the BMSY level and fishing mortality was well above FMSY. Under the Japan RTV series the model often failed to converge – mostly due to the crashing of the population. Model runs that did converge suggested even worse condition than the Hawaiian deep set series.
    b. The up weighting of the length frequency data did make the assessment more optimistic in terms of higher B/BMSY and lower F/FMSY but the stock was still estimated to be in an overfished state (but recovering). Continuing to increase the weight to these data will give further improved stock status, but as this is at the cost of fitting the CPUE series, this does not seem like good practice given what we know about the size data (i.e., that they are not expected to be particularly informative on trends in abundance).
    c. The higher natural mortality had similar impacts to the higher sample size in terms of optimism, but fit both CPUE series noticeably worse at the expense of a better fit to the size data. While the decision to use the lower mortality rates for the reference case was

relatively arbitrary, they do fit the CPUE series much better and provide a better overall model fit.

d. The response to changes is the LFSR was quite complex:

   i. For low Sfrac, MSY and FMSY (and overall stock condition) increased dramatically with increases of beta from 1 to 3, but the fit to the Japan late series was extremely poor (e.g. it did not predict the strong increase).

   ii. Under high Sfrac the model results were relatively consistent across the range of values of beta.

4. There are some concerns over all three late CPUE series used in this assessment in terms of whether the trend accurately changes in relative abundance over the extent of the stock. Given this and the extent of uncertainty even within the reference case model, it is our conclusion that the possibility that the abundance is not increasing or possibly declining in recent years should be a factor in any management advice from the assessment.

5. We suggest that depending on the nature of management action an updated assessment should be conducted in the next 2-3 years. This assessment should consider:

   - Alternative approaches to account for targeting in the Japanese fleet.
   - Examination of the potential to include some fisheries with asymptotic selectivity curves – this will likely involve examination of asymptotic length from the growth curve.
   - Determine if there are plausible alternative catch series – in particular ones with different trends through time. This should include detailed analysis of observer reports to estimate discards.
   - Continued development of alternative CPUE series
   - Detailed consideration of how the biology of blue sharks can be modelled within the SS framework (including the LFSR).

1 Background

This paper presents one of two stock assessment approaches being applied to blue sharks in the NPO. The ISC Shark WG has agreed to use a Bayesian Surplus Production (BSP) model for the main stock assessment and the age-based statistical catch-at-length length stock assessment conducted using Stock Synthesis (SS) (version 3.24F http://nft.nefsc.noaa.gov/Download.html) presented here to help confirm the results from the BSP. This paper should be read with the full assessment report of the ISC Shark WG (Takahashi et al. 2013) which provides greater details of the data sources (e.g., the fleets in each country and how their catches were estimated) as well as pertinent summaries of biological knowledge.

Here we focus on the key assumptions and decisions made in constructing both the reference case model (our best attempt to mimic the general assumptions of the BSP) and the numerous sensitivity analyses that were undertaken.

2 General assessment approach

As with previous shark assessments undertaken by SPC the general approach was to identify the key areas that we felt contributed greatest to our 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 natural mortality to be an area of uncertainty and consider two 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 can be useful to determine if there are particular interactions between model assumptions / data inputs.

3 Biological inputs and assumptions

Blue sharks have a pan-Pacific distribution, and genetic evidence of distinct population structure within the Pacific has not been found (Taguchi and Yokawa 2013). Conventional tagging in the eastern, central and western North Pacific regions has resulted in recoveries within each neighbouring North Pacific region, providing evidence of wide movement throughout the North Pacific (Sippel et al. 2012). However, no tagging data have demonstrated movement across the equator (Stevens et al. 2010, Sippel et al. 2012). Consensus within the ISC Shark Working Group supports a single stock within the North Pacific, distinct from the South Pacific, although more information is needed to further explore the potential for size and sex segregation in the North Pacific as proposed by Nakano (1994).

In addition to assumptions regarding stock structure the other critical information on the biology of blue shark necessary for the SS assessment relate to sex-specific growth, natural mortality, maturity and fecundity.

3.1 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.

Sex-specific estimates of growth from Nakano (1994) were assumed in the assessment (Figure 3) – no attempt was made to estimate growth due to the uninformative nature of the size data in this regard (e.g. it was not possible to clearly track cohorts through time).

We did consider the growth curves from Hsu et al. (2011) 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 considered 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.

3.2 Natural mortality

Two sets of age-specific natural mortality ogives were considered in the assessment (Table 1). These were taken from Takeuchi et al. (2005). We note that these represent estimates from the Atlantic Ocean, but this was a particularly useful study that provided age-specific estimates of natural mortality. We believe that the difference between the two estimates helpfully covers the potentially uncertainty in natural mortality. For the reference case we used the estimates based on the Peterson and Wroblewski (1984) method, with a sensitivity using the higher Chen and Watanabe (1989) method-based estimates from the same paper.

3.3 Maturity and fecundity

For a shark stock assessment it is critically important that you are measuring the correct units of spawning potential. For this assessment considered a single maturity ogive and did not consider age/length specific changes in fecundity in the final set of model runs[3]. In Section 5.1 below we describe a large range of potential relationships between pre-recruit survival and spawning potential (essentially the spawner recruitment relationship) that were examined in the assessment.

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.

4 Data compilation

Fisheries data used in the blue shark assessment consist of catch, effort and length-frequency data for the fisheries defined below. These data were amassed by the ISC shark working group. Agreed data inputs were determined and these are fully described in Takahashi et al. (2013) and are briefly summarised below.

4.1 Spatial and temporal stratification

As noted above, the assessment was based on a single North Pacific stock, bounded by the equator in the south, Asia in the west, and North and Central America in the east (Figure 1).

4.2 Temporal stratification

An annual (Jan 1-Dec 31) time-series of fishery data for 1976-2011 was used for the assessment.

[3] While it was examined in earlier model iterations the relationship described by Nakano (1994) was not statistically significant.

4.3 Definition of fisheries

The ISC Shark Working Group estimated catches of many fisheries from different nations and member sources in an effort to understand the nature of fishing mortality. While the BSP assessment only considered a single catch series, the SS model used the 18 fisheries defined in Table 2. This table also summarizes some of the key modelling assumptions relating to the fisheries.

The primary sources of catch were from longline and drift gillnet fisheries, with smaller catches also estimated from purse seines, trap, troll, and recreational fisheries. As in the previous assessment, highest catches came from Japan and Taiwan, with newly available Mexican fishery data providing a relatively smaller, but important source of catch. Temporal coverage of the data series used in the reference case model are provided in Figure 2.

4.4 Catch data

Fishery data from ISC member nations and observers were compiled, shared, and reviewed through a series of working papers which were presented and discussed at intercessional meetings of the ISC Shark Working Group held in the USA and Japan. Catches were extracted from databases of landings, vessel logbooks, and observer records. When reliable catch data were unavailable, catches were estimated using independently derived standardized catch per effort information, often applying assumptions on the species compositions of the catches, to transform effort data into catches. It was agreed to conduct the assessment on biomass, so catches were compiled in metric tons if available, or in numbers of sharks which were converted to tons with knowledge of the size of sharks caught and an agreed upon length-weight conversion equation. In addition to the catch sources included in the Kleiber et al. (2009) assessment, new sources of catch were available for this assessment including from fisheries operating along the west coast of North America (mainland USA, and Canada, Mexico and other catches north of the equator from IATTC member nations) as well as from China.

Only a single series of catch estimates have been used in the current assessment and these are provided in Figure 5. This series included the working groups best estimates for discard mortality.

4.5 Abundance indices

CPUE series are critical to every assessment and seven candidate standardized abundance indices were developed from catch and effort data of Japanese, Taiwanese, and US longline fisheries. It is well known that bias and uncertainty in the assessment results can likely occur if multiple indices with confounding trends are used in the same assessment. A suite of criteria were therefore used by the WG to select indices for the base case and sensitivity runs from the candidate indices. Key criteria include data quality, spatio-temporal coverage of data, potential changes in catchability due to changes in regulations and/or fishing operations, and the adequacy of diagnostics from model-based standardizations.

For the reference case model we used two CPUE series based on Japanese catch and effort data (Hiraoka et al. 2013). These were the early (1976-1993) and late (1994-2010) series. For sensitivity analysis the Hawaii deep set (1995-2011) longline index developed from the catch-and-effort data gathered by onboard observers on longline vessels based in Hawaii was used (Walsh and Teo 2012).

In addition this assessment considered an additional CPUE series based on Japanese Research and Training Vessel data (RTV) (Clarke et al. 2011; 2013). This series was not reviewed through the WG process described above and therefore there was no agreement for its inclusion. No results using this CPUE series are included in this paper, but are available from the lead author.

For the fitting of each CPUE series we assumed a constant CV across all years of 0.3.

4.6 Catch at length data

Some size and sex composition data of catches 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 data and the size data (see results below) we chose to give low weight to the size data in the model – to allow use to estimate selectivity, but not the overwhelm the model. We assumed a sample size of 10 for each record and applied a lambda of 0.2 for the reference case and 0.5 as a sensitivity analysis.

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

5 Population and fishery dynamics

The model partitions the population into 30 yearly age-classes in one region, defined as the NPO (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 1976-2011. The main population dynamics processes are as follows:

5.1 Recruitment and the Low Fecundity Spawner Recruitment relationship (LFSR)

"Recruitment" in terms of the SS model 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. A survival based spawner-recruitment function was used (Taylor et al. 2013) which we refer to as the Low Fecundity Spawner Recruitment relationship (LFSR).

Recruitment (R_y) in each year is then defined as

$$R_y = S_y B_y$$

Where B_y is the spawning output in year *y* and $S_y$is the pre –recruit survival given by the equation

$$S_y = exp\left(-z_0 + (z_0 - z_{min})\left(1 - \left(\frac{B_y}{B_0}\right)^{\beta}\right)\right)$$

Where:

$z_0 = -log\left(\frac{R_0}{B_0}\right)$, where *R*0 is the recruitment at equilibrium, resulting from the exponential of the estimated log(*R*0) parameter, and *B*0 is the equilibrium spawning output.

$z_{min} = z_0\,(1 - s_{Frac})$ is the limit of the pre-recruit mortality as depletion approaches 0, parameterized as a function of s_{Frac} (which represents the reduction in mortality as a fraction of *z*0) so the expression is well defined over a parameter range; and, Beta is a parameter controlling the shape of density-dependent relationship between spawning depletion and pre-recruit survival.

We did not attempt to estimate beta or s_{Frac} in this assessment – it is a task harder than estimating steepness as an extra parameter is involved. Based on discussions with the proponents of the LFSR relationship we selected values of 0.05, 0.13, 0.2, and 0.35 for s_{Frac} and 1, 2, 3, and 4 for beta. Examples of the behaviour of some of the resulting curves are provided in Figure 4.

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 (1985-1990) and one being the main recruitment deviates that covered the model period (1990 - 2011).

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.

5.2 Initial population state

It is not assumed that the blue shark population is at an unfished state of equilibrium at the start of the model (1976). The population age structure and overall size in the first year is determined as a function of the first years recruitment (R1) offset from virgin recruitment (R0), the initial 'equilibrium' fishing mortality, and the recruitment deviations prior to the start of the year. In this model the R1 offset, initial fishing mortality and the recruitment deviations are all estimated to correspond with the observed length compositions, selectivities and catch data.

5.3 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 and an offset on the peak and scale was estimated for sex-specific differences in selectivity that were evident in the data. Due to data deficiencies the only the selectivity curves for fleets 1,3,4,5,8, 14, and 16 were estimated. The rest were mirrored as shown in Table 2.

5.4 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 BSH.ctl documenting the phased procedure, initial starting values and model assumptions is available on the meeting FTP site and from the lead author.

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.

5.5 Assessment Strategy

As noted in Section 2, our strategy was to determine some main axes of uncertainty and these have been described in the preceding sections. A summary table of the model options considered in provided in Table 3. In total 192 model runs were undertaken in the full grid of which 131 models both converged and resulted in an extant population in 2011. 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 group to decide on the model(s) that it wishes to use for the provision of management advice.

From this set of 131 runs we selected our reference case model. The approach we used here was to go with the WG recommendation on the CPUE series, the lower natural mortality (arbitrary), the best practice approach for weighting size frequency data (down-weight to ensure that the data don't overwhelm the abundance indices) and then picked the combined of parameters of the LFSR that gave the best overall model fit. The one-change model runs from the reference case are presented as sensitivity analyses.

6 Results

In this section we will primarily focus on the basis for selection of the reference case model and the key results and diagnostics for this model. We will then comment on any important differences in both outputs and model diagnostics for the one-change sensitivity analyses. We will not comment on the full model grid in this report.

6.1 Reference case model

The basis for choosing the reference case model was provided in Section 5.5. It is important to reiterate that by using the grid approach all model runs are available for the WG to chose which model run(s) it wishes to chose to develop management advice.

The reference case model was the one with Sfrac of 0.35 and beta of 2 (Table 4). The next three best fits had the following combinations of Sfrac and beta: (0.35:3, 0.35:4, 0.35:1) suggesting that higher levels of Sfrac were most consistent with the CPUE and catch series.

Estimated parameters and model performance

We found strong differences in the sex-specific selectivity curves for many of the fisheries which reinforces the observations of biologists for areas of sex-segregation during the life history of blue sharks (Figure 6). With the exception of the Japanese large-mesh gillnet fishery and the Chinese longline fleet, all fisheries estimated a lower peak selectivity (therefore catchability) for females.

The fit to the CPUE indices was generally good for the reference case model (Figure 7). While it did not predict the same rate of increase as the early CPUE series, it is clearly difficult to fit this increase and still fit the late CPUE series.

For the fisheries for which we estimated selectivity curves, the overall fit to the length data was generally good, but for those fisheries where selectivity was mirrored (e.g. fishery 18; Figure 8 and 9) the fit was poor. When attempting to estimate selectivity curves for all fisheries we often encountered convergence issues. It is important to note that the individual length samples were often more 'messy' than the overall length sample suggests. However, with a better refined reference case model we believe that some of these problems could be overcome in future assessments.

Overall, there were not too many parameters to estimate in this model, nor data to fit to, and the reference case model appears to do a good job.

Estimated stock status and other quantities

The reference case model estimates that the spawning potential of the stock was at 29% of the unfished level at the start of the model period (Table 5 and Figure 10) then increased briefly before declining again to a low point of around 25% in 1993-94. Since that time the spawning potential has increased constantly to 42.5% of the unfished level. Recruitment generally follows the same trend (Figure 11) and is quite tightly constrained by the estimated LFSR relationship (Figure 12; but see Figure 4 to see the full curve).

SS provides estimates of the MSY-related quantities and these and other quantities of interest for management are provided in Table 5. We note that WCPFC has not yet adopted target or limit reference points for any shark species.

In the reference case the estimated MSY is 50,330 mt and this is predicted to occur at 46.9% of the unfished biomass, which is similar to the standard Schaefer production model (0.5). Current catches are less than the MSY.

While the stock is rebuilding and F is declining, F in the final year is 76% of FMSY, the stock is estimated to be 84.6% of the unfished level and 90% of BMSY . By the standard terminology, this would indicate that the stock is in an overfished state, but that overfishing is not occurring.

It would be in the lower left-hand corner quadrant of the Kobe plot (Figure 15) and given the LFSR relationship, under current fishing conditions, the stock will continue to rebuild towards (and likely above) the BMSY level. However there is considerable uncertainty around the estimates of current depletion and fishing mortality from the model. The 95% confidence limits for spawning depletion in the final year are 17.5%-152% of BMSY and fishing mortality at 20%-136% of FMSY. So the region of uncertainty around the point estimates covers all quadrants of the Kobe plot.

6.2 One-change sensitivity analyses

The sensitivity analyses with the greatest impact were those with alternative CPUE series. The one off change to swap the JP late series with the RTV series did not converge in fact many of the runs with this CPUE series 'crashed' due to running out of 'fish' reflecting an inconsistency between the RTV CPUE series and other data and model assumptions. We will not discuss runs with this series any further.

The run with the Hawaiian deepset series gave a very different set of model outcomes, and a fuller set of model outputs is provided for this run as Annex 1 of this paper. The model estimates that the stock was initially less depleted than the reference case (only down to 40% of unfished), but has continued to decline throughout the past 30 years to around 16% of the unfished level. Catches are less than MSY (MSY=42,574 mt), but not sustainable for the current stock size as F is around three times the FMSY level. This model actually fits the early Japan series better than the reference case and the best of any of the other model runs, but it does not fit the size composition data as well as the reference case.

A summary of the general outcomes from the other sensitivity analyses are as follows (see Table 4 and Table 5):

- <u>Higher weight to the size composition data</u>: this results in a worse fit to the CPUE series overall, mostly due to a much poorer fit to the Japan early series. It did make the assessment more optimistic in terms of higher B/BMSY and lower F/FMSY but the stock was still estimated to be in an overfished state (but recovering). Continuing to increase the weight to these data will give further improved stock status, but as this is at the cost of fitting the CPUE series, this does not seem like good practice given what we know about the size data (i.e., that they are not expected to be particularly informative on trends in abundance).
- <u>Higher natural mortality at age</u>: this had similar impacts to the higher sample size in terms of optimism, but fit both CPUE series noticeably worse at the expense of a better fit to the size data. While the decision to use the lower mortality rates for the reference case was relatively arbitrary, they do fit the CPUE series much better and provide a better overall model fit.
- <u>Alternative formulations of the LFSR relationship</u>: The response to these changes is quite complex:
    - For low Sfrac, MSY and FMSY (and overall stock condition) increased dramatically with increases of beta from 1 to 3, but the fit to the Japan late series was extremely poor (e.g. it did not predict the strong increase).

- Under high Sfrac the model results were relatively consistent across the range of values of beta.

7 Conclusions

The key conclusions of the SS stock assessment for blue sharks in the NPO are as follows:

1. For the reference case model current catches are two thirds of the MSY level (MSY=50,330 t), current biomass is 84.6% of BMSY and 90% in the last year of the model, and fishing mortality is 77.6% of FMSY level. The stock could be said to be in an overfished state, but the stock is rebuilding under current catches as fishing mortality is declining. However there is considerable uncertainty around the estimates of current depletion and fishing mortality from the model. The 95% confidence limits for spawning depletion in the final year are 17.5%-152% of BMSY and fishing mortality at 20%-136% of FMSY.
2. We found many significant sex-specific differences in selectivity and catchability which emphasises the importance of including these processes in the assessment.
3. Looking at the key sources of uncertainty, one off changes from the reference case lead to the following conclusions:
    a. The alternative late CPUE series had the greatest influence on the assessment conclusions. Under the Hawaiian deep set series the biomass was continually declining over the modelling period, MSY was lower, depletion was much greater with the stock 60% below the BMSY level and fishing mortality was well above FMSY. Under the Japan RTV series the model often failed to converge – mostly due to the crashing of the population. Model runs that did converge suggested even worse condition than the Hawaiian deep set series.
    b. The up weighting of the length frequency data did make the assessment more optimistic in terms of higher B/BMSY and lower F/FMSY but the stock was still estimated to be in an overfished state (but recovering). Continuing to increase the weight to these data will give further improved stock status, but as this is at the cost of fitting the CPUE series, this does not seem like good practice given what we know about the size data (i.e., that they are not expected to be particularly informative on trends in abundance).
    c. The higher natural mortality had similar impacts to the higher sample size in terms of optimism, but fit both CPUE series noticeably worse at the expense of a better fit to the size data. While the decision to use the lower mortality rates for the reference case was relatively arbitrary, they do fit the CPUE series much better and provide a better overall model fit.
    d. The response to changes is the LFSR was quite complex:
        i. For low Sfrac, MSY and FMSY (and overall stock condition) increased dramatically with increases of beta from 1 to 3, but the fit to the Japan late series was extremely poor (e.g. it did not predict the strong increase).
        ii. Under high Sfrac the model results were relatively consistent across the range of values of beta.
4. There are some concerns over all three late CPUE series used in this assessment in terms of whether the trend accurately changes in relative abundance over the extent of the stock. Given this and the extent of uncertainty even within the reference case model, it is our conclusion that the possibility that the abundance is not increasing or possibly declining in recent years should be a factor in any management advice from the assessment.
5. We suggest that depending on the nature of management action an updated assessment should be conducted in the next 2-3 years. This assessment should consider:

- Alternative approaches to account for targeting in the Japanese fleet.
- Examination of the potential to include some fisheries with asymptotic selectivity curves – this will likely involve examination of asymptotic length from the growth curve.
- Determine if there are plausible alternative catch series – in particular ones with different trends through time. This should include detailed analysis of observer reports to estimate discards.
- Continued development of alternative CPUE series
- Detailed consideration of how the biology of blue sharks can be modelled within the SS framework (including the LFSR).

8 Acknowledgements

We thank the other members of the ISC Shark Working Group for the useful discussions around the use of Stock Synthesis in the overall ISC assessment of blue shark in the North Pacific Ocean and the provision of the various data sets that have been used in this assessment. We particularly want to acknowledge Mark Maunder and Alex da Silva (IATTC), and Kevin Piner (SWFSC NOAA) for the considerable time spent examining models and model assumptions. This assessment would not have been completed without their help. We also thank Ian Taylor (NWFSC NOAA) and Simon Hoyle (SPC) for their useful insights.

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Table 1: Estimates of age-specific natural mortality used in the assessment. The reference case used those based on the approach of Petersen and Wroblewski (taken from Takeuchi et al. (2005)).

Age	Chen and Watanabe	Petersen and Wroblewski
0	0.788	0.476
1	0.502	0.335
2	0.385	0.272
3	0.321	0.236
4	0.282	0.213
5	0.256	0.197
6	0.237	0.186
7	0.223	0.177
8	0.213	0.171
9	0.205	0.166
10	0.199	0.162
11	0.195	0.158
12	0.192	0.156
13	0.191	0.154
14	0.191	0.152
15	0.192	0.151
16	0.195	0.149

Table 2: Summary of the 18 fisheries defined for the SS assessment. Note that the Japanese early and late CPUE series were based on F4 and F5 respectively and the Hawaiian deepset and RTV CPUE series were based on F16.

			Length Composition Weighting	
Fleet Number and Short Name	Gear (s)	Selectivity	Lo	High
F1 MEX	Longline & Gillnet	Estimated	0.2	0.5
F2 CAN	Longline and Trawl	Mirrored F1	0.2	0.5
F3 CHINA	Longline	Estimated	0.2	0.5
F4 JPN_KK_SH	Longline - Shallow	Estimated	0.2	0.5
F5 JPN_KK_DP	Longline - Deep	Estimated	0.2	0.5
F6 JPN_ENY_SHL	Longline - Shallow	Mirrored F4	0.2	0.5
F7 PN_ENY_DP	Longline - Deep	Mirrored F5	0.2	0.5
F8 JPN_LG_MESH	Gillnet	Estimated	0.2	0.5
F9 JPN_CST_Oth	Trap, Bait, Gillnet	Mirrored F4	0.2	0.5
F10 JPN_SM_MESH	Gillnet	Mirrored F4	0.2	0.5
F11 IATTC	Purse Seine	MIrrored F1	0.2	0.5
F12 KOREA	Longline	Mirrored F3	0.2	0.5
F13 NON_ISC	Longline	Mirrored F4	0.2	0.5
F14 USA_GIILL	Gillnet	Estimated	0.2	0.5
F15 USA_SPORT	Sport Fishing	Mirrored F14	0.2	0.5
F16 USA_Longline	Longline -- combined	Estimated	0.2	0.5
F17 TAIW_LG	Longline	Mirrored F3	0.2	0.5
F18 TAIW_SM	Longline	Mirrored M14	0.2	0.5

Table 3: The five axes of uncertainty considered in the full structural uncertainty grid.

Axis of uncertainty	Reference case assumption	Alternative assumptions
CPUE series	Japanese early and late CPUE series	Japanese early and HW deep set Japanese early and Japan RTV
Age-specific natural mortality approach	Chen and Watanabe (low)	Peterson and Wroblewski (hi)
Sample size for length frequency data	Scalar of 0.2	Scalar of 0.5 (upweight)
Sfrac of the LFSR	0.35	0.05, 0.13, 0.2
Beta of the LFSRR	2	1,3,4

Table 4: Key likelihood components / penalties from the reference case model and all one-change sensitivity analyses. Note: CPUE 1 is the run with the Japanese early and Hawaiian deepset series and CPUE 3 is the run with the Japanese early and RTV series (this did not converge).Note that the overall objective function for the CPUE and sample size weighting runs (shaded) are not comparable to the other runs.

	Reference	CPUE 1	CPUE 3	SampSize 0.5	M at Age HI	Sfrac 0.05 &Beta 1	Sfrac 0.05 &Beta 2	Sfrac 0.05 &Beta 3	Sfrac 0.05 &Beta4	Sfrac 0.13 &Beta 1
Catch	2.16E-10	1.68E-09	NA	1.68E-10	1.02E-12	4.40E-15	4.56E-15	2.87E-15	NA	2.92E-14
Survey_HW_DP	0	3.511	NA	0	0	0	0	0	NA	0
Survey JPN Early	2.072	1.742	NA	2.262	2.423	2.473	2.528	2.926	NA	2.415
Survey JPN Late	1.141	0	NA	1.102	1.437	2.394	2.318	2.125	NA	2.083
Survey JPN RTV	0	0	NA	0	0	0	0	0	NA	0
Length_comp	64.475	65.815	NA	155.764	63.861	75.552	72.384	69.850	NA	74.637
Recruitment	-7.654	-7.927	NA	-7.354	-7.345	-6.621	-6.807	-7.075	NA	-6.760
Parm_priors	0.005	0.004	NA	0.005	0.023	0.026	0.025	0.030	NA	0.018
TOTAL	17.908	21.013	NA	109.648	18.267	31.690	28.314	25.723	NA	30.260

	Sfrac 0.13 &Beta 2	Sfrac 0.13 &Beta 3	Sfrac 0.13 &Beta4	Sfrac 0.2 &Beta 1	Sfrac 0.2 &Beta 2	Sfrac 0.2 &Beta 3	Sfrac 0.2 &Beta4	Sfrac 0.35 &Beta 1	Sfrac 0.35 &Beta 3	Sfrac 0.35 &Beta4
Catch	3.36E-14	6.06E-14	7.63E-14	8.15E-14	9.45E-13	1.91E-12	2.46E-12	2.33E-11	4.10E-10	4.86E-10
Survey_HW_DP	0	0	0	0	0	0	0	0	0	0
Survey JPN Early	2.754	2.763	2.792	2.646	2.560	2.552	2.553	2.260	2.032	2.020
Survey JPN Late	1.785	1.720	1.682	1.713	1.490	1.430	1.411	1.238	1.188	1.221
Survey JPN RTV	0	0	0	0	0	0	0	0	0	0
Length_comp	64.418	64.418	68.774	64.412	64.418	64.427	64.432	64.421	64.538	64.571
Recruitment	-7.177	-7.204	-7.221	-7.202	-7.316	-7.369	-7.391	-7.482	-7.705	-7.718
Parm_priors	0.019	0.017	0.016	0.018	0.013	0.011	0.010	0.010	0.005	0.005
TOTAL	19.669	19.581	23.910	19.456	19.033	18.919	18.883	18.314	17.926	17.966

Table 5: Estimates of key management quantities for the reference case model and all one-change sensitivity analyses. For models with "NA's" – these models did not successfully converge. Latest = 2011 and cur = the mean over the period 2007-10. Note: CPUE 1 is the run with the Japanese early and Hawaiian deepset series and CPUE 3 is the run with the Japanese early and RTV series (this did not converge).

	Units	Reference	CPUE 1	CPUE 3	SampSize 0.5	M at Age HI	Sfrac 0.05 &Beta 1	Sfrac 0.05 &Beta 2	Sfrac 0.05 &Beta 3	Sfrac 0.05 &Beta4	Sfrac 0.13 &Beta 1
C_latest	T	33,744	33,744	NA	33,744	33,744	33,744	33,744	33,744	NA	33,744
C2011_msy		0.670	0.793	NA	0.673	0.674	1.832	0.768	0.505	NA	0.945
Y_MSY	T	50,330	42,574	NA	50,151	50,035	18,415	43,912	66,859	NA	35,722
equil_pt		0.469	0.469	NA	0.469	0.490	0.496	0.514	0.529	NA	0.488
Recr_Virgi	T	22983	18972	NA	23066	69890	77567	74130	93913	NA	54908
B_zero	T	2,791,650	2,304,460	NA	2,801,770	3,016,320	9,421,780	9,004,300	11,407,200	NA	6,669,390
B_msy	T	1,310,478	1,081,607	NA	1,314,623	1,476,933	4,668,657	4,631,547	6,035,983	NA	3,256,669
B_cur	T	1,108,347	427,490	NA	1,242,140	1,294,646	4,154,800	4,120,460	6,118,423	NA	2,410,571
SB_zero	T	321,845	265,678	NA	323,012	351,267	1,086,220	1,038,090	1,315,120	NA	768,905
SB_msy	T	151,083	124,697	NA	151,561	171,997	538,241	533,963	695,880	NA	375,457
SB_cur	T	127,780	49,285	NA	143,205	150,769	479,002	475,042	705,386	NA	277,912
B_cur_F0	T	2,820,515	2,239,417	NA	2,844,292	3,152,243	10,255,105	9,657,120	11,911,239	NA	7,267,157
SB_cur_F0	T	325,173	258,179	NA	327,914	367,096	1,182,293	1,113,353	1,373,230	NA	837,821
B_cur/B_zero		0.397	0.186	NA	0.443	0.429	0.441	0.458	0.536	NA	0.361
B_cur/B_msy		0.846	0.395	NA	0.945	0.877	0.890	0.890	1.014	NA	0.740
B_cur/B_cur_F0		0.393	0.191	NA	0.437	0.411	0.405	0.427	0.514	NA	0.332
Bratio_1976		0.290	0.403	NA	0.298	0.337	0.443	0.449	0.450	NA	0.328
Bratio_2011		0.425	0.159	NA	0.479	0.447	0.442	0.460	0.541	NA	0.366
Bratio_cur		0.397	0.186	NA	0.443	0.429	0.441	0.458	0.536	NA	0.361
B_msy/ B_zero		0.469	0.469	NA	0.469	0.490	0.496	0.514	0.529	NA	0.488
SB_cur/SB_zero		0.397	0.186	NA	0.443	0.429	0.441	0.458	0.536	NA	0.361
SB_cur/SB_msy		0.846	0.395	NA	0.945	0.877	0.890	0.890	1.014	NA	0.740
SB_cur/SB_cur_F0		0.393	0.191	NA	0.437	0.411	0.405	0.427	0.514	NA	0.332
SB_msy/SB_zero		0.469	0.469	NA	0.469	0.490	0.496	0.514	0.529	NA	0.488
SB_cur_init		1.368	0.460	NA	1.489	1.274	0.995	1.020	1.191	NA	1.101
Fcur		0.229	0.676	NA	0.205	0.160	0.062	0.065	0.059	NA	0.100
F_msy		0.226	0.225	NA	0.226	0.176	0.026	0.069	0.109	NA	0.069
F_2011_msy		0.776	2.889	NA	0.716	0.735	1.712	0.699	0.454	NA	1.038
F_cur_msy		1.012	3.004	NA	0.911	0.913	2.395	0.950	0.540	NA	1.460

	Units	Sfrac 0.13 &Beta 2	Sfrac 0.13 &Beta 3	Sfrac 0.13 &Beta4	Sfrac 0.2 &Beta 1	Sfrac 0.2 &Beta 2	Sfrac 0.2 &Beta 3	Sfrac 0.2 &Beta4	Sfrac 0.35 &Beta 1	Sfrac 0.35 &Beta 3	Sfrac 0.35 &Beta4
C_latest	T	33,744	33,744	33,744	33,744	33,744	33,744	33,744	33,744	33,744	33,744
C2011_msy		0.632	0.595	0.580	0.718	0.643	0.625	0.633	0.605	0.636	0.603
Y_MSY	T	53,420	56,709	58,166	46,967	52,461	54,028	53,313	55,819	53,022	55,963
equil_pt		0.506	0.523	0.537	0.479	0.495	0.514	0.531	0.460	0.494	0.516
Recr_Virgi	T	57378	50471	47136	54213	40807	36188	33086	33343	21377	21141
B_zero	T	6,969,460	6,130,450	5,725,430	6,585,060	4,956,700	4,395,540	4,018,810	4,050,040	2,596,560	2,567,850
B_msy	T	3,525,536	3,206,956	3,073,564	3,151,575	2,453,668	2,261,150	2,133,077	1,861,756	1,283,396	1,325,330
B_cur	T	3,156,968	2,916,499	2,855,389	2,733,630	2,047,441	1,912,066	1,874,004	1,405,749	1,006,040	968,834
SB_zero	T	803,499	706,772	660,077	759,183	571,451	506,756	463,324	466,923	299,354	296,043
SB_msy	T	406,454	369,726	354,347	363,341	282,880	260,685	245,920	214,639	147,961	152,795
SB_cur	T	363,962	336,240	329,194	315,156	236,046	220,440	216,052	162,067	115,985	111,696
B_cur_F0	T	7,304,352	6,438,026	5,997,016	6,878,534	5,183,771	4,561,786	4,116,686	4,201,432	2,541,687	2,430,366
SB_cur_F0	T	842,108	742,232	691,388	793,017	597,630	525,922	474,608	484,377	293,028	280,193
B_cur/B_zero		0.453	0.476	0.499	0.415	0.413	0.435	0.466	0.347	0.387	0.377
B_cur/B_msy		0.895	0.909	0.929	0.867	0.834	0.846	0.879	0.755	0.784	0.731
B_cur/B_cur_F0		0.432	0.453	0.476	0.397	0.395	0.419	0.455	0.335	0.396	0.399
Bratio_1976		0.352	0.368	0.381	0.308	0.307	0.324	0.345	0.241	0.292	0.286
Bratio_2011		0.462	0.487	0.512	0.424	0.427	0.453	0.487	0.364	0.420	0.411
Bratio_cur		0.453	0.476	0.499	0.415	0.413	0.435	0.466	0.347	0.387	0.377
B_msy/ B_zero		0.506	0.523	0.537	0.479	0.495	0.514	0.531	0.460	0.494	0.516
SB_cur/SB_zero		0.453	0.476	0.499	0.415	0.413	0.435	0.466	0.347	0.387	0.377
SB_cur/SB_msy		0.895	0.909	0.929	0.867	0.834	0.846	0.879	0.755	0.784	0.731
SB_cur/SB_cur_F0		0.432	0.453	0.476	0.397	0.395	0.419	0.455	0.335	0.396	0.399
SB_msy/SB_zero		0.506	0.523	0.537	0.479	0.495	0.514	0.531	0.460	0.494	0.516
SB_cur_init		1.287	1.294	1.310	1.346	1.346	1.344	1.351	1.438	1.328	1.320
Fcur		0.105	0.112	0.113	0.119	0.149	0.156	0.157	0.198	0.241	0.246
F_msy		0.131	0.151	0.161	0.124	0.166	0.177	0.180	0.224	0.217	0.208
F_2011_msy		0.663	0.608	0.579	0.790	0.727	0.705	0.696	0.702	0.835	0.881
F_cur_msy		0.803	0.740	0.707	0.959	0.899	0.880	0.873	0.885	1.111	1.182

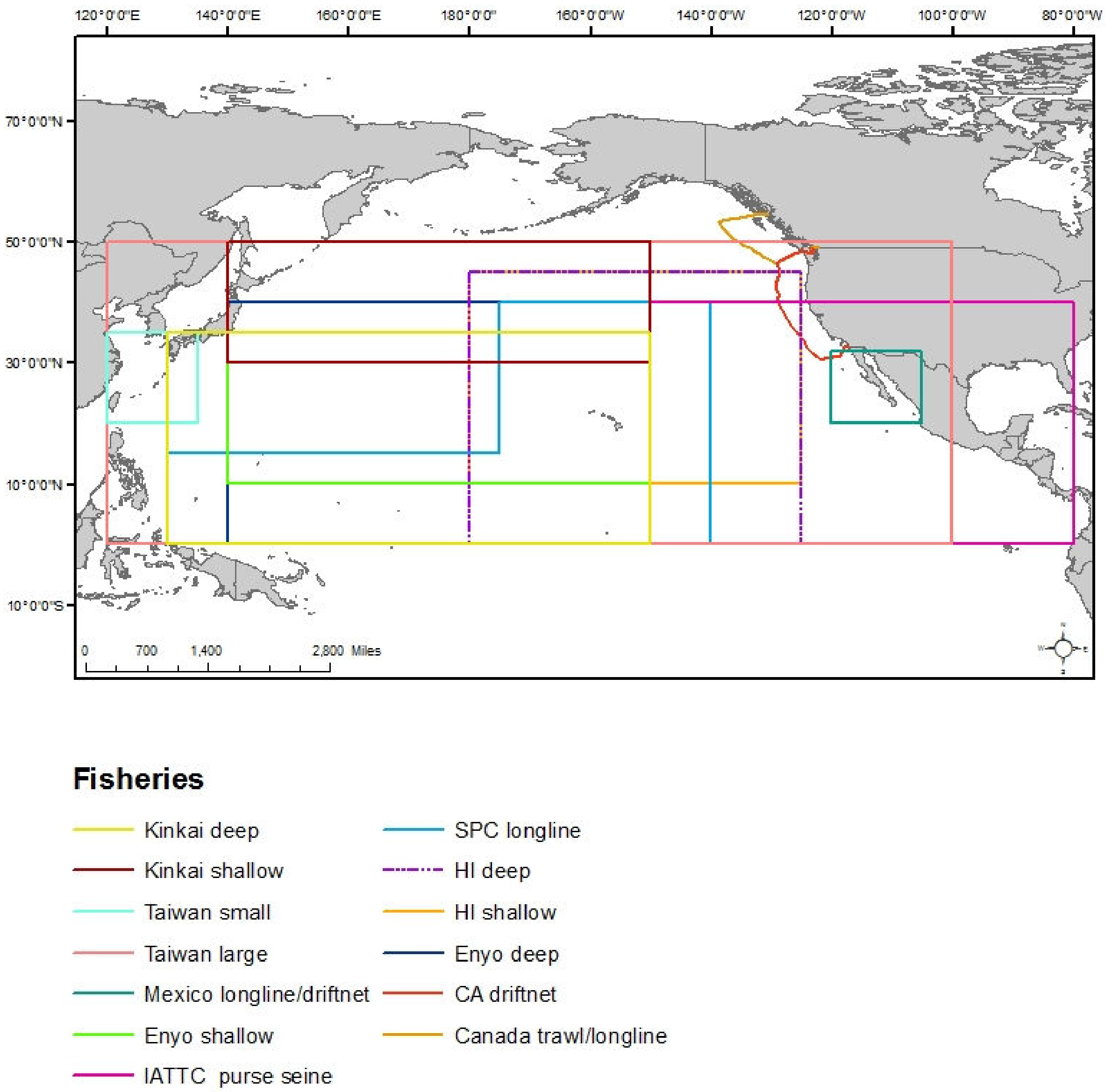


Figure 1: Spatial coverage of the assessment and the individual sources of catch and CPUE data used.

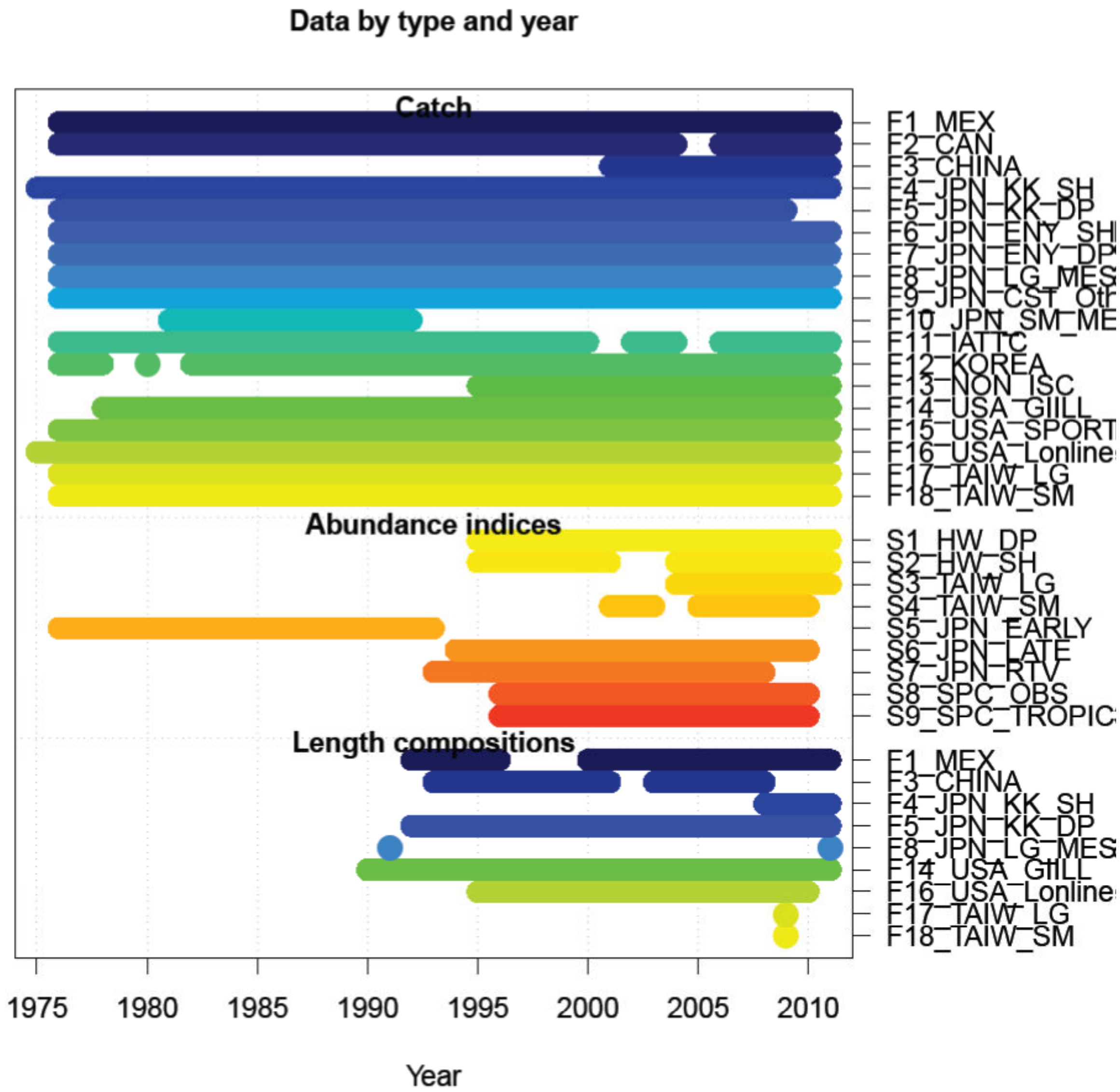


Figure 2: Temporal data coverage for the reference case model.

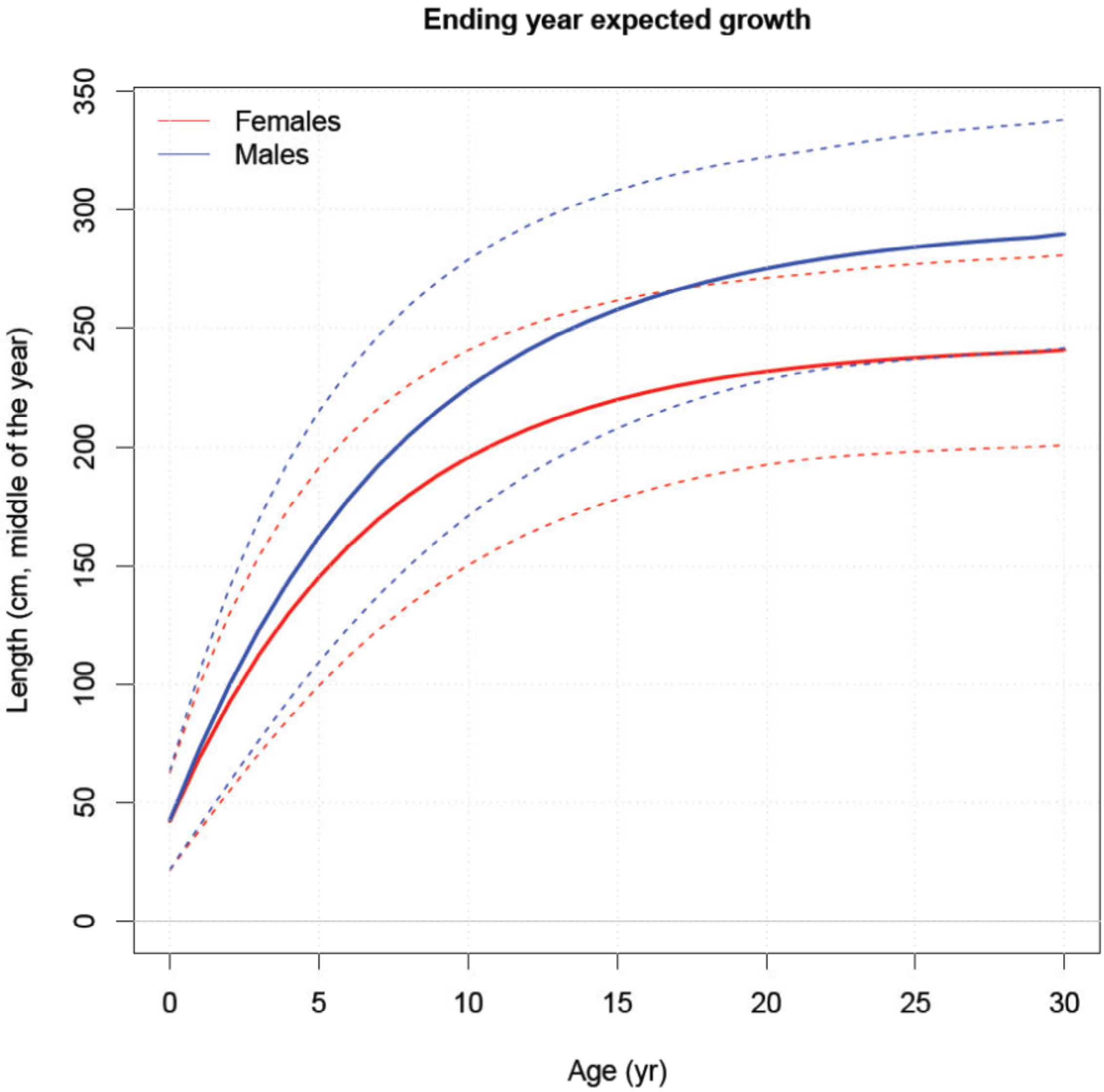


Figure 3: Sex-specific growth curves assumed in the analysis (from Nakano 1994).

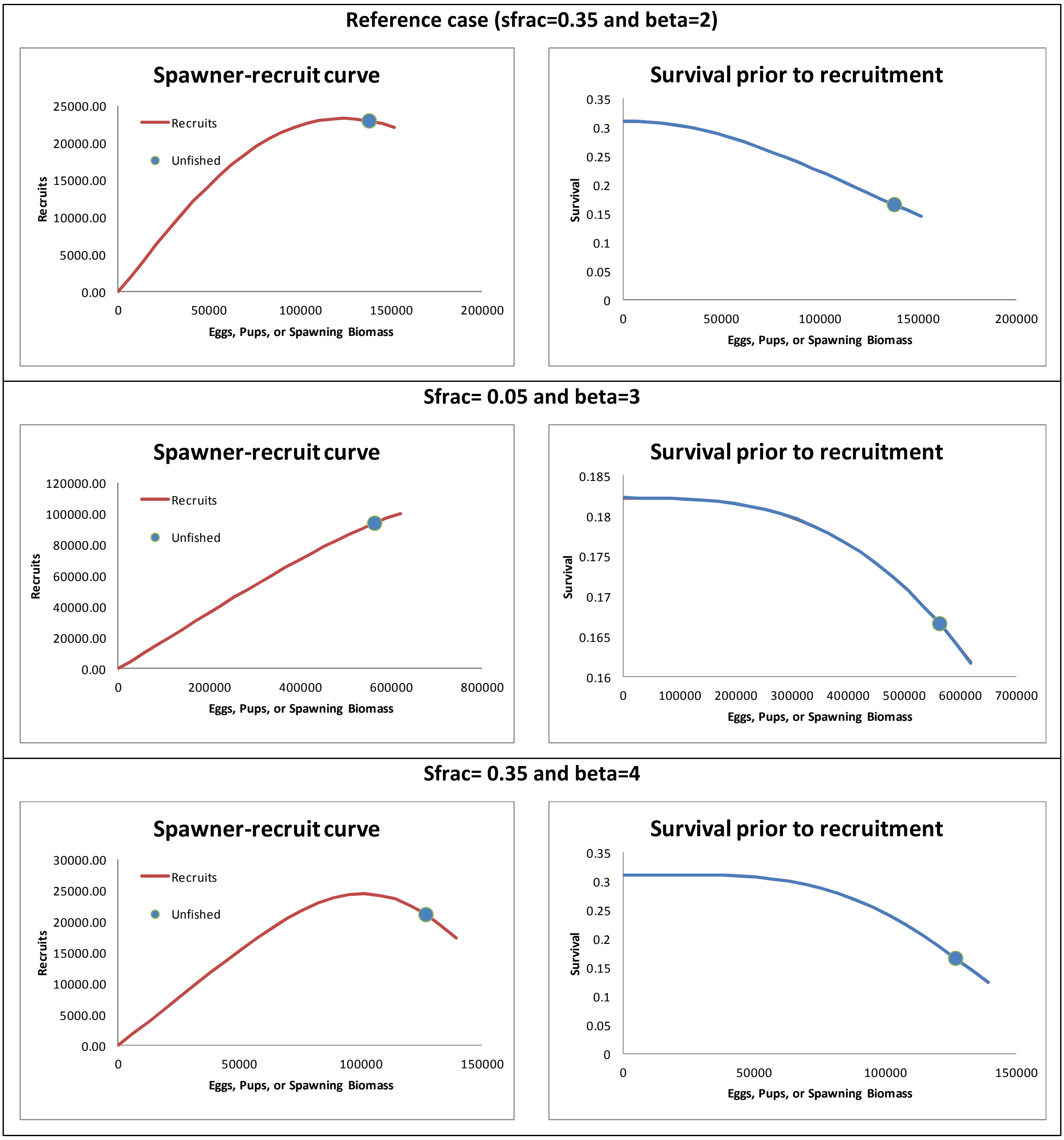


Figure 4: Spawner recruitment curve (left) and pre-recruitment survival (right) for the reference case model (top), and two sensitivity analyses: middle – sfrac=0.05 and beta=3; bottom: sfrac=0.35 and beta=4

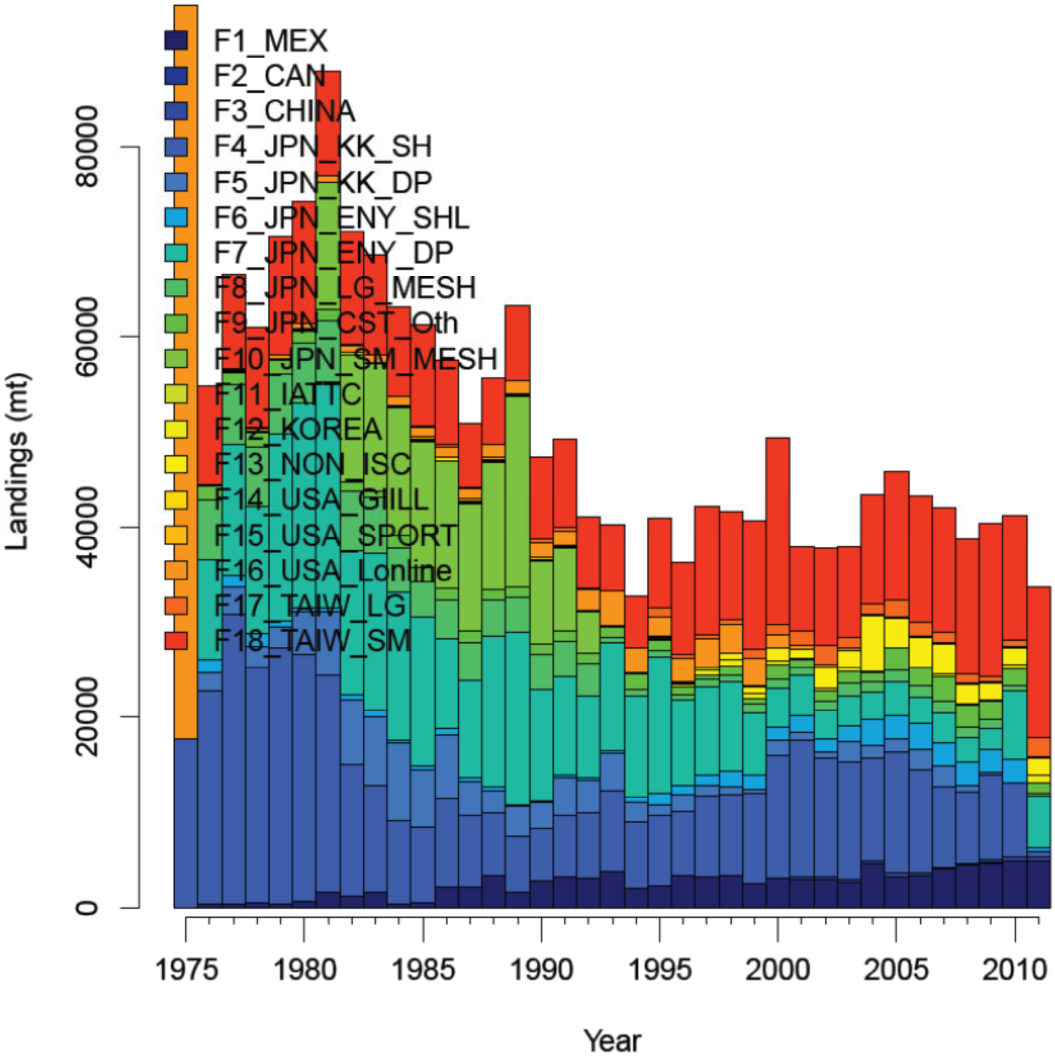


Figure 5: Assumed and estimated (initial) catches from the reference case model.

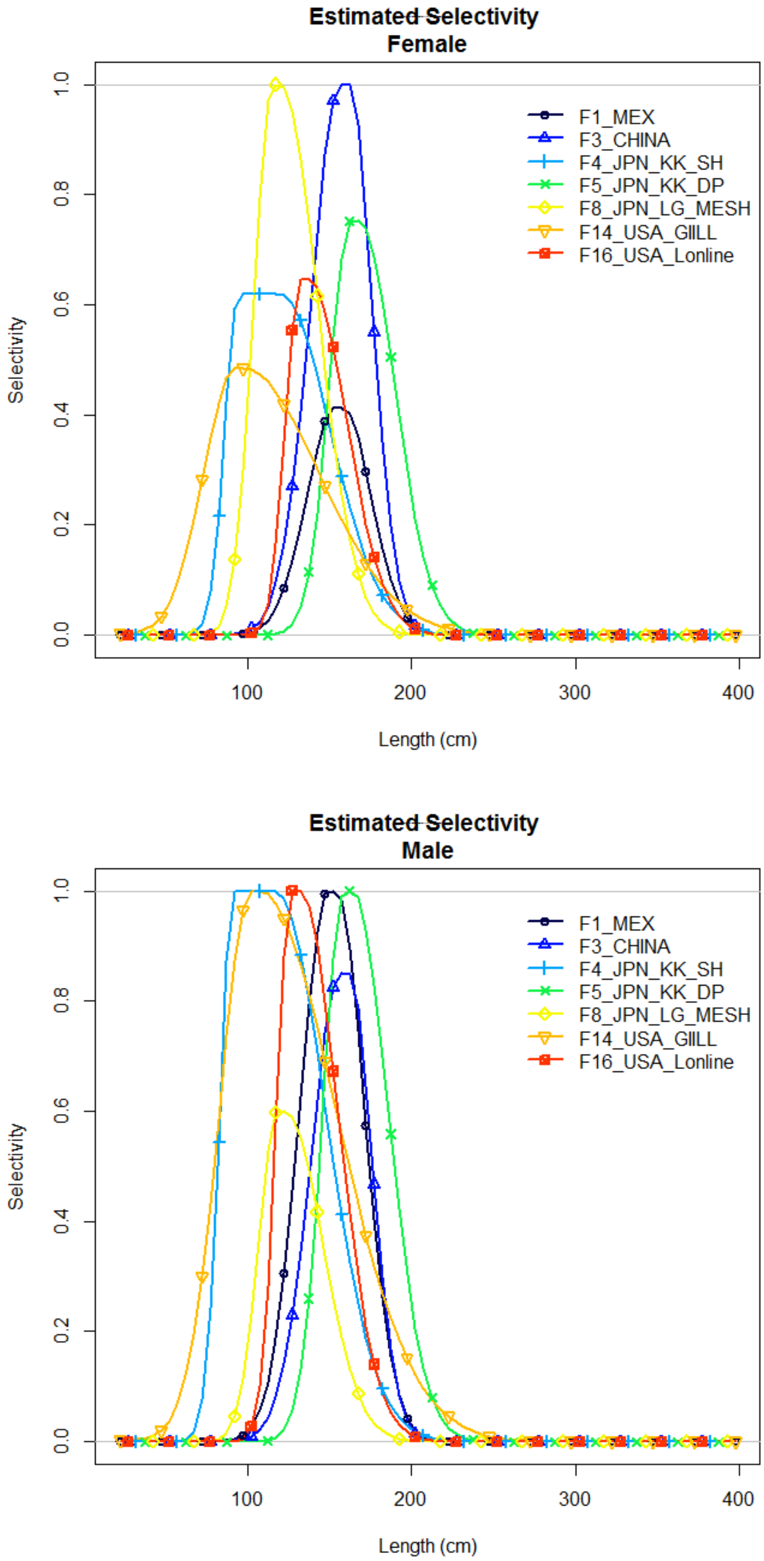


Figure 6: Selectivity curves estimated for female (top) and male (bottom) from the reference case model.

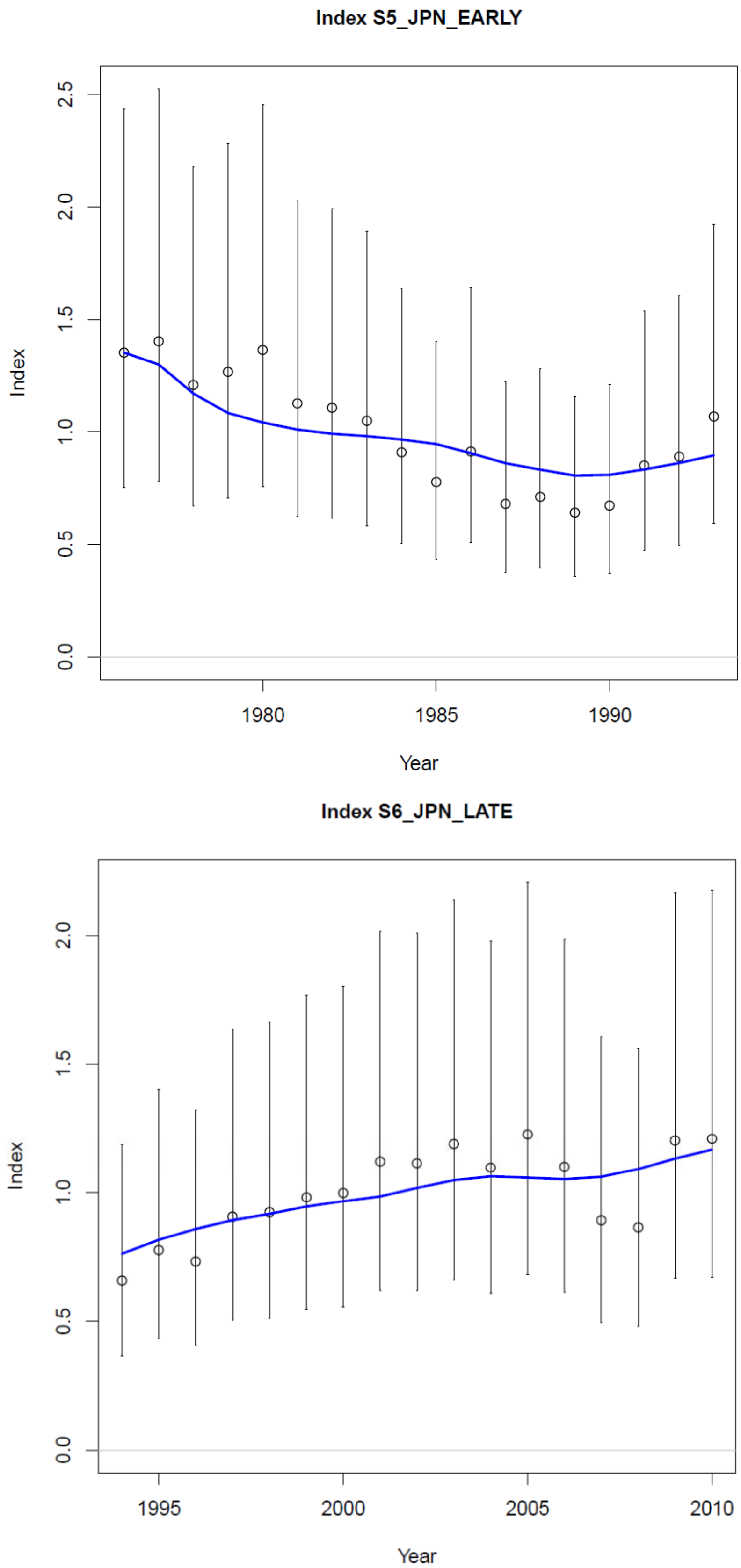


Figure 7: Fit to the Japanese early (top) and late (bottom) CPUE time series for the reference case model.

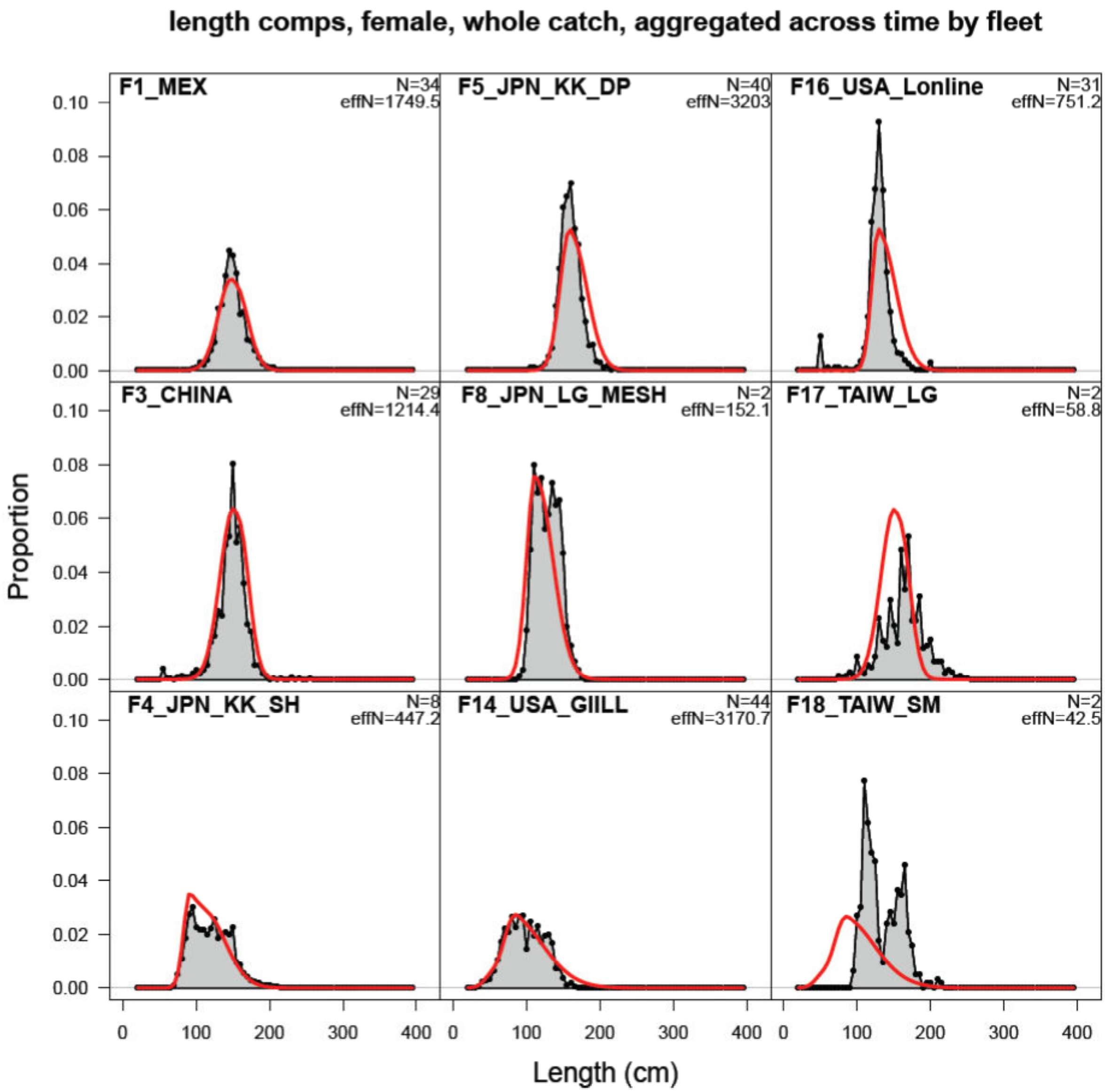


Figure 8: Fit to the female length frequency data for the reference case model.

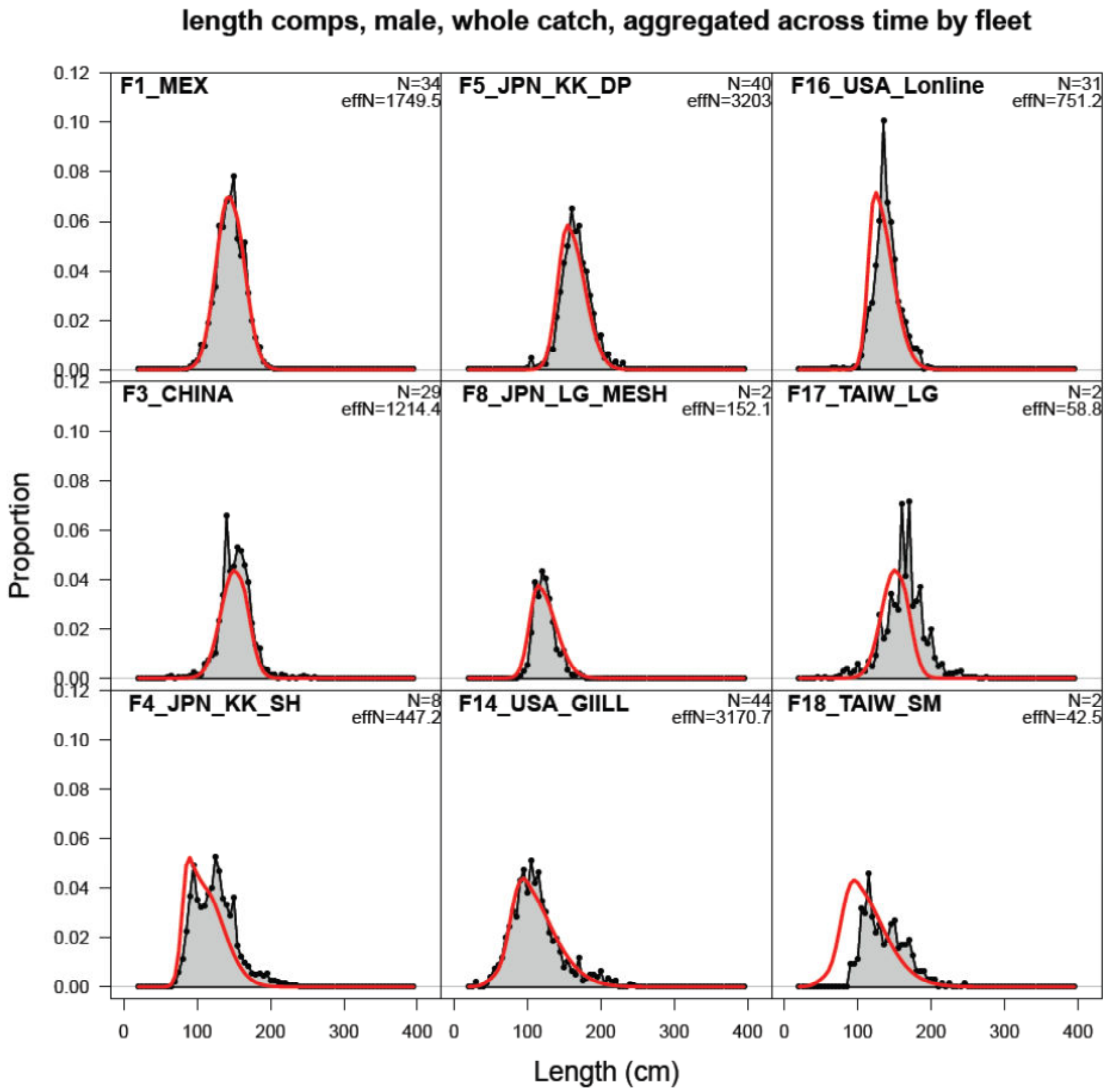


Figure 9: Fit to the male length frequency data for the reference case model.

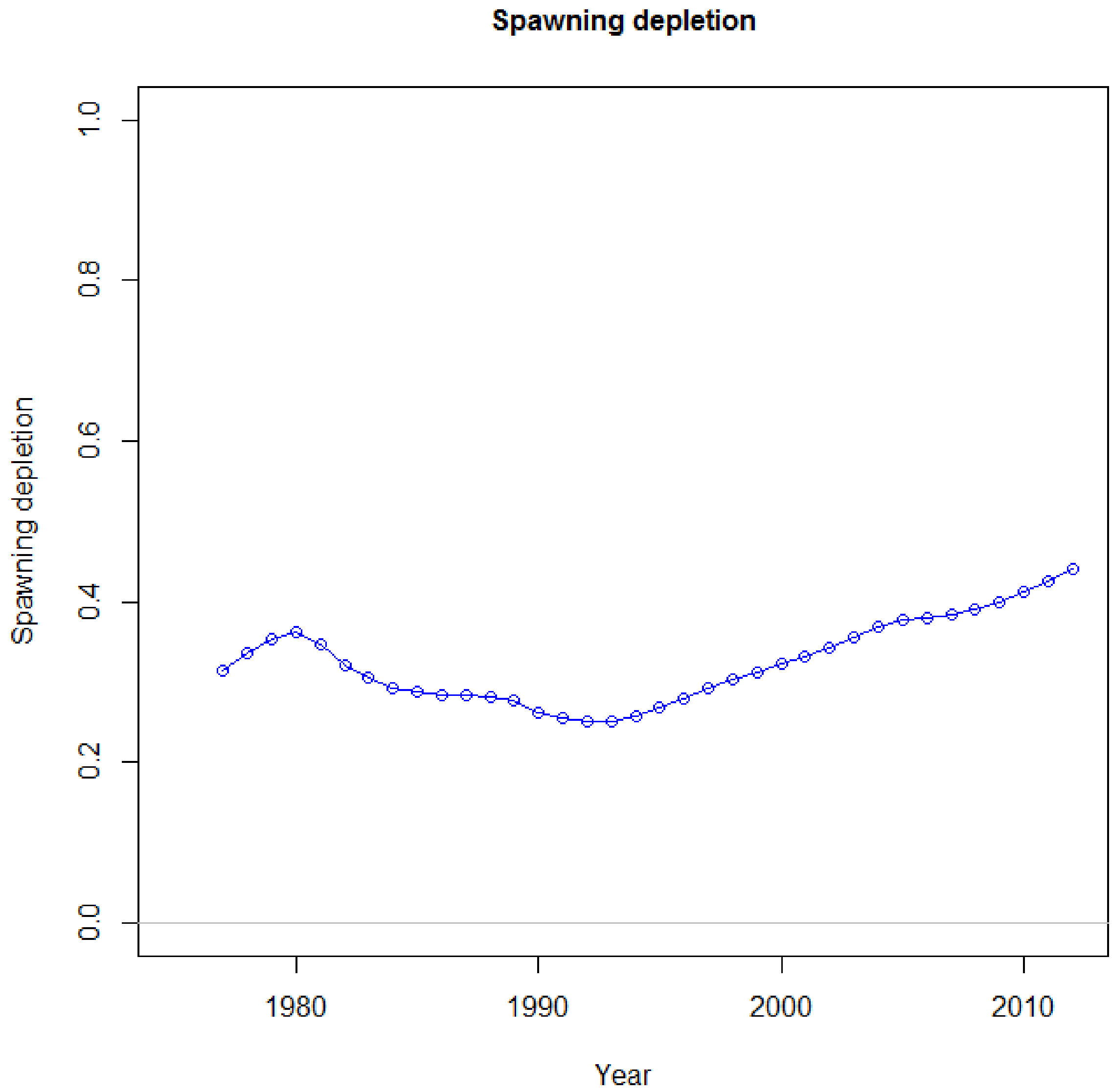


Figure 10: Spawning depletion for the reference case model.

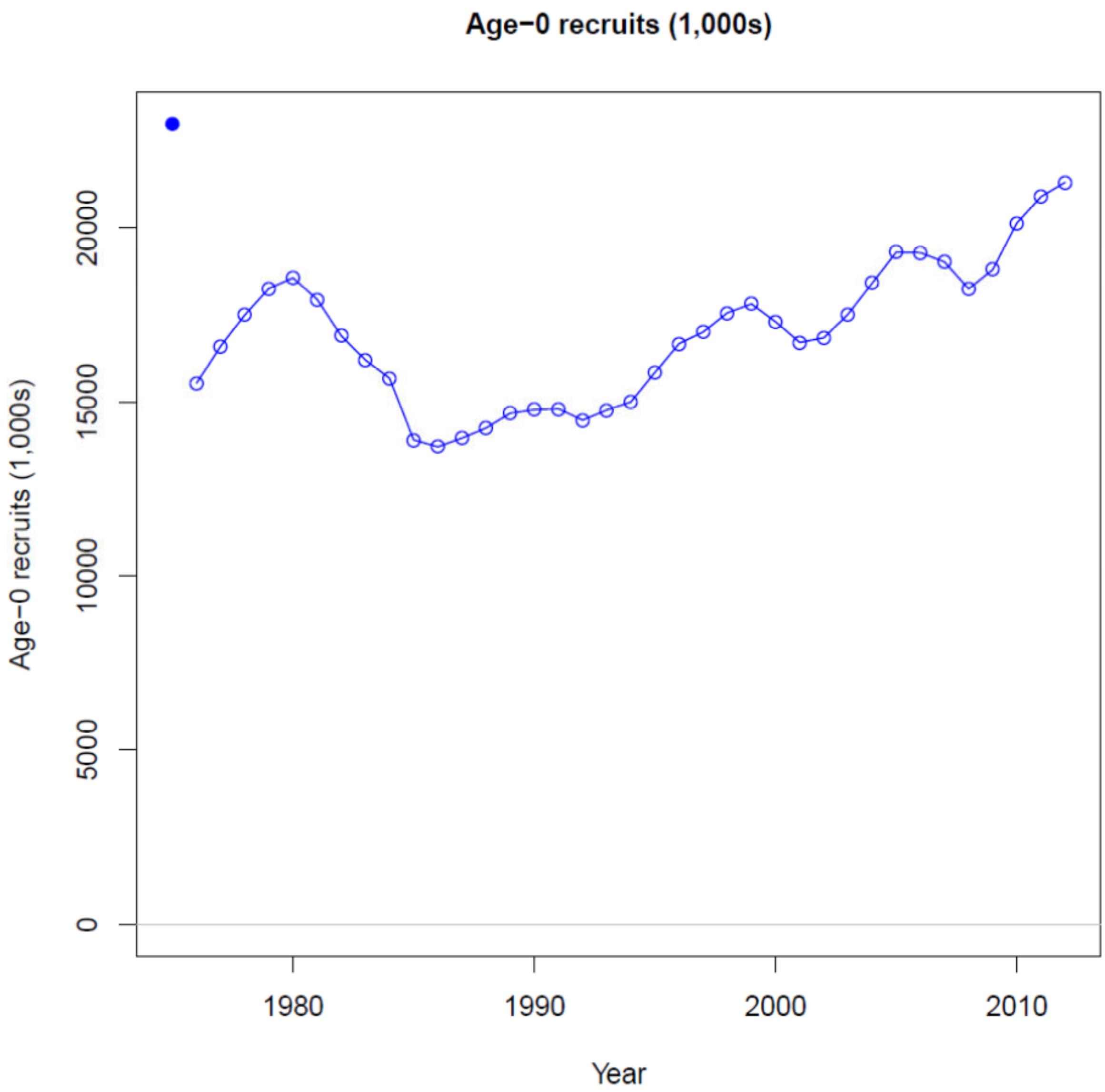


Figure 11: Estimated recruitment including the estimate of virgin recruitment (filled circle at the start of the time series) for the reference case model.

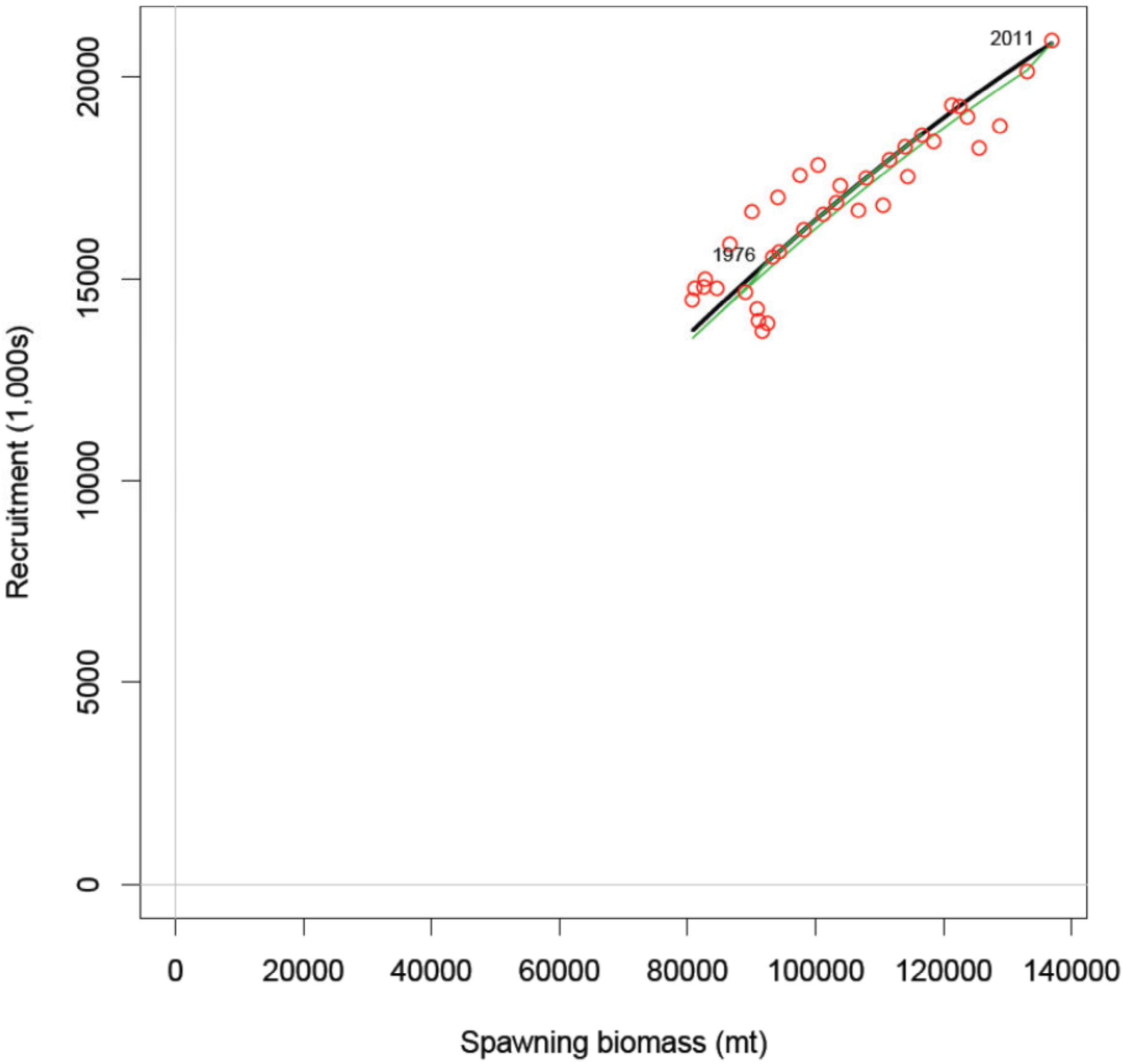


Figure 12: Spawner recruitment time series for the reference case model.

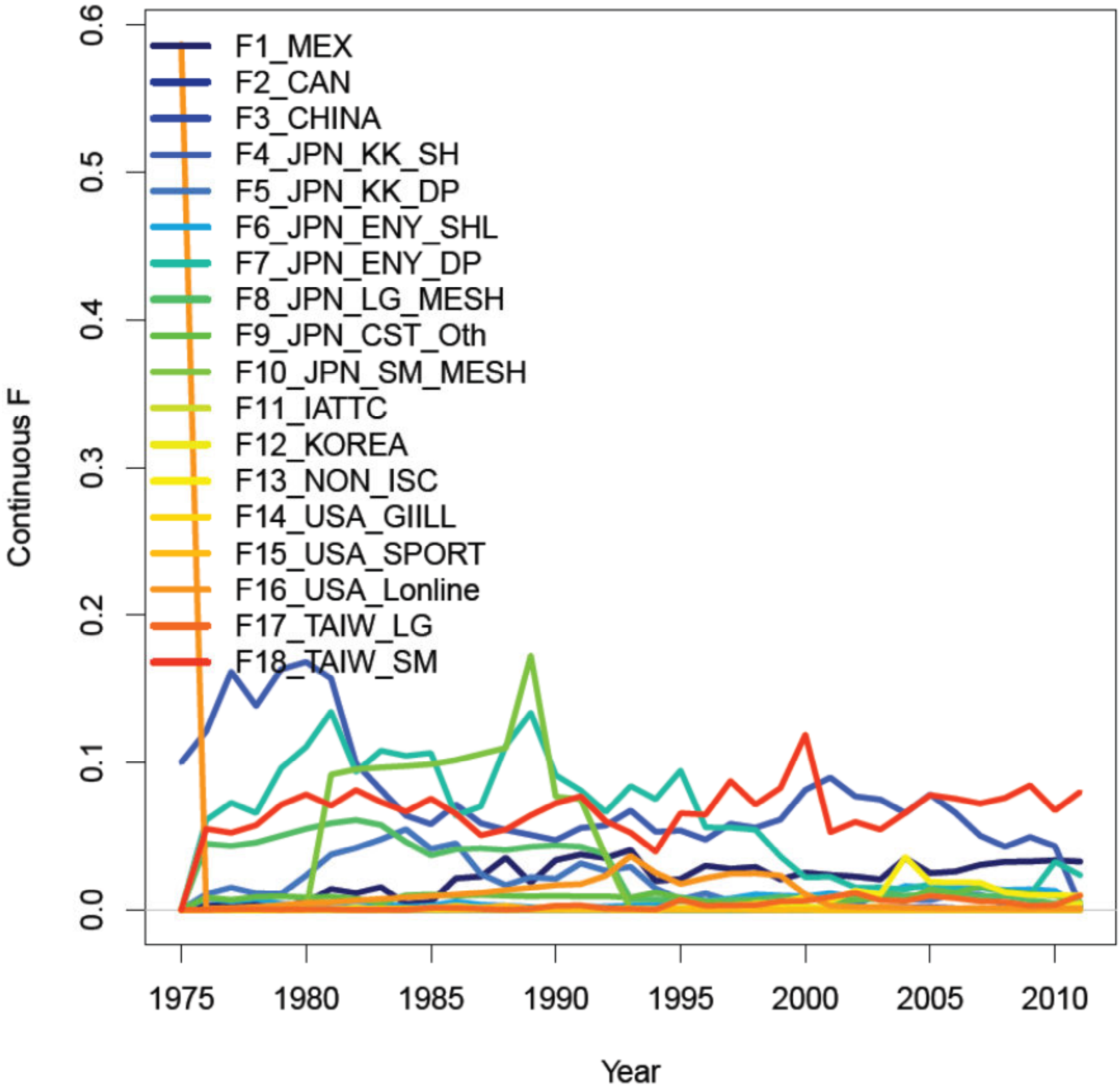


Figure 13: Estimated fishing mortality for each fishing gear.

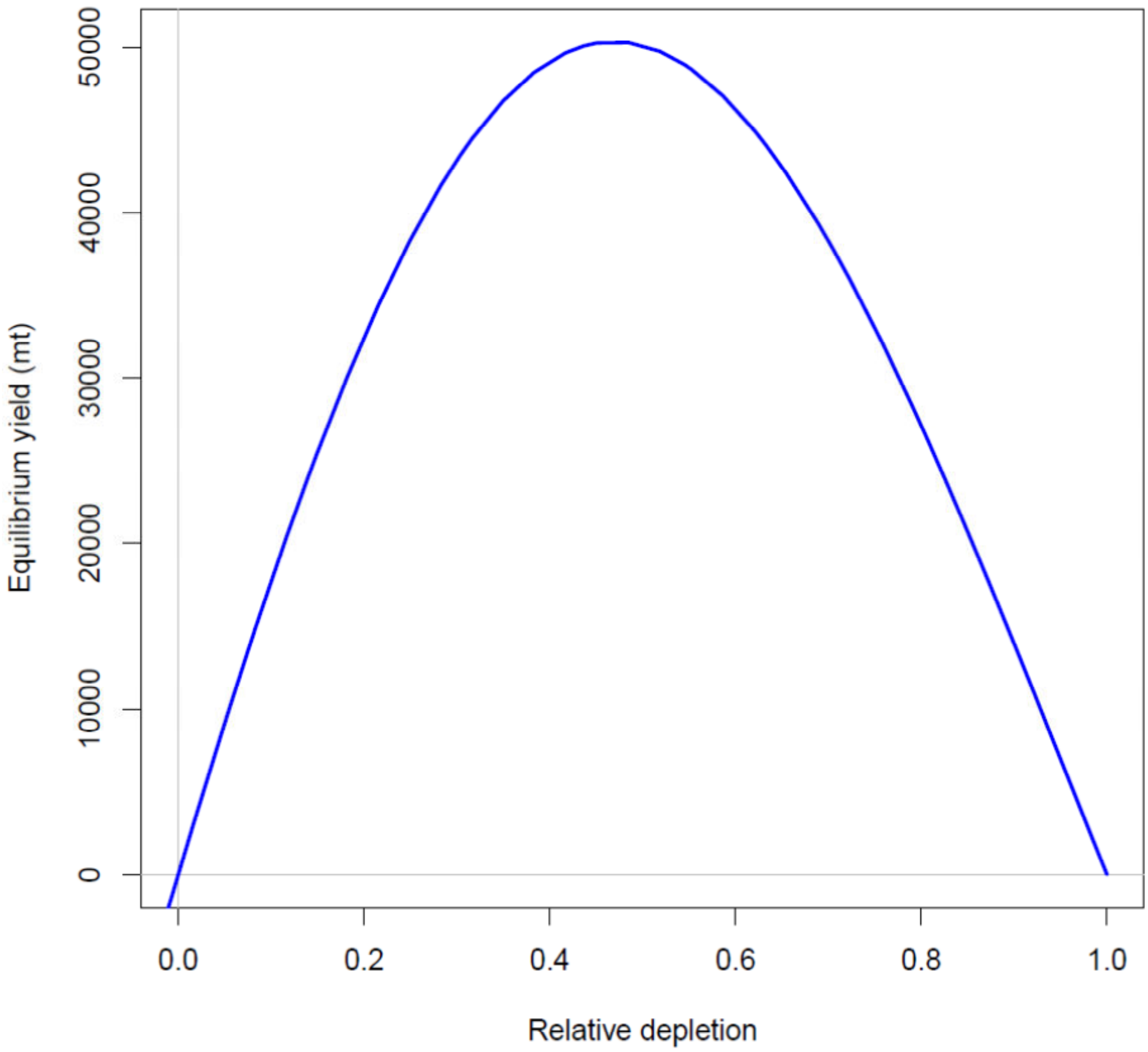


Figure 14: Equilibrium yield curve for the reference case model.

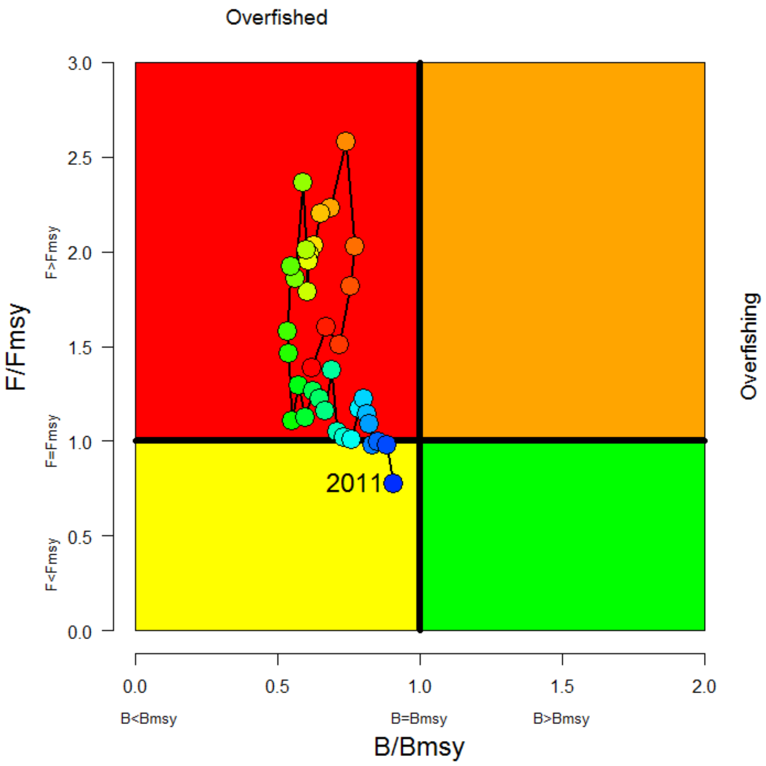
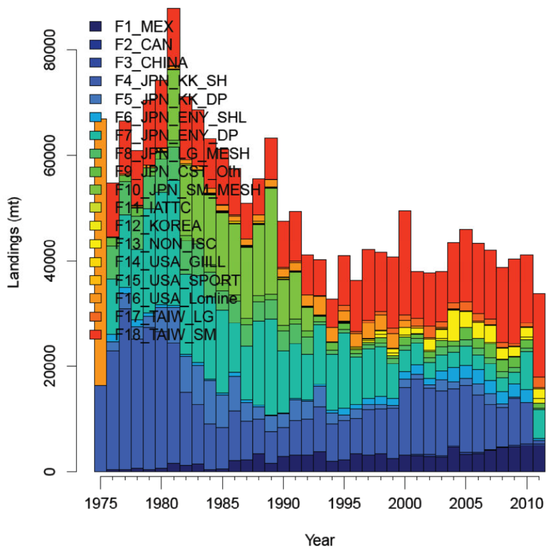
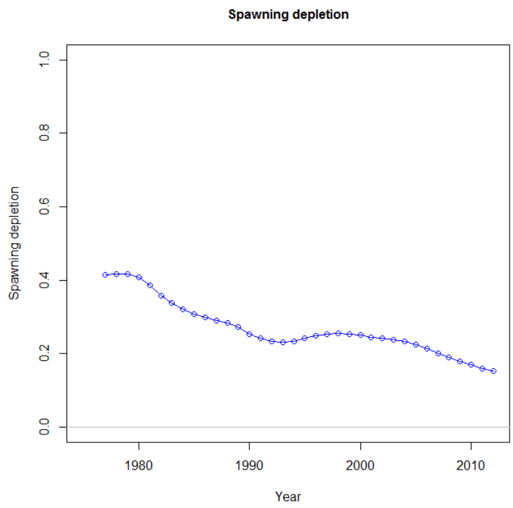
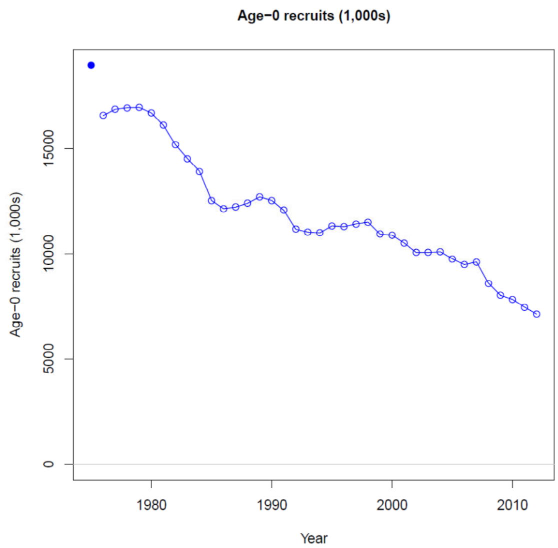


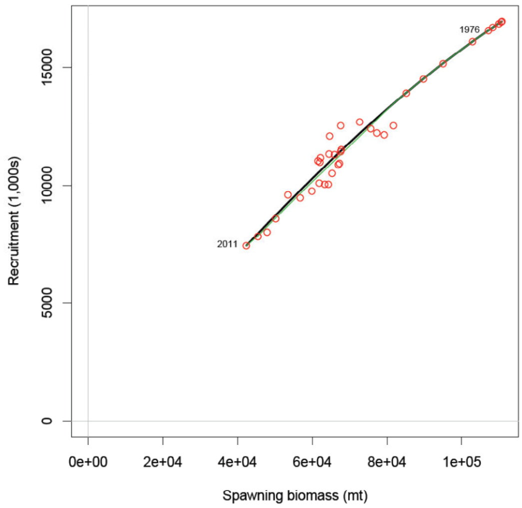
Figure 15: Kobe plot for the reference case model.

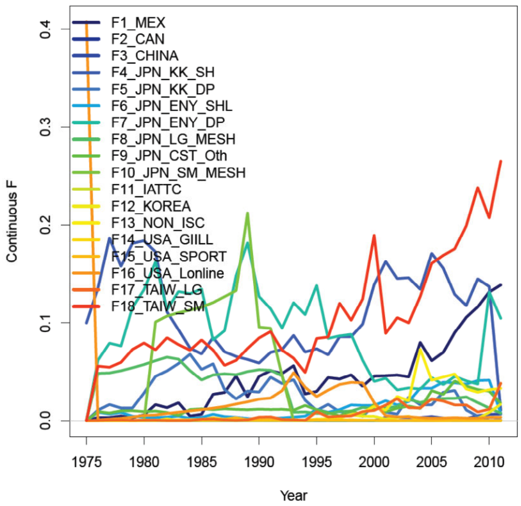
ANNEX 1: Summary of key outputs for the model that used the Hawaiian deepset CPUE series (please see main figures for the figure legends).



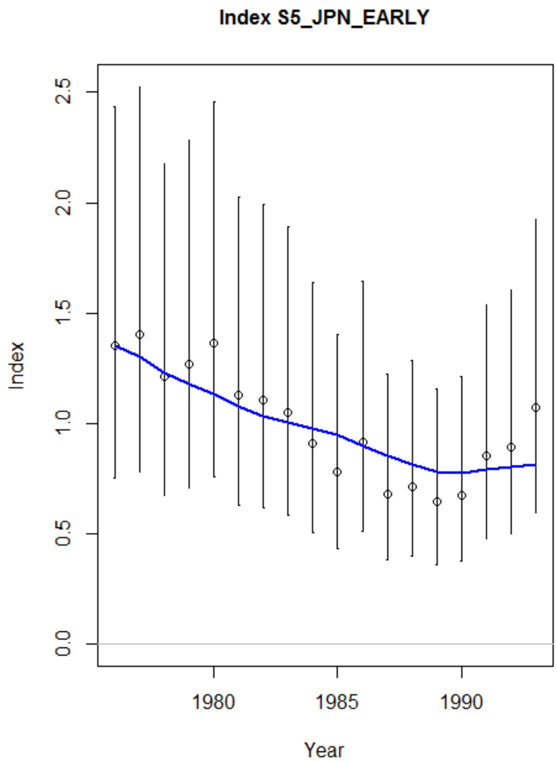




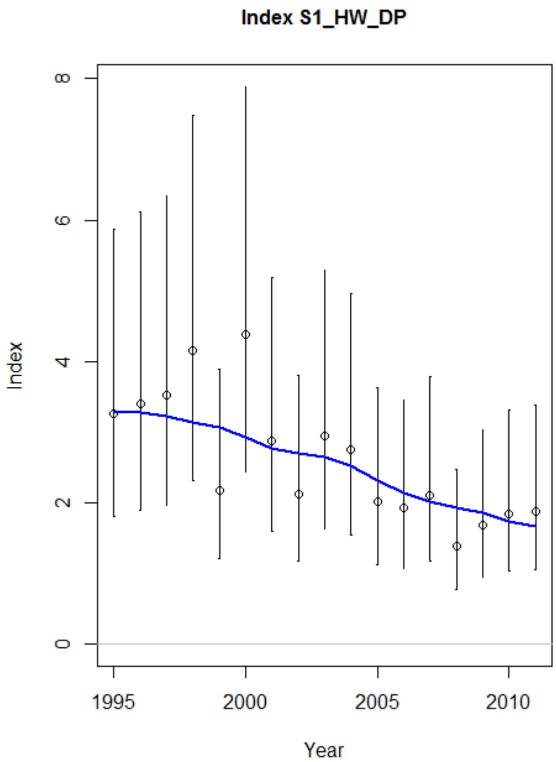




F1_MEX
F2_CAN
F3_CHINA
F4_JPN_KK_SH
F5_JPN_KK_DP
F6_JPN_ENY_SHL
F7_JPN_ENY_DP
F8_JPN_LG_MESH
F9_JPN_CST_Oth
F10_JPN_SM_MESH
F11_IATTC
F12_KOREA
F13_NON_ISC
F14_USA_GIILL
F15_USA_SPORT
F16_USA_Lonline
F17_TAIW_LG
F18_TAIW_SM
Continuous F
Year



Index S5_JPN_EARLY
Index
Year



Index S1_HW_DP
Index
Year

ANNEX 2: Age structured production model sensitivity analysis

To show the influence of the length composition data weighting on the assessment results and as a model diagnostic an age structured production model (ASPM) was compared to the reference case, and the reference case under higher and lower parameterizations of the sample size weighting. Note that the ASPM is the reference case model with the recruitment deviates turned off, and the model run from the converged parameter estimates, with the estimated selectivity fixed. This allows direct comparison of the estimates of scale and the influence of the length composition in the model.

The results show that the reference case estimate of current spawning biomass is approximately 11% higher than the ASPM (Table A2.1, Figure A2.1). It is important to note that down weighting the length composition weights to nearly zero (0.005) results in estimate 6% higher than the ASPM. This suggests that if the ASPM is assumed as an absolute guide for the 'true' scale of the biomass then the size data should be down-weighted to zero (or less than 0.005). The trends in recruitment and spawning depletion (Figures A2.2, and A2.3) show similar increasing trends since the mid 1990s. Figure A2.4 shows the Kobe plot showing the reference case, ASPM and sample size weighting sensitivities.

Table A2.1. Parameterizations and results of the References case, ASPM, and reference case sensitivities incorporating higher and lower sample size weightings.

	Model Run			
	Reference Case	ASPM	Ref +SS=0.5	Ref +SS=0.005
CPUE	CPUE_0	CPUE_0	CPUE_0	CPUE_0
Beta	2	2	2	2
S_Frac	0.35	0.35	0.35	0.35
MatAge	lo	lo	lo	lo
SampSize	0.2	0.2	0.5	0.005
C_latest	33,744	33,744	33,744	33,744
C2011_msy	0.67	0.59	0.67	0.65
Y_MSY	50,330	57,055	50,151	51,665
equil_pt	0.47	0.47	0.47	0.47
Recr_Virgin	22,983	25,999	23,066	23,434
B_zero	2,791,650	3,158,000	2,801,770	2,846,440
B_msy	1,310,478	1,482,486	1,314,623	1,337,071
B_cur	1,108,347	998,057	1,242,140	1,058,045
SB_zero	321,845	364,082	323,012	328,162
SB_msy	151,083	170,914	151,561	154,149
SB_cur	127,780	115,065	143,205	121,981
B_cur_F0	2,820,515	3,158,000	2,844,292	2,869,356
SB_cur_F0	325,173	364,082	327,914	330,804
B_cur/B_zero	0.4	0.32	0.44	0.37
B_cur/B_msy	0.85	0.67	0.94	0.79
B_cur/B_cur_F0	0.39	0.32	0.44	0.37
Bratio_1976	0.29	0.24	0.3	0.28
Bratio_2011	0.43	0.34	0.48	0.4
Bratio_cur	0.4	0.32	0.44	0.37
B_msy/ B_zero	0.47	0.47	0.47	0.47
SB_cur/SB_zero	0.4	0.32	0.44	0.37
SB_cur/SB_msy	0.85	0.67	0.94	0.79
SB_cur/SB_cur_F0	0.39	0.32	0.44	0.37
SB_msy/SB_zero	0.47	0.47	0.47	0.47
SB_cur_init	1.37	1.31	1.49	1.32
Fcur	0.23	0.25	0.21	0.24
F_msy	0.23	0.23	0.23	0.23
F_2011_msy	0.78	0.82	0.72	0.8
F_cur_msy	1.01	1.1	0.91	1.05
Fleet_19	0	0	0	0
Fleet_23	2.07	2.64	2.26	2.01
Fleet_24	1.14	1.75	1.1	1.17
Fleet_25	0	0	0	0
Total_Like	17.91	-37.74	109.65	-11.82
LenghtComp_Like	64.47	0	155.76	34.83

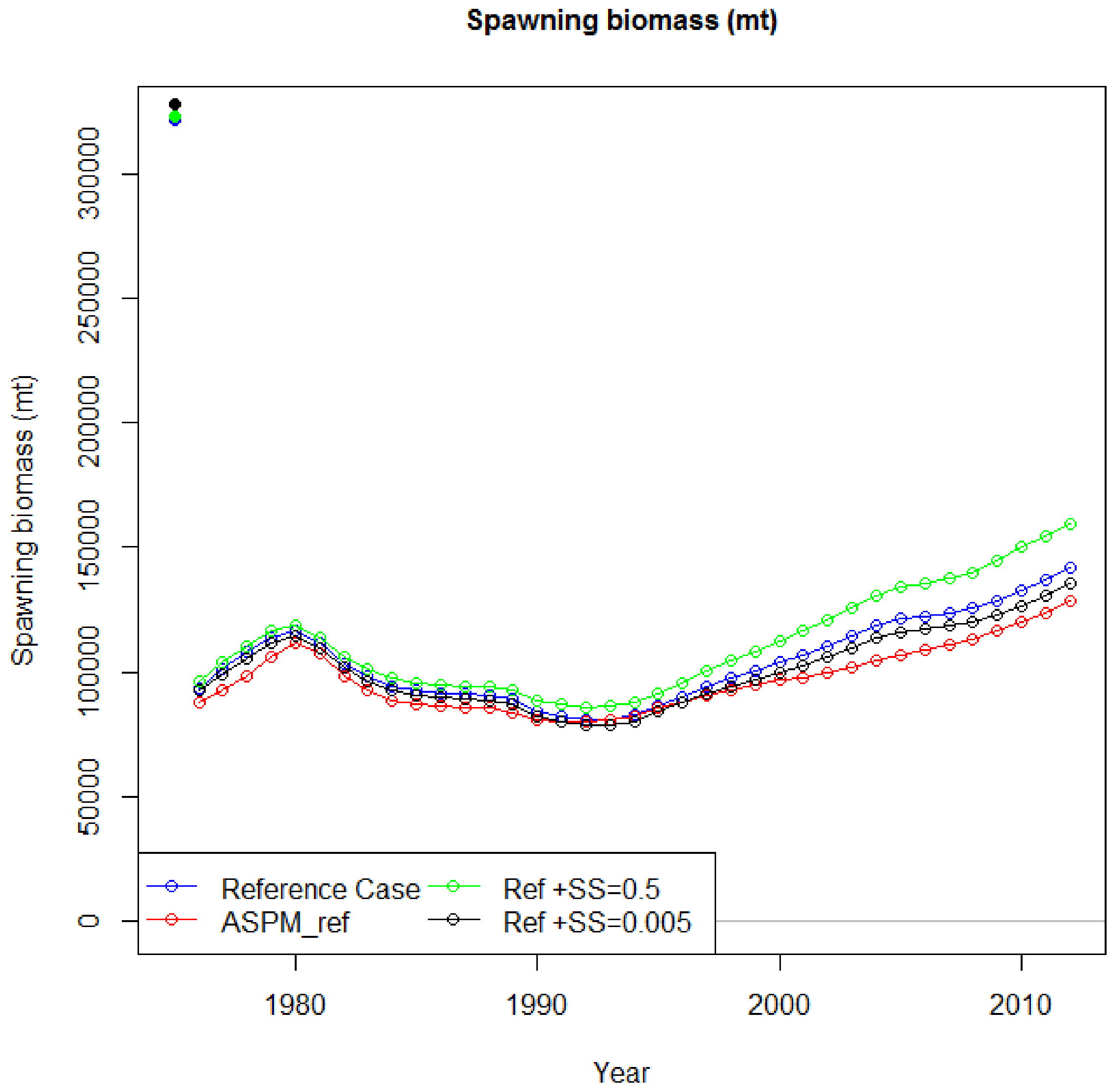


Figure A2.1: Spawning biomass trend for the reference case, ASPM and sample size weighting sensitivities

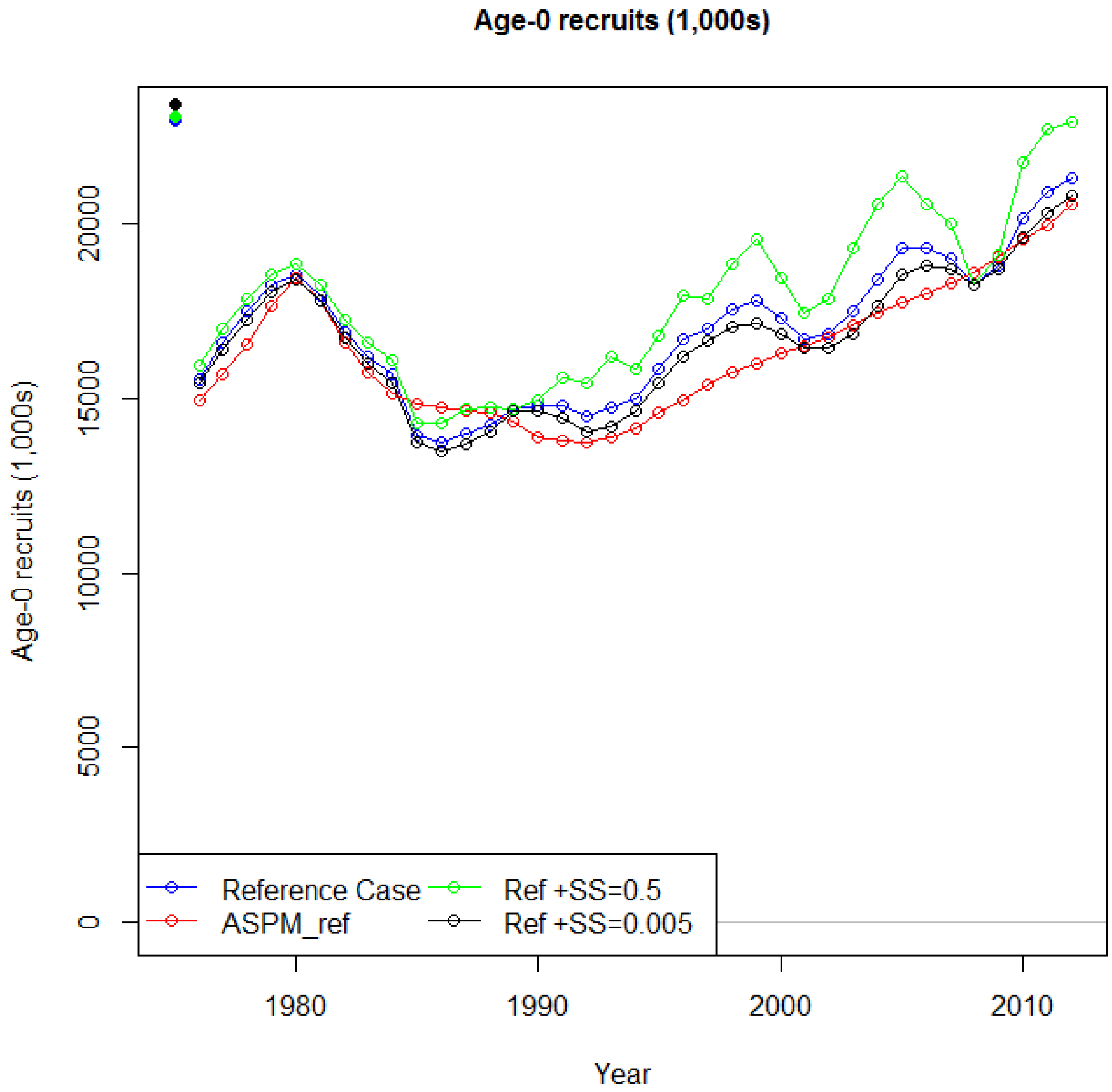


Figure A2.2: Recruitment trend for the reference case, ASPM and sample size weighting sensitivities

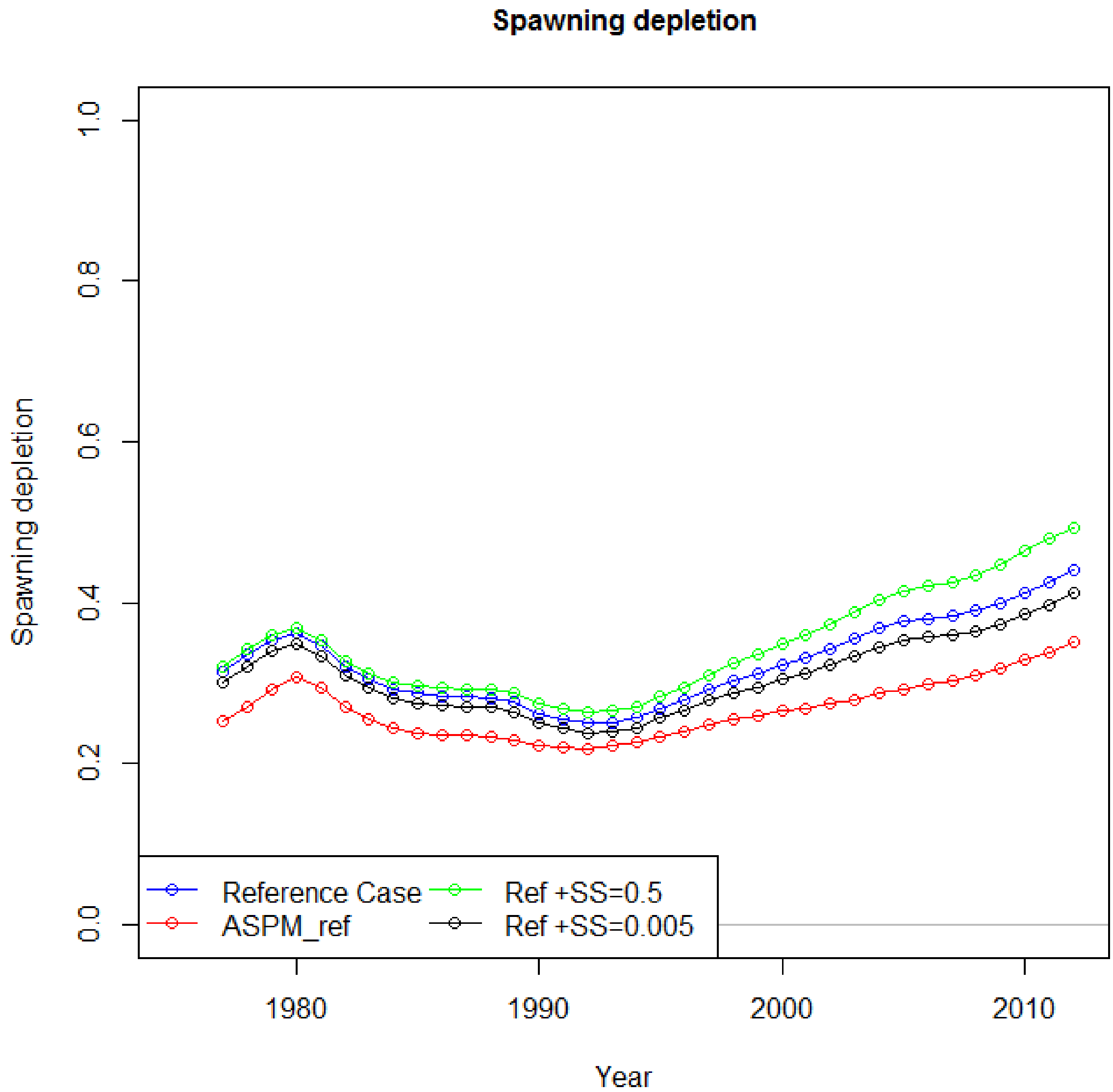


Figure A2.3: Spawning depletion trend for the reference case, ASPM and sample size weighting sensitivities

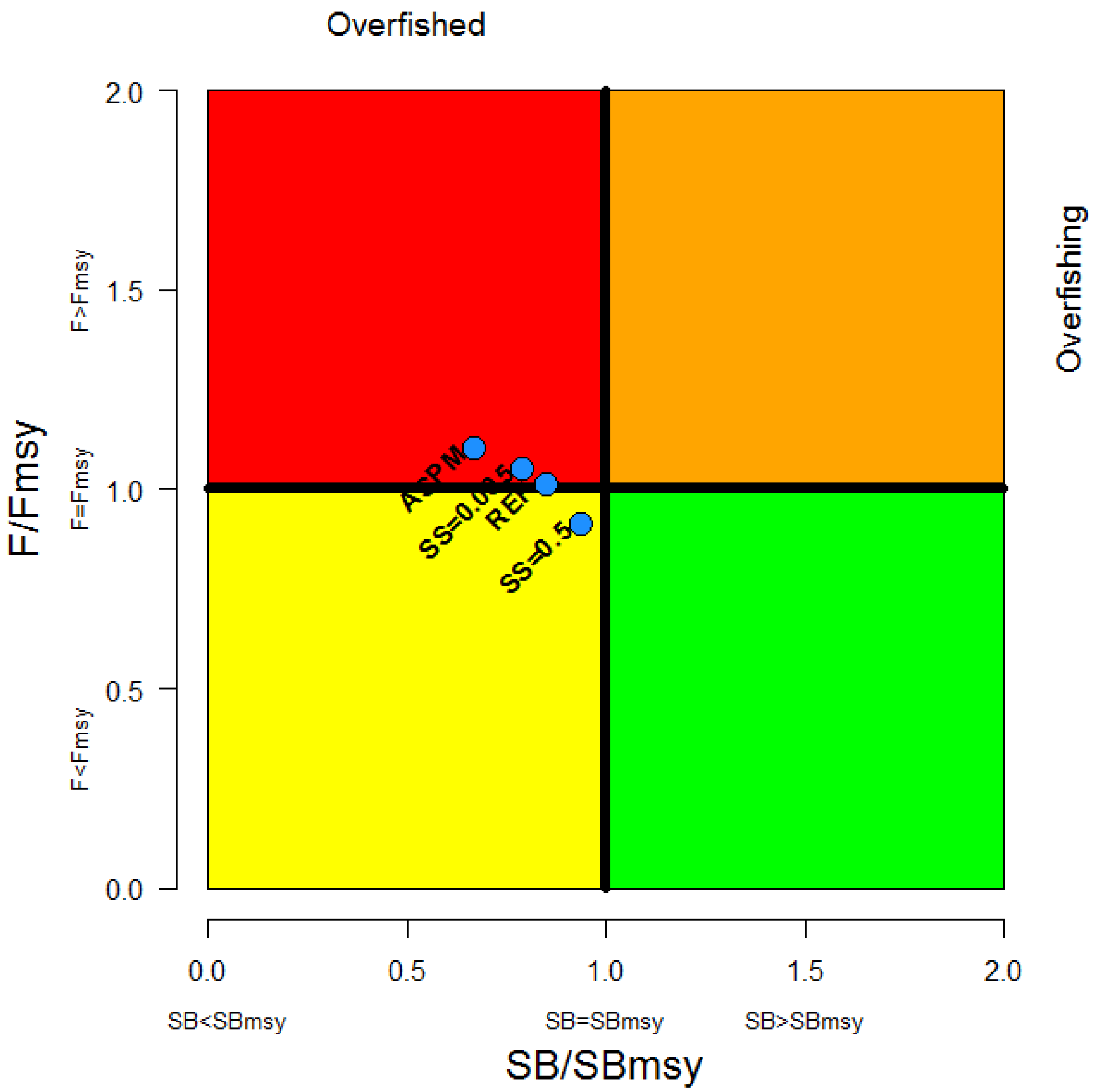


Figure A2.4: Kobe plot showing the reference case, ASPM and sample size weighting sensitivities