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Stock assessment of Blue Shark in the North Pacific Ocean using Stock Synthesis

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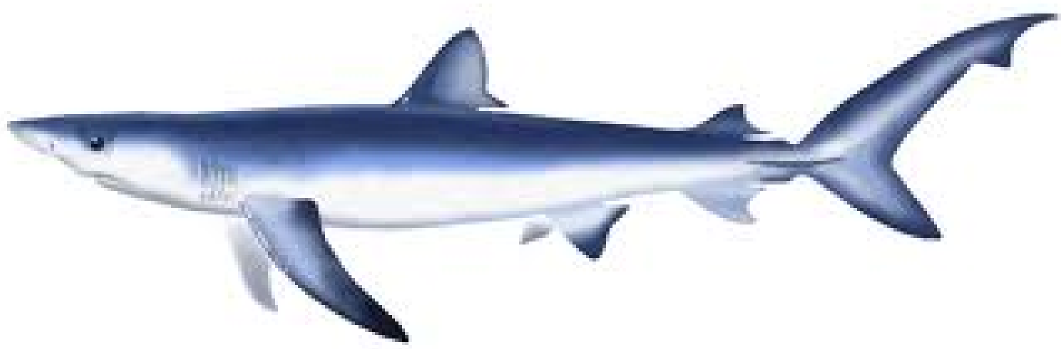


Executive summary

This paper presents an updated 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 Working Group (WG) has agreed to use both a Bayesian Surplus Production (BSP) model and the age-based statistical catch-at-length stock assessment, presented here, to examine the status of this stock. This paper should be read with the full assessment report of the WG which provides greater details of the data sources and how they were derived as well as pertinent summaries of biological knowledge and the papers describing each CPUE series.

The updated assessment represents the efforts of the WG to address concerns raised by the Western and Central Pacific Fisheries Commission (WCPFC) Scientific Committee (SC). Generally speaking the major concerns were:

- Both assessments: the key Japanese late CPUE series could be biased due to inadequate accounting of targeting practices;
- Stock Synthesis model: 1) the basis for the weighting applied to the length frequency data; and 2) why the model had the greater level of initial depletion compared to the BSP.

The main differences between the present assessment and that presented to SC9 are 1) the inclusion of revised CPUE series; 2) changing the time period of the model to 1971-2012 to utilize earlier catch estimates and more recent indices of abundance; 3) more structured examination of exploitation levels prior to the start time of the model; and 4) sex-specific estimates of natural mortality-at-age based on growth studies from the north Pacific.

The primary reasons to use Stock Synthesis were to a) explicitly model the different sizes of blue sharks taken in each fishery; b) utilize the Low Fecundity Spawner Recruitment relationship (LFSR) functionality; c) incorporate the strong sex-specific patterns that are seen in many of the biological and fishery data sets; and d) provide an alternative approach that could be compared to the production modelling.

This is an integrated stock assessment using estimated catch, several standardized catch per unit effort time series, catch-at-length, and published life history information. The model is age (30 years) structured; spatially aggregated (1 region); and sex specific. The catch, effort and size composition of catch are grouped into 18 fisheries from 1971 to 2012. The fisheries within in the assessment cover a range of fleets, bycatch and target fisheries and both longline and gillnet gears.

Observer data play an important role in this assessment as commercial reporting of blue shark landings has been minimal. Observer catch and effort data 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 exist.

Due to uncertainty in the input data and life history parameters, multiple models were run with alternative data/parameters. These models with different combinations of input datasets and structural model hypotheses (axes of uncertainty) were used to assess the plausible range of stock status for blue shark. Reference case model(s) are presented here for the purpose of assessing model performance. It is expected that the most appropriate model run(s) upon which to base management advice will be determined by the SC considering the recommendations from the ISC Plenary.

The axes of uncertainty considered are provided in the table below. A full factorial grid of all options was run (this gave a total of 1080 model runs) – and full results for any run are available on request. The major axes of uncertainty were CPUE (five options) and the form of the LFSR (nine options).

Axes of uncertainty and options considered

GROUP	Variable	Options Run
CPUE (five)		
	CPUE Series	1. JPN Early and JPN Late
		2. JPN Early and HW Deep Late
		3. HW Deep Late
		4. SPC Late
		5. Taiwan Late
Natural Mortality (two)		
	Natural Mortality (Peterson and Wroblewski (1984) method with data from :	1. Nakano 1994
		2. Hsu et al. 2011
Length Composition (two)		
	Sample Size weighting	0.2 and 1
Stock Recruitment (nine)		
	Low Fecundity Stock Recruitment Function	Beta S_Frac (all combinations)
		1 0.1
		2 0.3
		3 0.5
Recruitment variation (two)		
	Sigma R (SD on the recruitment deviations)	0.1 and 0.3
Initial Equilibrium Catch (three)		
	Fit to exact amount	20,000 MT
		40,000 MT
		60,000 MT
Total	1080 combinations	

There are other sources of uncertainty that have not been considered here, in particular, stock structure, total catch and the shape of the catch trajectory.

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 assessment are as follows:

1. The outcomes of the Stock Synthesis modelling for blue shark in the North Pacific Ocean provide three key areas of concern regarding the reliability of the stock assessments:
    a. Insufficient information to estimate initial depletion: approaches at estimating initial fishing mortality or catches proved to be unsuccessful and therefore there is not sufficient information in the size data (a typical source of information on depletion) or other model inputs to reliably estimate the level of depletion at the start of the model;
    b. Lack of a CPUE series that extends through the temporal model domain: no CPUE series spans the entire period of the model and therefore there is nothing to link relative abundance across the model period. This is demonstrated by the very different biomass trajectories that were obtained with the same CPUE series; and
    c. Variety of spawner-recruitment relationships with similar 'productivity (SB/SBmsy)': through the use of the Low Fecundity Spawner Recruitment Relationship (LFSR) in Stock Synthesis we were able to consider a wide range of LFSR shapes which gave similar productivity to that assumed in the production model. The resulting stock status conclusions were extremely sensitive to the shape of the LFSR function.
2. The results from using alternative CPUE series in the current assessment are less different, in terms of their implied changes in abundance, than the individual CPUE series are. There are only minor differences in stock status across the CPUE series with model runs using the Japanese early and late indices producing slightly more optimistic stock status than model runs using the SPC model series.
3. The LFSR parameterisation has the most influence on the assessment. Across the LFSR options tested, stock status can range from heavily overfished and rapidly declining to lightly exploited and strongly increasing, and almost everything in between. Moderate to good fit to the CPUE series can be obtained across the total spectrum of stock status outcomes, i.e., you can fit the data equally well and have a very optimistic or very pessimistic stock status. We believe that it is possible that the LFSR relationship is not performing as expected at higher values of S_Frac and Beta, i.e., the model indicates that you can have strongly declining recruitment with increasing stock size.
4. In order to use the model runs from Stock Synthesis in the provision of management advice, will require the Scientific Committee to clearly articulate the reason(s) for determining which set(s) of LRSR parameters are most representative of range of biological responses one might expect from blue shark. This decision could be based on ecological theory of compensatory processes and/or model performance (see note below).
5. The following patterns in terminal stock status were seen across the other axes of uncertainty:
    a. The LFSR overwhelmed other sources of uncertainty. There was a strong trend with S_Frac, with the large majority of runs undertaken with 0.1 giving results where $F>F_{MSY}$ and $B<B_{MSY}$ and the majority of runs at 0.3 and 0.5 result in terminal stock status where $F<F_{MSY}$ and $B>B_{MSY}$.
    b. There was also a strong trend in stock status with Beta, but it was less extreme than for S_Frac.

c. Stock status improved considerably with higher initial equilibrium catches, as this increased mean recruitment levels relative to the observed catch history over the modelled period.

d. Higher weights on the length data generally lead to more optimistic stock status results. We believe this reflects a positive bias being introduced into the model as demonstrated by the Age-Structured Production Model (ASPM) diagnostic analyses presented to SC9.

e. Alternative values considered for the standard deviation of the recruitment deviates had little impact on the estimates of stock status.

6. 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 consideration of alternative LFSR parameterisations will be important and we suggest [Beta:S_Frac] combinations such as [1:0.5], [2:0.3], and [3:0.1]. Some of the flatter curves exhibit almost no compensation and some of the stronger curves displayed poor performance in the modelling. Stock status summaries for any set of model runs can be provided on request.

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

    - Detailed consideration of how the biology of blue sharks can be modelled within the Stock Synthesis modelling framework (including the LFSR).
    - 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.
    - Further development of the CPUE series, including consideration of alternative approaches to model changes in targeting, approaches to develop longer time series or constrain catchability differences across CPUE series. Development of simulation models to test alternative approaches is recommended.

1 Background

This paper presents one of two stock assessment approaches being applied to blue sharks in the North Pacific Ocean (NPO) (Figure 1). The ISC Shark Working Group (WG) agreed to use a Bayesian Surplus Production (BSP) model and an age-based statistical catch-at-length stock assessment conducted using Stock Synthesis (SS) (version 3.24F http://nft.nefsc.noaa.gov/Download.html), presented here, to assess the status of the stock. This paper should be read in conjunction with the full assessment report of the WG (Takahashi et al. 2014) 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 blue shark biology.

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 is 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 WG 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 relates 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 of an average fish.

Sex-specific estimates of growth and length-weight parameters from Nakano (1994) were assumed in the assessment (Figure 2**Error! Reference source not found.**) – 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) 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).

3.2 Natural mortality

Two 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 1). We note that in general these estimates are similar; however they represent spatially separate studies and have differences in the particularly influential early life stages. For the reference case we used the estimates based on the Nakano (1994) data, with a sensitivity using the Hsu et al. (2011) 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. This assessment considered a single maturity ogive and did not consider age/length specific changes in fecundity in the final set of model runs[1]. In Section 5.1 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 WG. Agreed data inputs were determined and these are described in Takahashi et al. (2014) and are summarised below. Temporal coverage of the data series used in the reference case model are provided in Figure 3.

4.1 Spatial and temporal stratification

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 1971-2012 was used for the assessment.

4.3 Definition of fisheries

The WG 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

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

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 small, but important source of catch.

4.4 Catch

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 WG held in the USA and Japan. Catches were extracted from databases of landings, vessel logbooks and observer records. When catch data were unavailable, catch was estimated using independently derived standardized catch per effort information, often applying assumptions on the species compositions of the catch, to transform effort data into catch. It was agreed to conduct the assessment on biomass, so catch was 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 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 7). This series included the working groups' best estimates for discard mortality.

4.5 Abundance indices

CPUE series are critical to every assessment and five candidate standardized abundance indices were developed from catch and effort data of Japanese, Taiwanese, US longline fisheries, and longline fisheries in the tropical north Pacific subject to the SPC observer program (Figure 6). It is well known that bias and uncertainty in the assessment results can 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.

Five combinations of CPUE series were used to describe the uncertainty with respect to the indices of abundance. The combination of indices used were: (1) two CPUE series from the Japanese fleet early (1976-1993) and late (1994-2010) (Kai et al. 2014); (2) the Japanese early (1976-1993) and Hawaii deep set (2000-2012) from onboard observer data on longline vessels based in Hawaii (Walsh and Dinald 2014); (3) a longline index developed from data gathered (1993-2009) by observers onboard longline vessels participating the SPC's observer program (Rice and Harley 2014); (4) the Hawaiian CPUE only (Walsh and Dinald 2014); and (5) the standardized CPUE from Taiwanese large longline fishery in the north Pacific ocean (Wen-Pei et al. 2014).

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

4.6 Catch-at-length

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". This matter was considered in detail in age-structured production model sensitivity analysis undertaken in the previous assessment.

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 1971-2012. The main population dynamics processes are as follows:

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

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. 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 0.1, 0.3 and 0.5, for s_{Frac} and 1, 2 and 3 for beta. Examples of the behaviour of some of the resulting curves are provided in

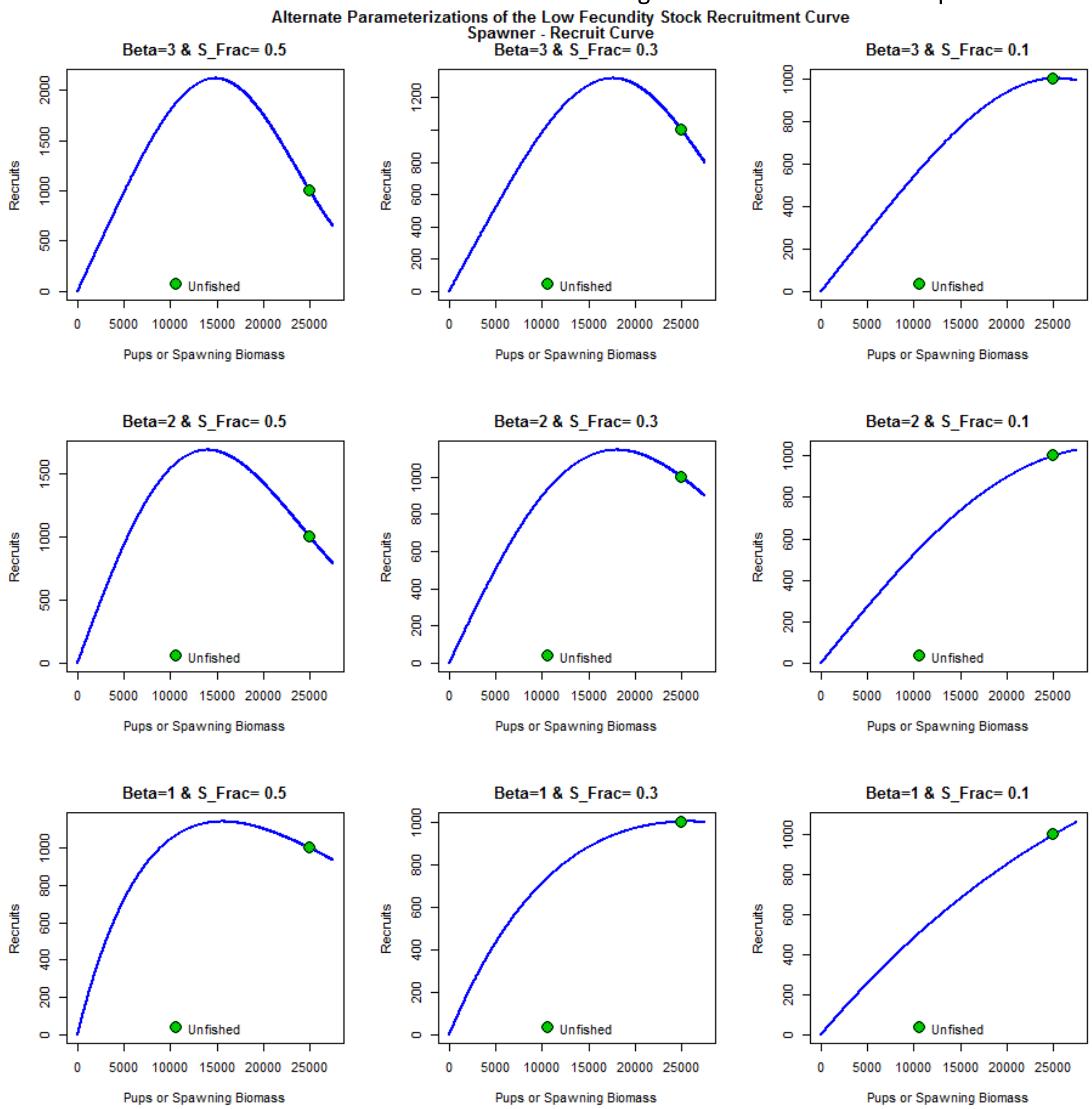


Figure 4: Spawner recruitment curves for the nine Low Fecundity Spawner Recruitment (LFSR) curves considered in the assessment of blue sharks in the north Pacific. The reference case model used S_Frac = 0.3 and Beta = 2.

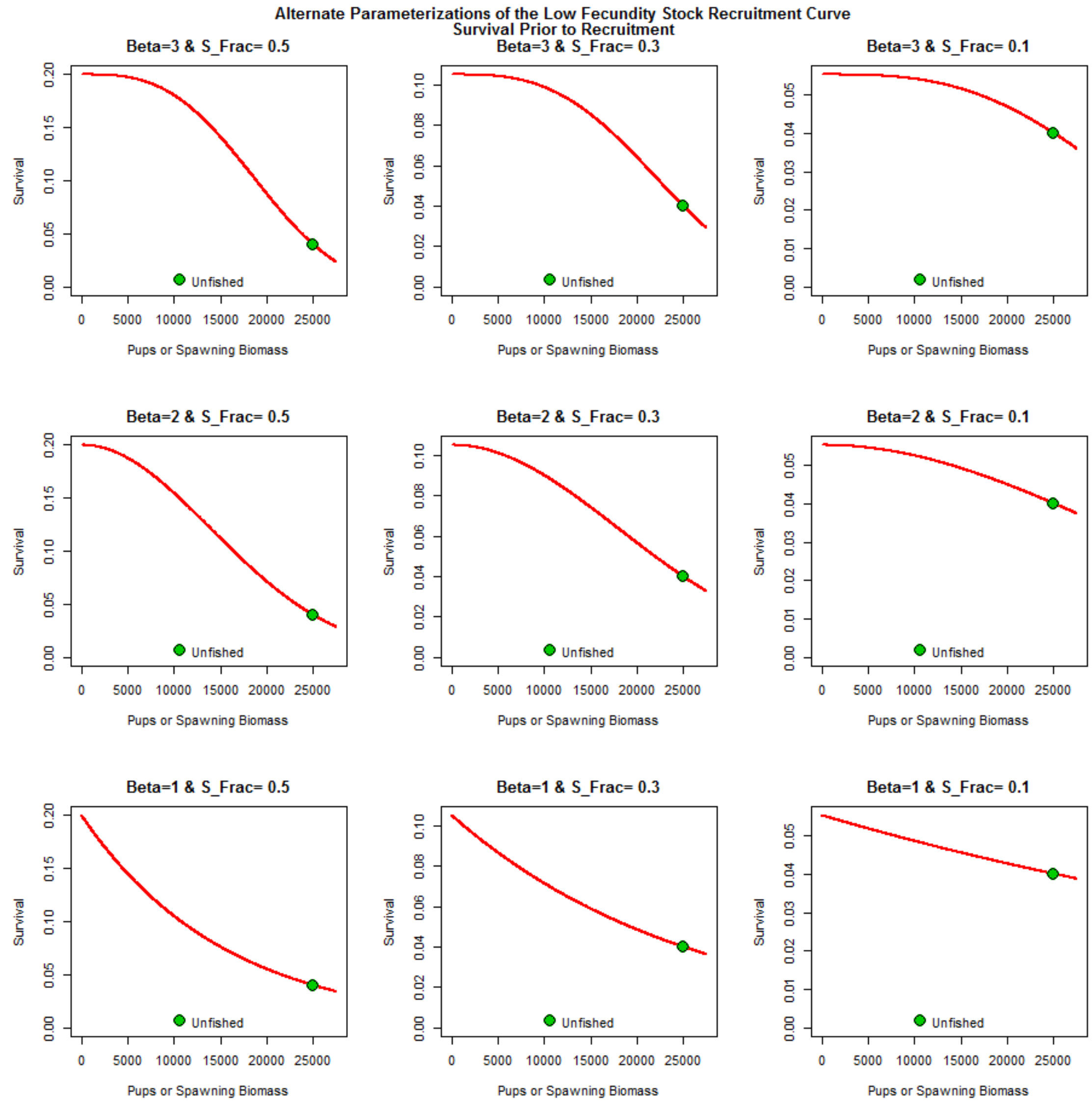


Figure 5: Pre-recruitment survival for the nine Low Fecundity Spawner Recruitment (LFSR) pre-recruit survival curves considered in the assessment of blue sharks in the north Pacific. The reference case model used S_Frac = 0.3 and Beta = 2.

, with the impact of alternative parameterizations on the pre-recruit survival in Figure 5. Note for the in many cases recruitment for a depleted stock is higher than virgin due to the compensation implied by the parameterization of the LFSR.

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 two 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 was at an unfished state of equilibrium at the start of the model (1971) as significant longline fishing occurred in the region from the 1950s and in Japanese coastal waters prior to that. Stock Synthesis has several approaches to start from a fished state and two of these were considered over this and the previous assessments.

The first approach involved an initial equilibrium fishing mortality, while the current approach involved an initial equilibrium catch. Whichever approach is used, a selectivity curve needs to be specified to apply the fishing mortality and take the catch. It was not possible to estimate an initial F or initial catch so the alternatives available were to either investigate a range of fixed values of initial F or initial catch. It was decided that catch was easier to fix in a pragmatic way, i.e., if you fix F then catch can differ depending on estimated abundance and you can end up with an unintended discontinuity. We examined three values for equilibrium catch set at 20,000, 40,000 and 60,000 mt. These values represent approximately 50%, 100% and 150% of the first four years estimated catch).

For this approach we had to choose a selectivity to assign this catch to. The selectivity estimated for one of the Japanese fleets (F4 JPN_KK_SH) was selected as it dominated catches in the early years and its selectivity was not extreme towards small or large fish.

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.

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 only the selectivity curves for fleets 1, 3, 4, 5, 8, 10, 14, 16, 17 and 18 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 are available from the lead author (joelr@spc.int).

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 is provided in Table 3. In total 1080 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 group to decide on the model(s) that it wishes to use for the provision of management advice.

From this set of 1080 runs we selected our reference case model. The reference case model selected used: the WG recommendation on the CPUE series (JPN early and JPN late); the high natural mortality (Nakano (1994); the best practice approach for weighting size frequency data (down-weight (0.2) to ensure that the data don't overwhelm the abundance indices); sigma r of 0.1; and initial catch fixed at 40,000 mt and picked the combined of parameters of the LFSR that were most biologically plausible and gave the best overall model fit (S_Frac = 0.3 and Beta=2) (Table 4). The one-change model runs from the reference case are presented as sensitivity analyses.

6 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. We do not comment on the full model grid in this report.

6.1 Reference case model

The reference case model choice is described in Section 5.5. It is important to reiterate that by using the grid approach all model runs are available for the WG to develop management advice.

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 8). With the exception of the Japanese large-mesh gillnet fishery and the longline fleet for China; all fisheries estimated lower peak selectivity (therefore catchability) for females.

The fit to the CPUE indices was generally good for the reference case model (Figure 9). 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 10 and 11) 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.

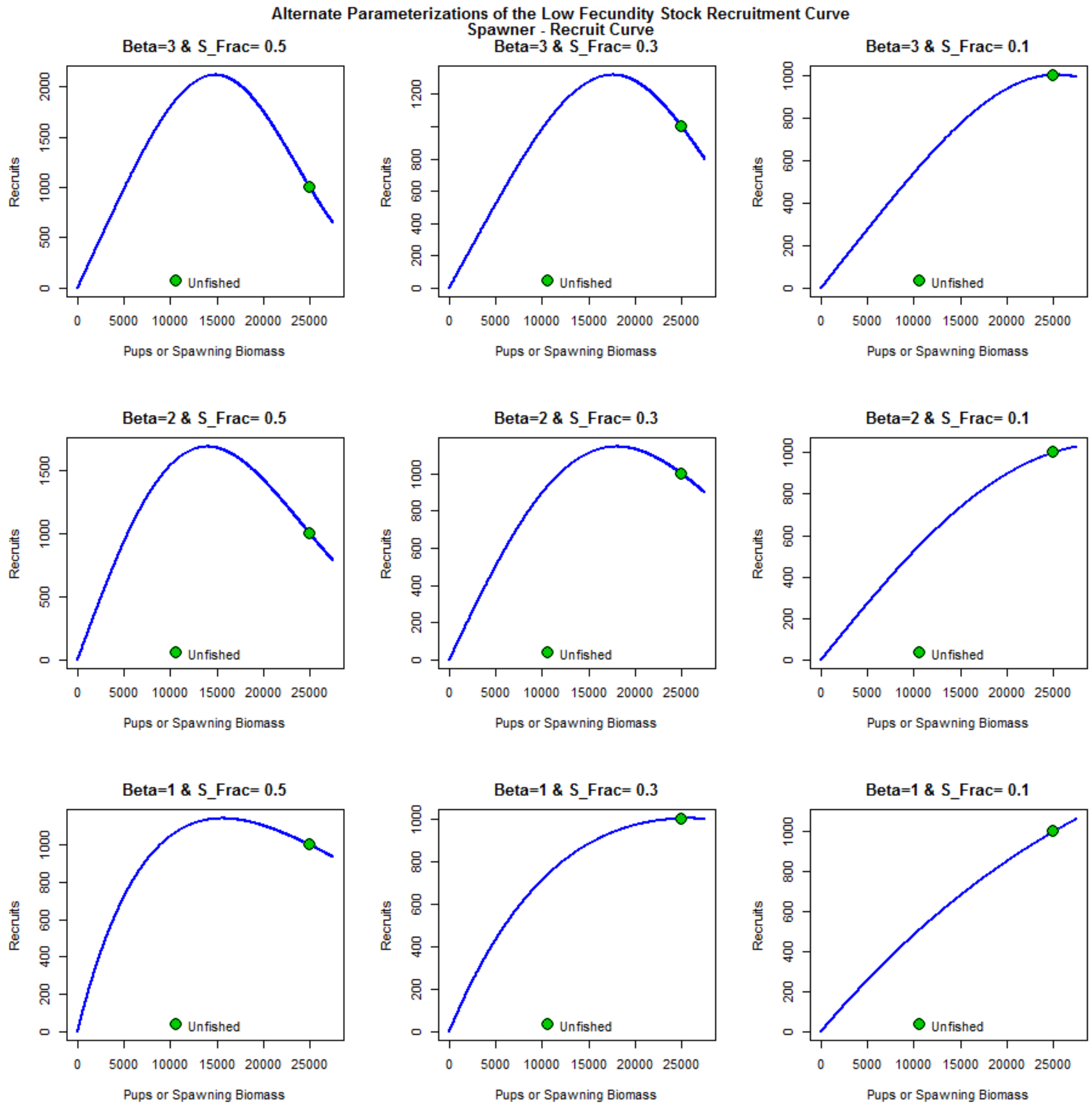
Overall, there were not too many parameters to estimate in this model, nor data to fit to, and the reference case model appears to do a good job.

Estimated stock status and other quantities

The reference case model estimates that the spawning potential of the stock was at 73% of the unfished level at the start of the model period (Table 5 and Figure 12) it then decreased through the mid-1990s before climbing again to a recent high point of around 79% in 2012. Recruitment is higher than virgin throughout the model time period due to the compensation implied by the parameterization of the LFSR and is relatively consistent (Figure 13). The estimates of recruitment quite tightly constrained by the estimated LFSR relationship (Figure 14; but see Figure 4 for the full suite of curves). The main trends in the population dynamics can be explained through the estimated fishing mortality which was greatly increased in the 1980's and early 1990's due to the small mesh gillnet fishery (Figure 15).

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, so a broad suite of MSY-related quantities are presented.

In the reference case the estimated MSY is approximately 73,600 mt and this is predicted to occur at 47% of the unfished biomass (Figure 16), which is similar to the sta



ndard Schaefer production model (0.5). Current catches are estimated to be about half the MSY.

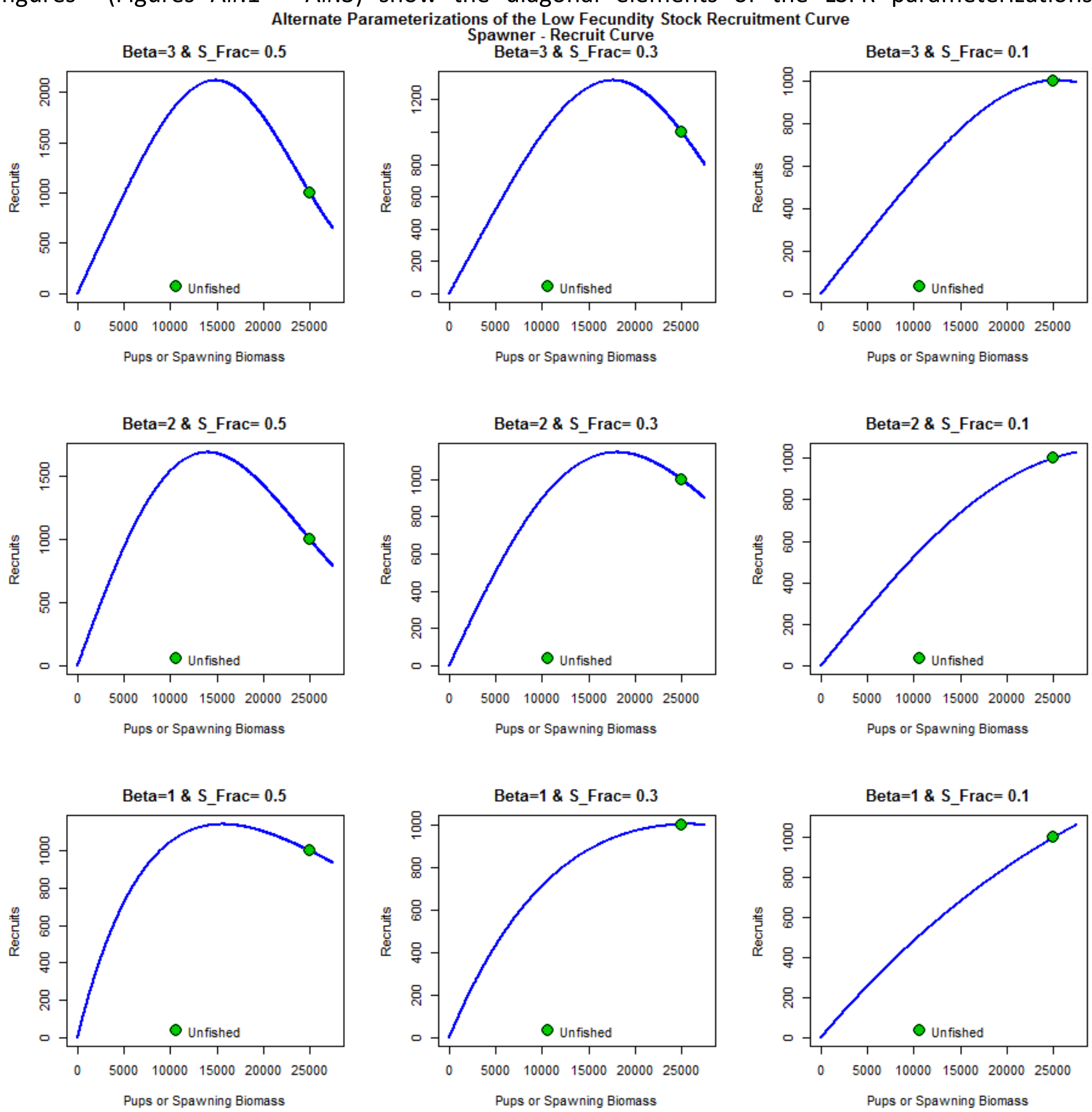
The stock is rebuilding and F is declining, F in the final year is 33% of F_{MSY}, and based on recent conditions (cur) the stock is estimated to be 76% of the unfished level and 162% of B_{MSY}. By the standard terminology, this would indicate that the stock is not in an overfished state, and that overfishing is not occurring (Figure 17). Given the LFSR relationship, under current fishing conditions, the stock will continue to increase.

6.2 One-change sensitivity analyses

A summary of the general outcomes from the other sensitivity analyses are as follows (see Table 4 and Table 5). The sensitivity analyses with the greatest impact were those with alternative stock recruitment parameterizations. LFSR was highly influential in the model and runs with low S_Frac (0.1) produced estimates where the stock was in an overfished state and overfishing occurring, while higher values (S_Frac=0.5) resulted in populations that were above not overfished and not experiencing overfishing. Higher levels of Beta increased the probability of the stock having $F<F_{MSY}$ and $B>B_{MSY}$. Among the alternative CPUE series used in the one change sensitivity analyses only CPUE 6 (TW) resulted in a lower estimate of B_{zero} and $B_{CURRENT}$ / B_{MSY}. The higher natural mortality-at-age estimates resulted in a lower estimate of B_{zero} and $B_{CURRENT}$ / $B_{MSY.}$ The up-weighted sample size runs resulted in higher estimates of estimate of B_{zero} and $B_{CURRENT}$ / B_{MSY}. The higher sigma r runs resulted in slightly lower estimates of estimate of B_{zero} and $B_{CURRENT}$ / B_{MSY}. The axis that had the greatest impact aside from the stock recruitment relationship was the initial catch. Lower initial catches resulted in lower estimates of B_{zero} and $B_{CURRENT}$ / B_{MSY} while higher initial catches produced higher estimates of the same quantities. These same trends are evident in the overall results (Figure 18).

6.3 General patterns from model runs presented in the annex materials.

The annex material (Annex 1-5) presents CPUE specific results. Each annex presents CPUE specific results for the CPUE series (or series combination listed in the title). The first three multi-panel figures (Figures A#.1 – A#.3) show the results based on three parameterizations (Beta =1 & S_Frac=0.1, Beta =2 & S_Frac=0.3 and Beta =3 & S_Frac=0.5) of the LFSR to illustrate the effect of changing these parameters. The panel heading shows the parameterizatoins used for the other parameters not shown in the figures, these were the same as the reference case run. The three figures (Figures A#.1 – A#.3) show the diagonal elements of the LSFR parameterizations (



) and thus illustrate the extreme and middle parameterizations.

The WG noted that the SS model used CPUE and catch data through to 2012. The WG had recommended against using 2012 data as catch estimates were not available for the majority of fleets. A model (the base case) was run using data up to 2011, and results showed that estimated dynamics were not influenced by the inclusion of 2012 data. The WG concluded that the grid of models using 2012 data were appropriate for making stock conservation advice. For the figures below, 2011 was used as the diagnostic year for comparison to the production model.

In Figures A#.1 – A#.3, the pannels are: Total biomass tragectory (top left); stock recruitment curve (second from top left); equilibrium catch curve with the equilibrium point printed in the figure; and the catch in 2011 / MSY shown atop the figure; the fit to the index (or indices of abundance); the estimated selectivity; and the temporal kobe plot, with the year 2011 marked with a blue dot.

Figures A#.4 shows the SSB/SSB_{MSY} trajectories color coded for each of the axes of uncertaity considered in this assessment. Figures A#.5 shows the CPUE specific results via bar plots in a Kobe matrix results framework. Figures A#.6 shows the management quantites (B_{2011}/B_{ZERO} upper left hand plot, catch in 2011/MSY, upper right hand plot, and current fishing mortality / F_{MSY}) for the 9 parameterizations of the LFSR curve. These plots are color coded by Beta values.

In general the cross cutting themes are that

a. There was a strong trend with S_Frac, with the large majority of runs undertaken with 0.1 giving results where $F>F_{MSY}$ and $B<B_{MSY}$ and the majority of runs at 0.3 and 0.5 result in terminal stock status where $F<F_{MSY}$ and $B>B_{MSY}$.
b. There was also a strong trend in stock status with Beta, but it was less extreme than for S_Frac.
c. Stock status improved considerably with higher initial equilibrium catches, as this increased mean recruitment levels relative to the observed catch history over the modelled period.
d. Higher weight on the length data generally resulted in estimates of a less depleted stock. We believe this reflects a positive bias being introduced into the model as demonstrated by the Age-Structured Production Model (ASPM) diagnostic analyses presented to SC9.
e. The alternative values considered for the standard deviation of the recruitment deviates had little impact on the estimates of stock status.

Annex 6 provides projections of catch and stock status from the present to 2031. For the reference case model, most model runs provide optimistic projections, whereas an alternative model run set to have the LFSR curve with less compensation, most scenarios were pessimistic.

7 Conclusions

1. The outcomes of the Stock Synthesis modelling for blue shark in the North Pacific Ocean provide three key areas of concern regarding the reliability of the stock assessments:
    a. <u>Insufficient information to estimate initial depletion</u>: approaches at estimating initial fishing mortality or catches proved to be unsuccessful and therefore there is not sufficient information in the size data (a typical source of information on depletion) or other model inputs to reliably estimate the level of depletion at the start of the model;

b. Lack of a CPUE series that extends through the temporal model domain: no CPUE series spans the entire period of the model and therefore there is nothing to link relative abundance across the model period. This is demonstrated by the very different biomass trajectories that were obtained with the same CPUE series; and

c. Variety of spawner-recruitment relationships with similar 'productivity (SB/SBmsy)': through the use of the Low Fecundity Spawner Recruitment Relationship (LFSR) in Stock Synthesis we were able to consider a wide range of LFSR shapes which gave similar productivity to that assumed in the production model. The resulting stock status conclusions were extremely sensitive to the shape of the LFSR function.

2. The results from using alternative CPUE series in the current assessment are less different, in terms of their implied changes in abundance, than the individual CPUE series are. There are only minor differences in stock status across the CPUE series with model runs using the Japanese early and late indices producing slightly more optimistic stock status than model runs using the SPC model series.

3. The LFSR parameterisation has the most influence on the assessment. Across the LFSR options tested, stock status can range from heavily overfished and rapidly declining to lightly exploited and strongly increasing, and almost everything in between. Moderate to good fit to the CPUE series can be obtained across the total spectrum of stock status outcomes, i.e., you can fit the data equally well and have a very optimistic or very pessimistic stock status. We believe that it is possible that the LFSR relationship is not performing as expected at higher values of S_Frac and Beta, i.e., the model indicates that you can have strongly declining recruitment with increasing stock size.

4. In order to use the model runs from Stock Synthesis in the provision of management advice, will require the Scientific Committee to clearly articulate the reason(s) for determining which set(s) of LRSR parameters are most representative of range of biological responses one might expect from blue shark. This decision could be based on ecological theory of compensatory processes and/or model performance (see note above).

5. The following patterns in terminal stock status were seen across the other axes of uncertainty:

   a. The LFSR overwhelmed other sources of uncertainty. There was a strong trend with S_Frac, with the large majority of runs undertaken with 0.1 giving results where $F>F_{MSY}$ and $B<B_{MSY}$ and the majority of runs at 0.3 and 0.5 result in terminal stock status where $F<F_{MSY}$ and $B>B_{MSY}$.

   b. There was also a strong trend in stock status with Beta, but it was less extreme than for S_Frac.

   c. Stock status improved considerably with higher initial equilibrium catches, as this increased mean recruitment levels relative to the observed catch history over the modelled period.

   d. Higher weights on the length data generally lead to more optimistic stock status results. We believe this reflects a positive bias being introduced into the model as demonstrated by the Age-Structured Production Model (ASPM) diagnostic analyses presented to SC9.

   e. Alternative values considered for the standard deviation of the recruitment deviates had little impact on the estimates of stock status.

6. 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 consideration of alternative LFSR parameterisations will be important and we suggest [Beta:S_Frac] combinations such as [1:0.5], [2:0.3], and [3:0.1]. Some of the flatter curves exhibit almost no compensation and some of the stronger curves displayed poor

performance in the modelling. Stock status summaries for any set of model runs can be provided on request.

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

    - Detailed consideration of how the biology of blue sharks can be modelled within the Stock Synthesis modelling framework (including the LFSR).
    - 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.
    - Further development of the CPUE series, including consideration of alternative approaches to model changes in targeting, approaches to develop longer time series or constrain catchability differences across CPUE series. Development of simulation models to test alternative approaches is recommended.

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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 Peterson and Wroblewski (1984) method and the Nakano data (Rice and Semba 2014).

	Nakano		Hsu	
Age	Male	Female	Male	Female
0	0.564	0.535	0.359	0.366
1	0.300	0.309	0.245	0.245
2	0.220	0.233	0.195	0.195
3	0.180	0.194	0.166	0.168
4	0.156	0.171	0.147	0.151
5	0.140	0.155	0.134	0.139
6	0.128	0.144	0.125	0.130
7	0.120	0.135	0.118	0.124
8	0.114	0.129	0.112	0.119
9	0.109	0.124	0.108	0.115
10	0.105	0.120	0.104	0.112
11	0.101	0.117	0.101	0.110
12	0.099	0.114	0.099	0.108
13	0.096	0.112	0.097	0.106
14	0.095	0.110	0.095	0.105
15	0.093	0.109	0.094	0.104
16	0.092	0.107	0.092	0.103
17	0.090	0.106	0.091	0.102
18	0.089	0.105	0.090	0.102
19	0.089	0.105	0.090	0.101
20	0.088	0.104	0.089	0.101
21	0.087	0.103	0.088	0.100
22	0.087	0.103	0.088	0.100
23	0.086	0.103	0.087	0.100
24	0.086	0.102	0.087	0.099
25	0.085	0.102	0.087	0.099
26	0.085	0.102	0.086	0.099
27	0.085	0.101	0.086	0.099
28	0.085	0.101	0.086	0.099
29	0.084	0.101	0.086	0.099
30	0.084	0.101	0.085	0.099

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

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

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

Axes of uncertainty and options considered			
GROUP	**Variable**	**Options Run**	
CPUE (five)			
	CPUE Series	1. JPN Early and JPN Late	
		2. JPN Early and HW Deep Late	
		3. HW Deep Late	
		4. SPC Late	
		5. Taiwan Late	
Natural Mortality (two)			
	Natural Mortality (Peterson and Wroblewski (1984) method with data from:	1. Nakano (1994)	
		2. Hsu et al. 2011	
Length Composition (two)			
	Sample Size weighting	0.2 and 1	
Stock Recruitment (nine)			
	Low Fecundity Stock Recruitment Function	Beta	S_Frac (all combinations)
		1	0.1
		2	0.3
		3	0.5
Recruitment variation (two)			
	Sigma R (SD on the recruitment deviations)	0.1 and 0.3	
Initial Equilibrium Catch (three)			
	Fit to exact amount	20,000 MT	
		40,000 MT	
		60,000 MT	
	1080 combinations		

Table 4: Key likelihood components / penalties from the reference case model and all one-change sensitivity analyses. Note: CPUE 2 is the run with the Japanese early and Hawaiian deepset series and CPUE 4 is based on the SPC CPUE series, CPUE 5 is based on the HW CPUE series, and CPUE 6 is based on the Taiwanese CPUE series. Note that the overall objective function for the CPUE and sample size weighting runs (shaded) are not comparable to the other runs. Lower likelihoods indicate better fit.

	Reference	CPUE 2	CPUE 4	CPUE 5	CPUE 6	Beta =1 & Sfrac= 0.1	Beta =2 & Sfrac= 0.1	Beta =3 & Sfrac= 0.1	Beta =1 & Sfrac= 0.3
Catch	4.60E-07	9.38E-08	8.52E-09	9.13E-09	4.31E-06	1.22E-06	5.36E-07	2.80E-07	4.71E-07
Fleet_19	0.0	6.5	0.0	5.9	0.0	0.0	0.0	0.0	0.0
Fleet_21	0.0	0.0	0.0	0.0	15.2	0.0	0.0	0.0	0.0
Fleet_23	1.3	1.8	0.0	0.0	0.0	2.6	1.9	1.7	1.3
Fleet_24	1.2	0.0	0.0	0.0	0.0	2.2	1.7	1.6	1.2
Fleet_27	0.0	0.0	9.2	0.0	0.0	0.0	0.0	0.0	0.0
Length_comp	49.9	49.8	49.8	49.8	50.2	51.0	50.7	50.6	50.2
Recruitment	-2.527	-2.287	-2.171	-2.369	-2.627	-2.359	-2.488	-2.524	-2.538
Parm_priors	0.008	0.009	0.012	0.012	0.006	0.013	0.013	0.012	0.011
TOTAL	7.776	18.495	36.472	37.768	52.010	11.912	9.867	9.266	8.030

	Beta =3& Sfrac= 0.3	Beta =1 & Sfrac= 0.5	Beta =2& Sfrac= 0.5	Beta =3& Sfrac= 0.5	M at Age = Lo	Sample Size = 1	SigmaR = 0.3	Initial Catch = 20,000	Initial Catch = 60,000
Catch	2.98E-07	9.02E-07	2.95E-06	3.74E-06	5.59E-07	2.20E-07	6.95E-07	2.61E-05	3.54E-07
Fleet_19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fleet_21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fleet_23	1.4	1.1	0.7	0.8	1.2	1.5	0.8	1.9	1.4
Fleet_24	0.9	1.1	0.8	3.1	1.0	1.0	0.8	1.8	1.3
Fleet_27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Length_comp	49.7	49.8	49.5	50.0	50.2	124.4	49.8	50.7	49.9
Recruitment	-2.541	-2.541	-2.623	-1.283	-2.546	-2.393	-0.905	-1.992	-2.522
Parm_priors	0.006	0.007	0.003	0.002	0.004	0.008	0.007	0.005	0.008
TOTAL	7.403	7.308	6.204	10.563	7.734	82.480	8.406	11.270	7.940

Table 5: Estimates of key management quantities for the reference case model and all one-change sensitivity analyses. Latest = 2012 and cur = the mean over the period 2008-2012. Note: CPUE 2 is the run with the Japanese early and Hawaiian deepset series and CPUE 4 is based on the SPC CPUE series, CPUE 5 is based on the HW CPUE series, and CPUE 6 is based on the Taiwanese CPUE series.

	Units	Reference	CPUE 2	CPUE 4	CPUE 5	CPUE 6	Beta =1 & Sfrac= 0.1	Beta =2 & Sfrac= 0.1	Beta =3 & Sfrac= 0.1	Beta =1 & Sfrac= 0.3
C_latest	T	36,636	36,636	36,636	36,636	36,636	36,636	36,636	36,636	36,636
C2012_msy		0.50	0.44	0.36	0.36	0.57	1.44	0.83	0.70	0.51
Y_MSY	T	73,636	83,392	103,050	102,656	64,586	25,528	43,994	52,694	71,230
equil_pt		0.47	0.47	0.47	0.47	0.47	0.49	0.51	0.52	0.46
Recr_Virgin	T	27,666	31,497	39,119	38,988	24,057	41,101	39,910	39,378	34,560
B_zero	T	7,744,990	8,817,190	10,951,000	10,914,500	6,734,630	11,505,900	11,172,300	11,023,400	9,674,850
B_msy	T	3,619,704	4,120,616	5,116,571	5,099,602	3,147,899	5,608,698	5,659,559	5,767,556	4,424,184
B_cur	T	5,875,342	7,322,606	9,671,608	9,709,793	4,166,278	3,706,312	4,465,870	5,078,334	5,451,778
SB_zero	T	606,493	690,454	857,550	854,687	527,374	900,998	874,881	863,219	757,616
SB_msy	T	283,451	322,676	400,668	399,337	246,505	439,203	443,189	451,645	346,448
SB_cur	T	460,085	573,417	757,364	760,349	326,252	290,232	349,714	397,674	426,917
B_cur_F0	T	7,726,971	8,835,876	10,885,403	10,938,476	6,744,715	11,694,879	11,272,615	11,084,725	9,683,546
SB_cur_F0	T	605,082	691,917	852,413	856,565	528,164	915,797	882,737	868,021	758,297
B_cur/B_zero		0.76	0.83	0.88	0.89	0.62	0.32	0.40	0.46	0.56
B_cur/B_msy		1.62	1.78	1.89	1.90	1.32	0.66	0.79	0.88	1.23
B_cur/B_cur_F0		0.76	0.83	0.89	0.89	0.62	0.32	0.40	0.46	0.56
Bratio_1971		0.73	0.76	0.81	0.81	0.69	0.81	0.81	0.81	0.79
Bratio_2012		0.79	0.85	0.89	0.90	0.66	0.31	0.39	0.46	0.58
Bratio_cur		0.76	0.83	0.88	0.89	0.62	0.32	0.40	0.46	0.56
B_msy/ B_zero		0.47	0.47	0.47	0.47	0.47	0.49	0.51	0.52	0.46
SB_cur/SB_zero		0.76	0.83	0.88	0.89	0.62	0.32	0.40	0.46	0.56
SB_cur/SB_msy		1.62	1.78	1.89	1.90	1.32	0.66	0.79	0.88	1.23
SB_cur/SB_cur_F0		0.76	0.83	0.89	0.89	0.62	0.32	0.40	0.46	0.56
SB_msy/SB_zero		0.47	0.47	0.47	0.47	0.47	0.49	0.51	0.52	0.46
SB_cur_init		1.04	1.09	1.09	1.10	0.90	0.40	0.49	0.57	0.72
Fcur		0.09	0.08	0.07	0.07	0.12	0.19	0.15	0.12	0.10
F_msy		0.22	0.22	0.23	0.23	0.22	0.07	0.12	0.14	0.22
F_2012_msy		0.33	0.29	0.23	0.24	0.42	2.21	0.98	0.71	0.37
F_cur_msy		0.42	0.36	0.29	0.29	0.54	2.66	1.20	0.88	0.47

	Units	Beta =3& Sfrac= 0.3	Beta =1 & Sfrac= 0.5	Beta =2& Sfrac= 0.5	Beta =3& Sfrac= 0.5	M at Age =Lo	Sample Size = 1	SigmaR = 0.3	Initial Catch = 20,000	Initial Catch = 60,000
C_latest	T	36,636	36,636	36,636	36,636	36,636	36,636	36,636	36,636	36,636
C2012_msy		0.49	0.36	0.43	0.44	0.44	0.47	0.51	0.63	0.48
Y_MSY	T	74,229	102,443	85,596	82,584	83,767	77,845	71,960	57,761	76,327
equil_pt		0.49	0.42	0.43	0.46	0.46	0.47	0.47	0.47	0.47
Recr_Virgin	T	24,849	26,059	16,861	14,425	20,489	29,151	27,079	21,093	28,697
B_zero	T	6,956,360	7,294,980	4,720,130	4,038,190	8,048,720	8,160,680	7,580,500	5,904,710	8,033,440
B_msy	T	3,425,497	3,077,713	2,027,665	1,873,758	3,706,437	3,815,781	3,542,484	2,763,415	3,754,351
B_cur	T	6,227,309	5,489,866	4,317,995	3,597,734	6,724,706	6,499,918	5,637,279	2,807,882	6,106,483
SB_zero	T	544,737	571,254	369,623	316,222	666,345	639,044	593,612	462,385	629,081
SB_msy	T	268,243	241,009	158,782	146,730	306,852	298,805	277,404	216,397	293,995
SB_cur	T	487,647	429,900	338,133	281,731	556,732	508,994	441,443	219,879	478,185
B_cur_F0	T	6,938,440	7,280,971	4,720,788	4,146,886	8,032,830	8,153,992	7,493,670	5,860,500	8,014,796
SB_cur_F0	T	543,334	570,157	369,675	324,734	665,030	638,520	586,813	458,923	627,621
B_cur/B_zero		0.90	0.75	0.91	0.89	0.84	0.80	0.74	0.48	0.76
B_cur/B_msy		1.82	1.78	2.13	1.92	1.81	1.70	1.59	1.02	1.63
B_cur/B_cur_F0		0.90	0.75	0.91	0.87	0.84	0.80	0.75	0.48	0.76
Bratio_1971		0.70	0.71	0.54	0.46	0.73	0.74	0.72	0.81	0.60
Bratio_2012		0.91	0.78	0.89	0.81	0.86	0.82	0.77	0.51	0.79
Bratio_cur		0.90	0.75	0.91	0.89	0.84	0.80	0.74	0.48	0.76
B_msy/ B_zero		0.49	0.42	0.43	0.46	0.46	0.47	0.47	0.47	0.47
SB_cur/SB_zero		0.90	0.75	0.91	0.89	0.84	0.80	0.74	0.48	0.76
SB_cur/SB_msy		1.82	1.78	2.13	1.92	1.81	1.70	1.59	1.02	1.63
SB_cur/SB_cur_F0		0.90	0.75	0.91	0.87	0.84	0.80	0.75	0.48	0.76
SB_msy/SB_zero		0.49	0.42	0.43	0.46	0.46	0.47	0.47	0.47	0.47
SB_cur_init		1.28	1.06	1.70	1.93	1.15	1.07	1.03	0.59	1.27
Fcur		0.09	0.10	0.15	0.22	0.09	0.09	0.10	0.17	0.09
F_msy		0.22	0.39	0.31	0.27	0.24	0.22	0.22	0.22	0.22
F_2012_msy		0.36	0.21	0.40	0.57	0.30	0.31	0.35	0.58	0.32
F_cur_msy		0.44	0.26	0.48	0.80	0.36	0.39	0.44	0.76	0.40

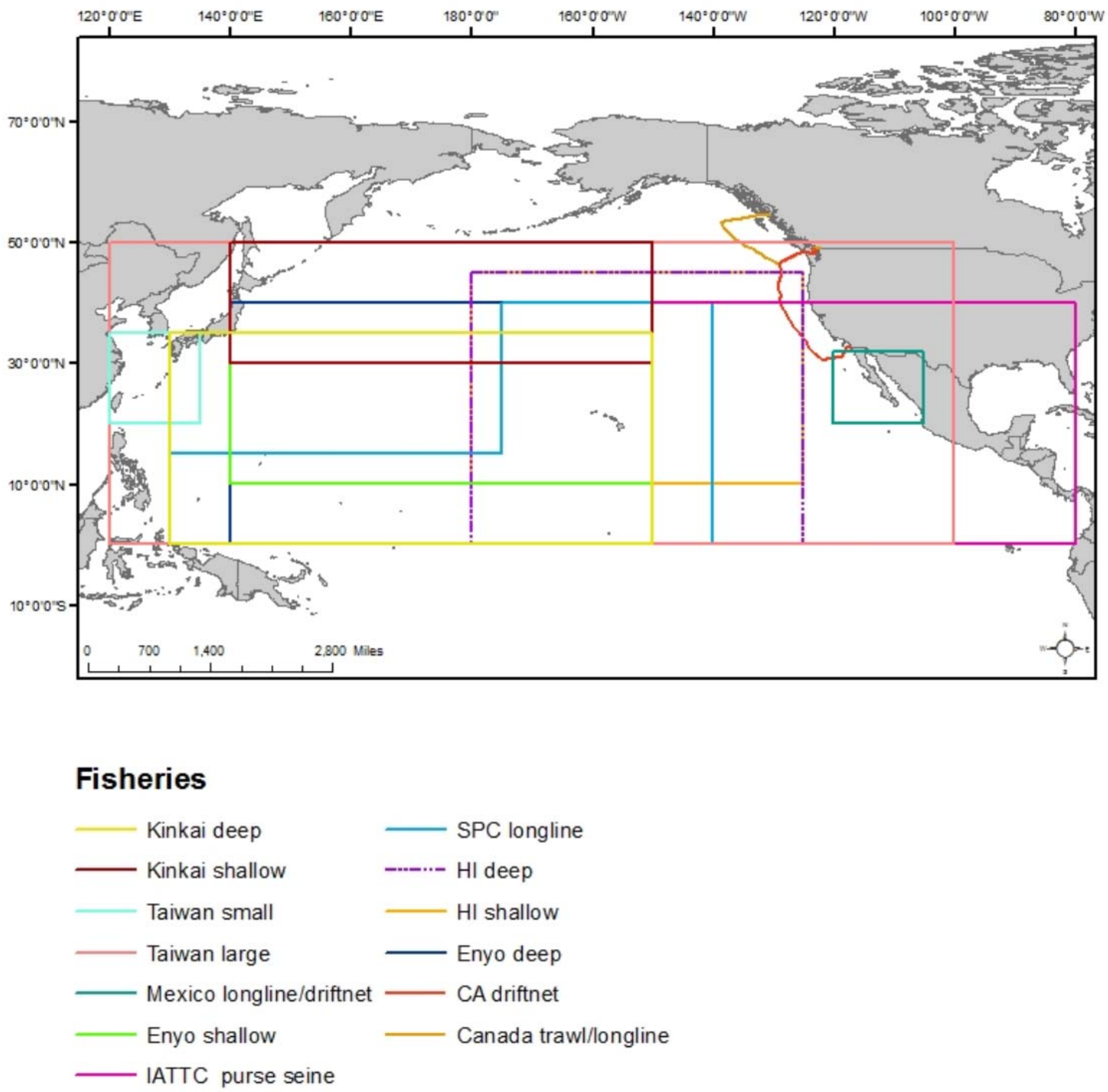


Figure 1: Spatial coverage of the assessment and the individual sources of catch and CPUE data used in the assessment of blue sharks in the north Pacific.

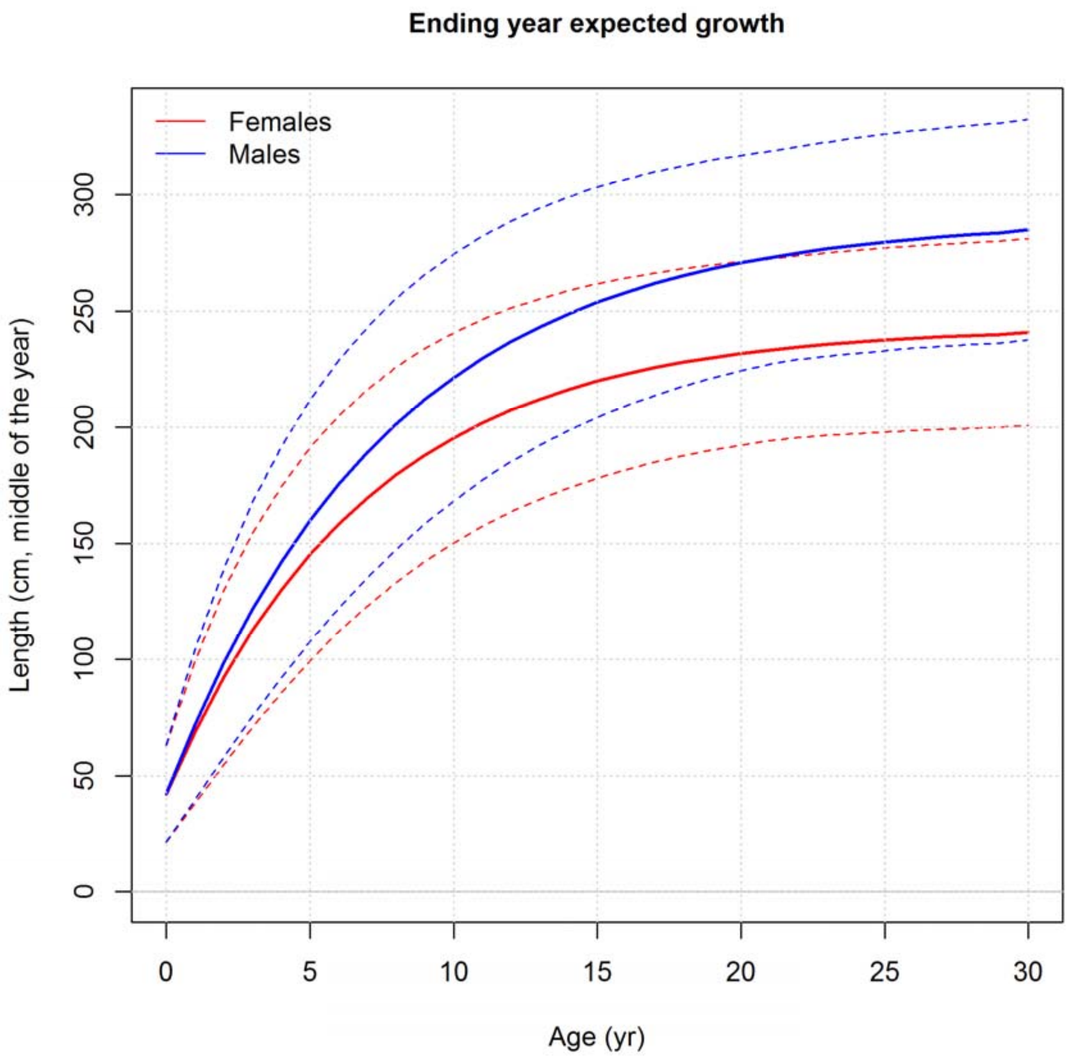


Figure 2: Sex-specific growth curves (from Nakano 1994) assumed in for the assessment of blue sharks in the north Pacific.

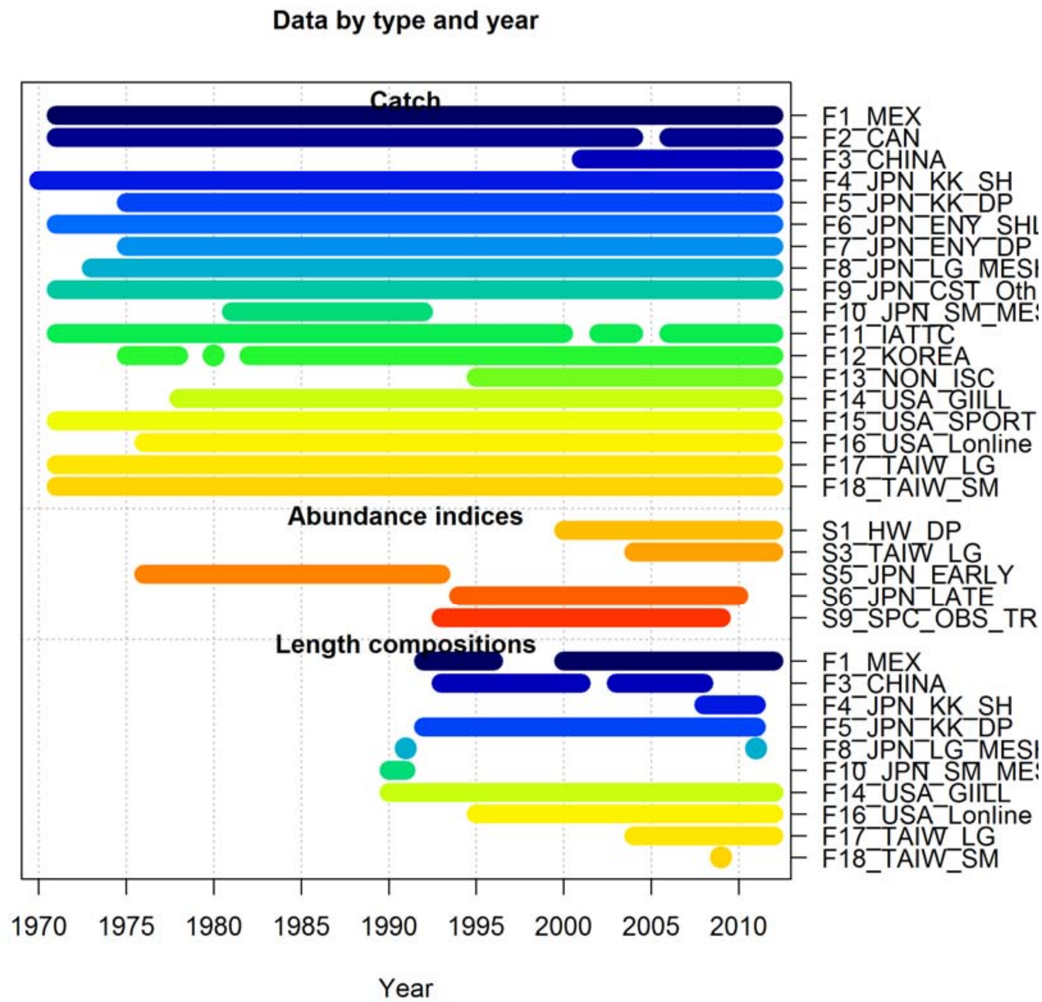


Figure 3: Temporal data coverage for the reference case model for the assessment of blue sharks in the north Pacific.

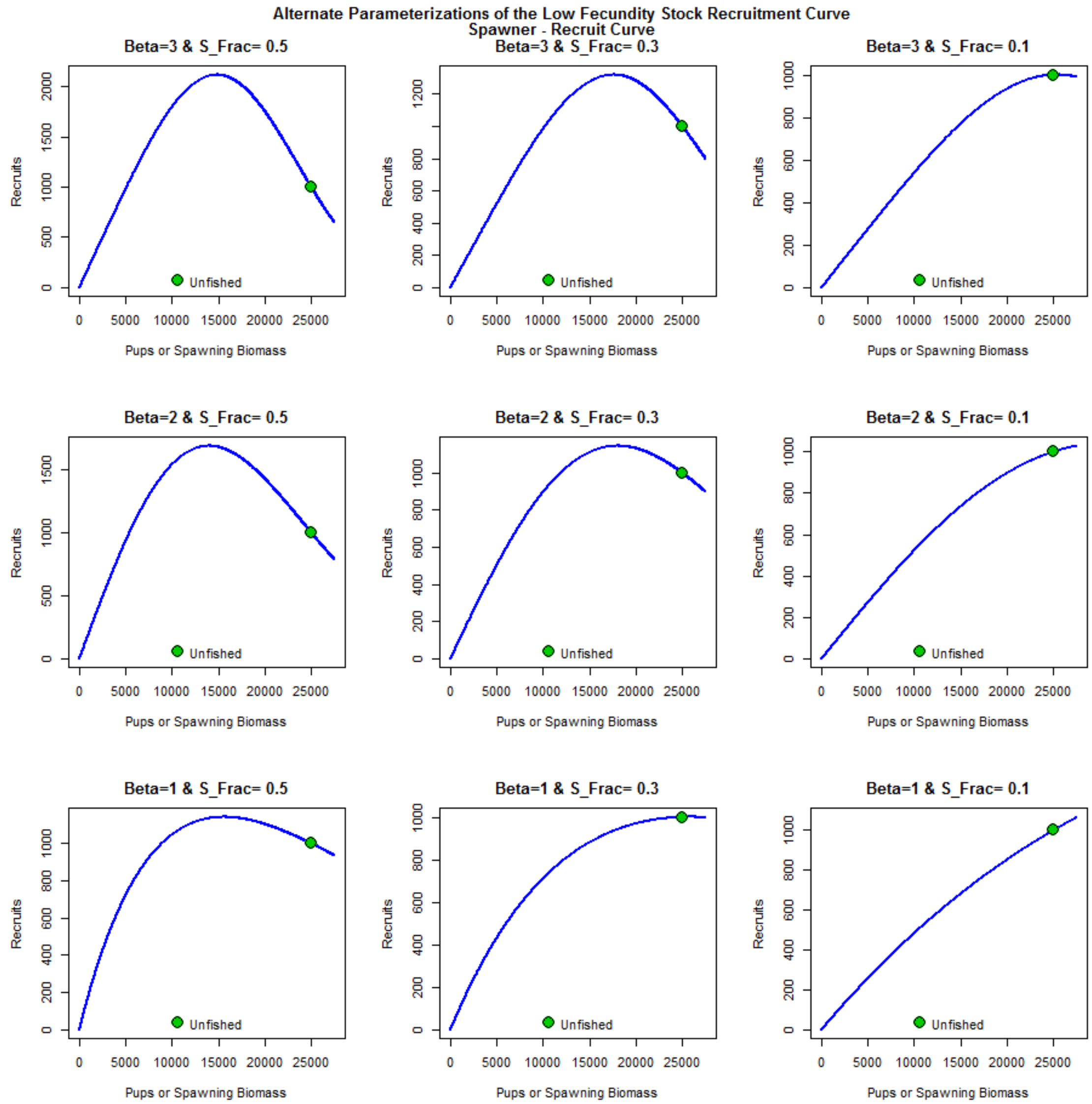


Figure 4: Spawner recruitment curves for the nine Low Fecundity Spawner Recruitment (LFSR) curves considered in the assessment of blue sharks in the north Pacific. The reference case model used S_Frac = 0.3 and Beta = 2.

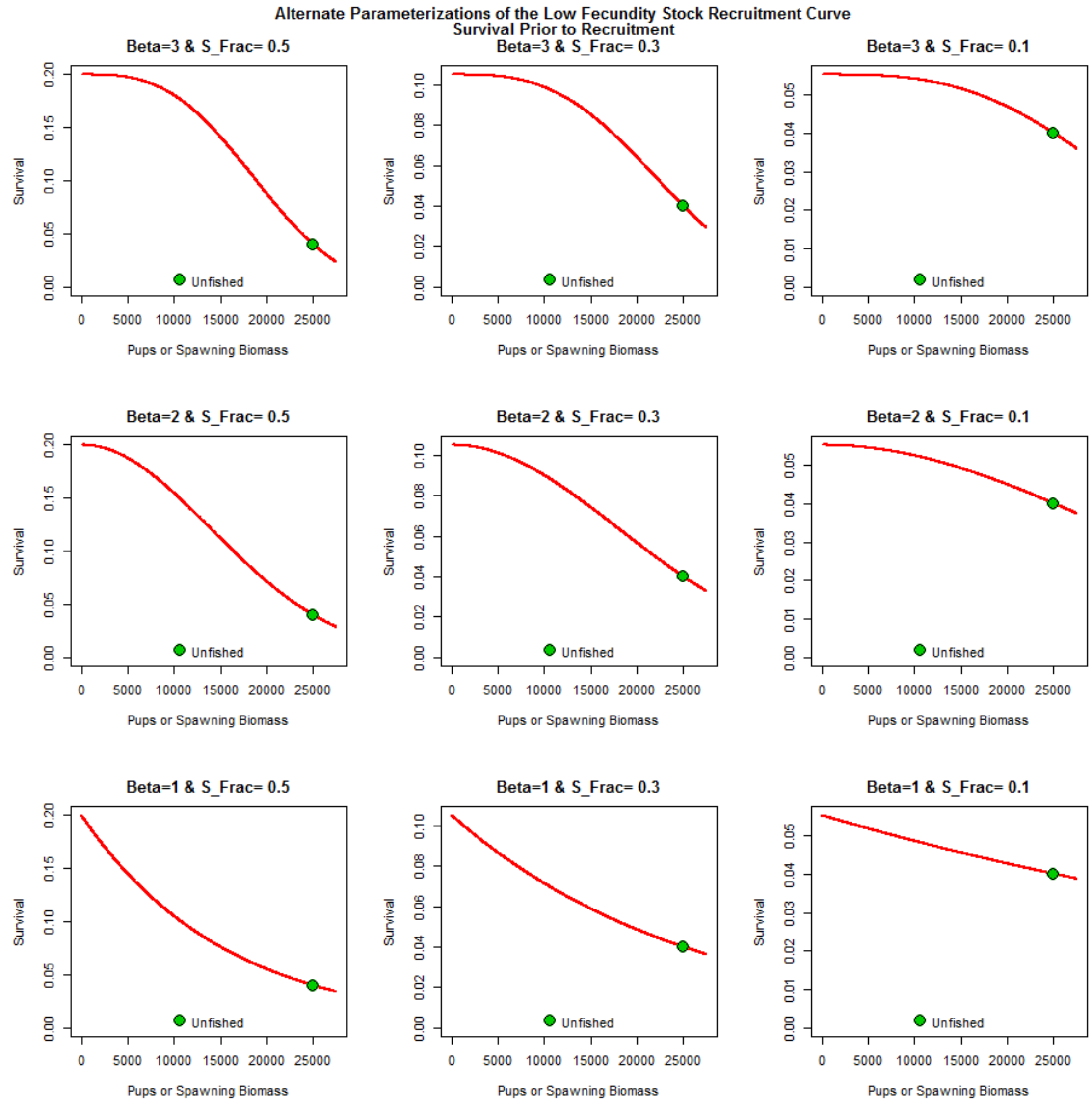


Figure 5: Pre-recruitment survival for the nine Low Fecundity Spawner Recruitment (LFSR) pre-recruit survival curves considered in the assessment of blue sharks in the north Pacific. The reference case model used S_Frac = 0.3 and Beta = 2.

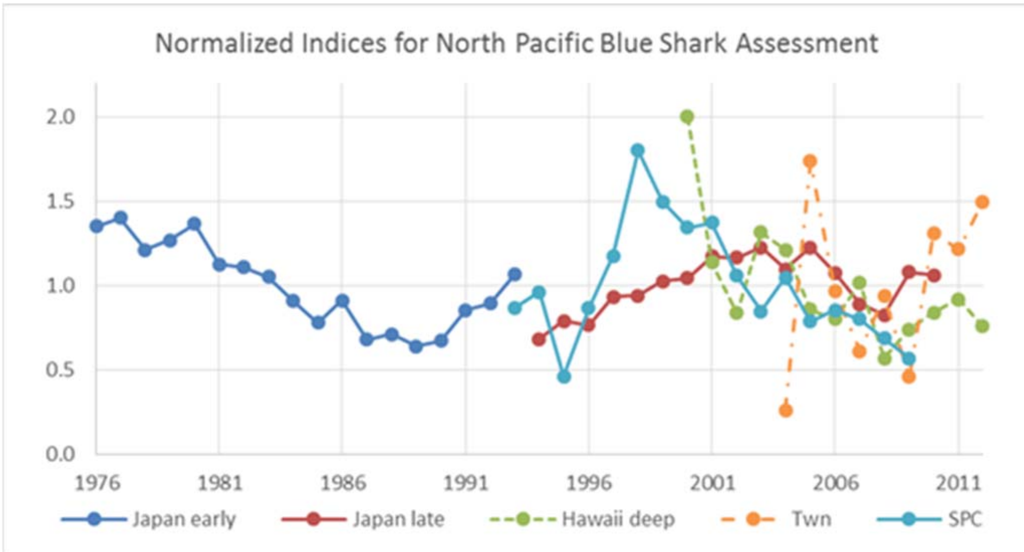


Figure 6: CPUE time series used in the assessment of blue sharks in the north Pacific.

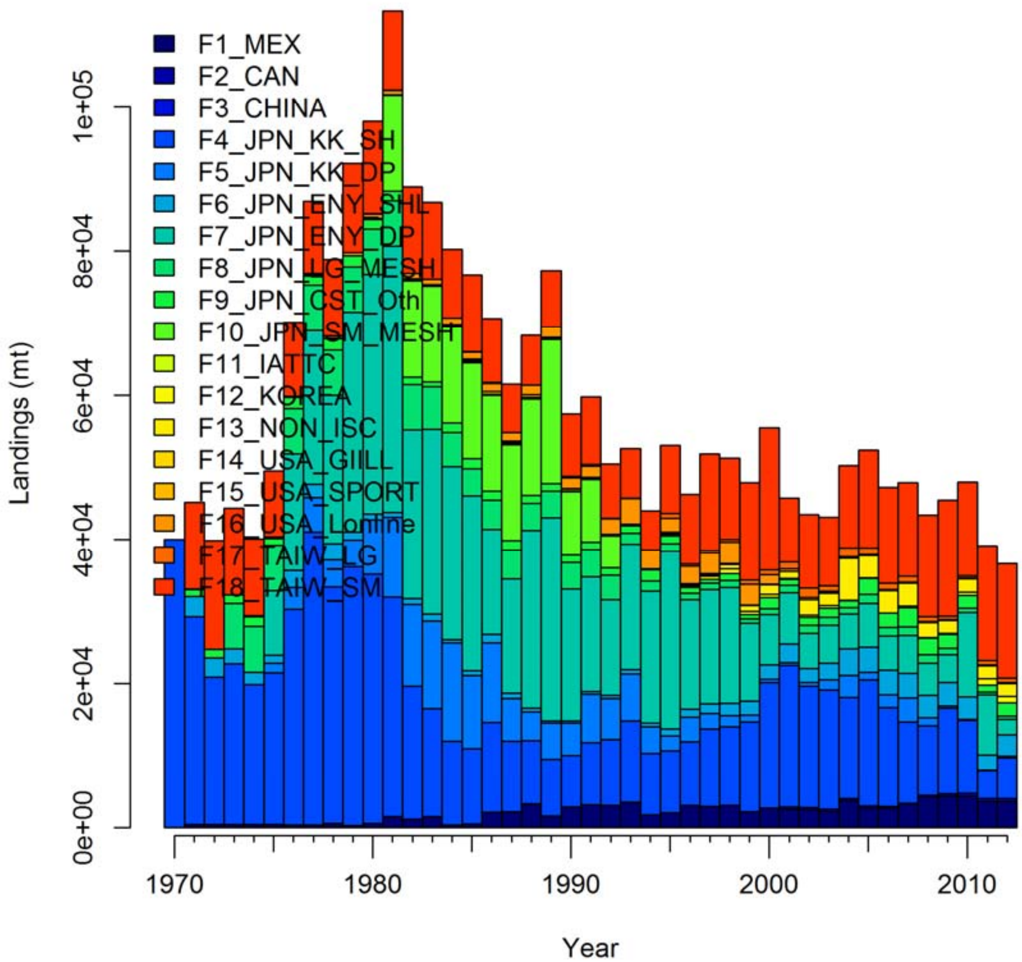
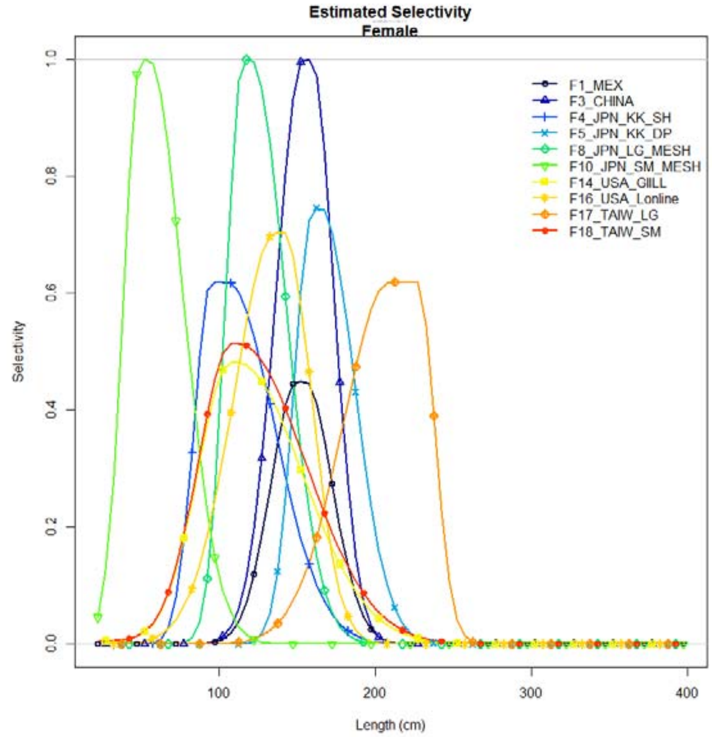


Figure 7: Assumed catches from the reference case model for blue sharks in the north Pacific. The assumed equilibrium historical catch for the reference case is provided as the first year in the time series. Note: catch in 1970 is an assumed level of catch used to derive the equilibrium fished condition and the selectivity of fishery 4 was assumed for these catches – this does not represent the actual assumed catches of this fleet.



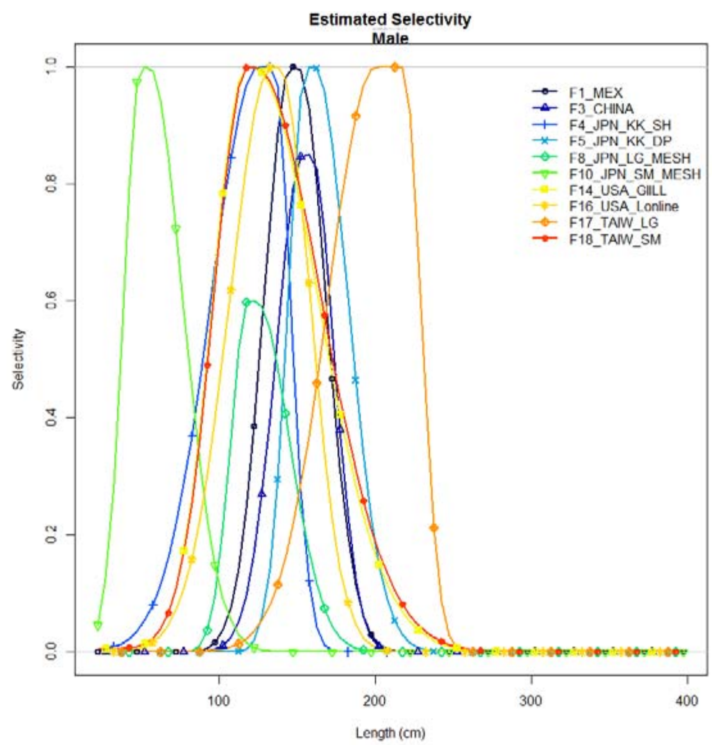
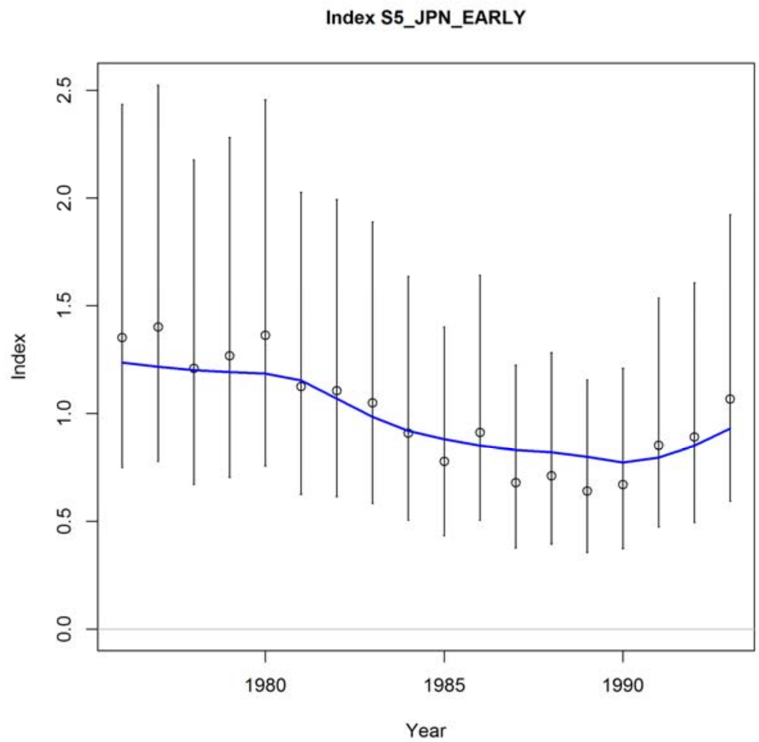


Figure 8: Selectivity curves estimated for female (top) and male (bottom) from the reference case model for the assessment of blue sharks in the north Pacific.



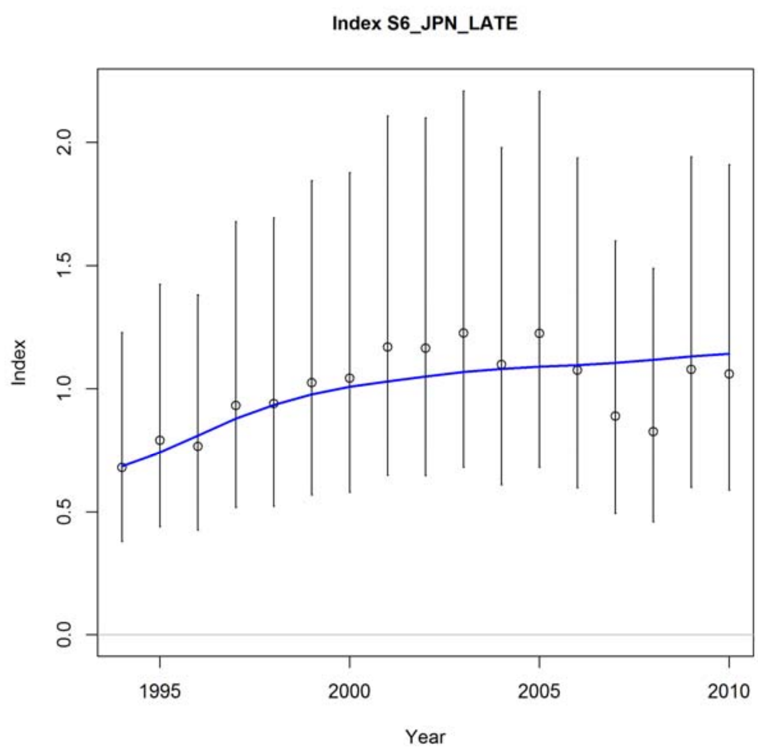


Figure 9: Fit to the Japanese early (top) and late (bottom) CPUE time series for the reference case model for the assessment of blue sharks in the north Pacific.

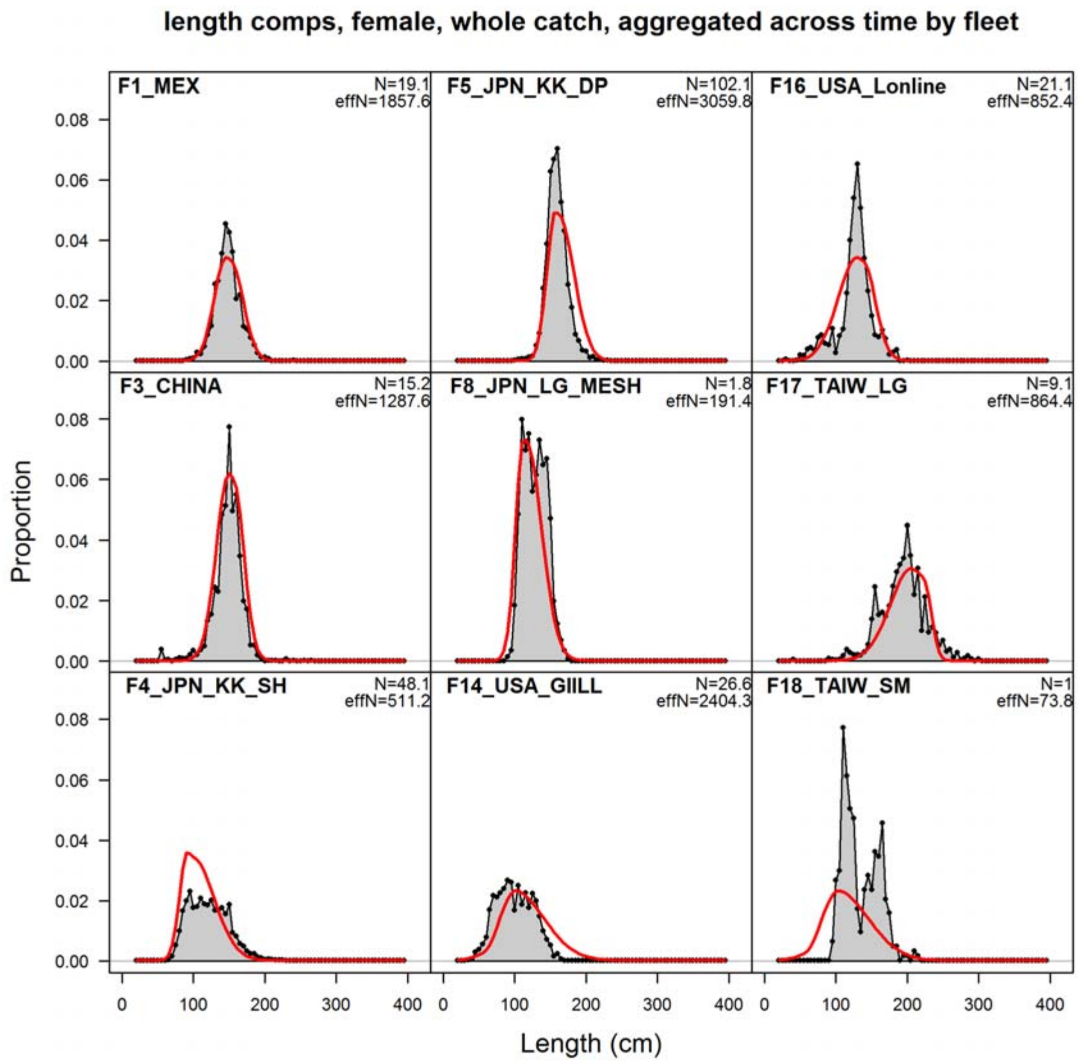


Figure 10: Fit to the female length frequency data for the reference case model for the assessment of blue sharks in the north Pacific.

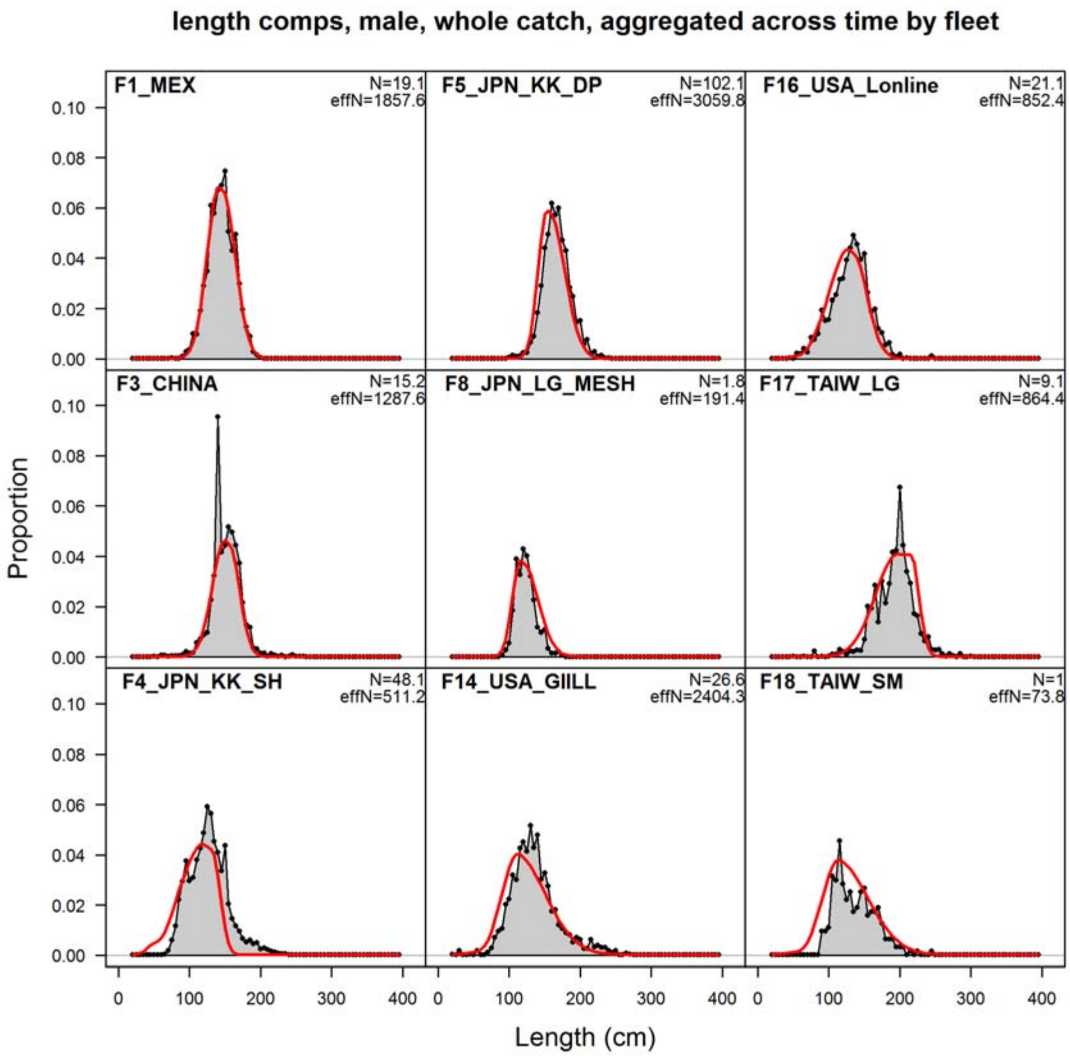


Figure 11: Fit to the male length frequency data for the reference case model for the assessment of blue sharks in the north Pacific.

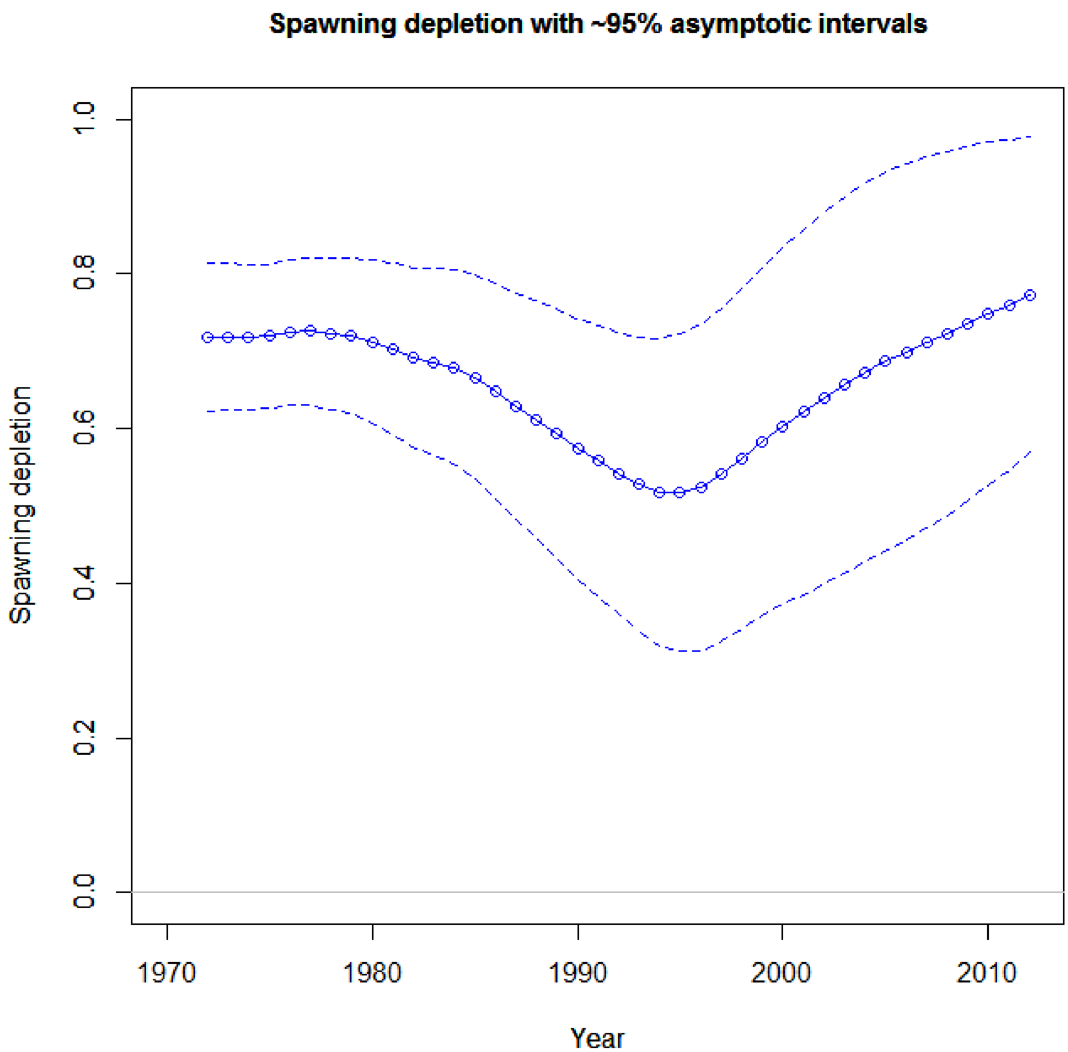


Figure 12: Spawning depletion for the reference case model for the assessment of blue sharks in the north Pacific.

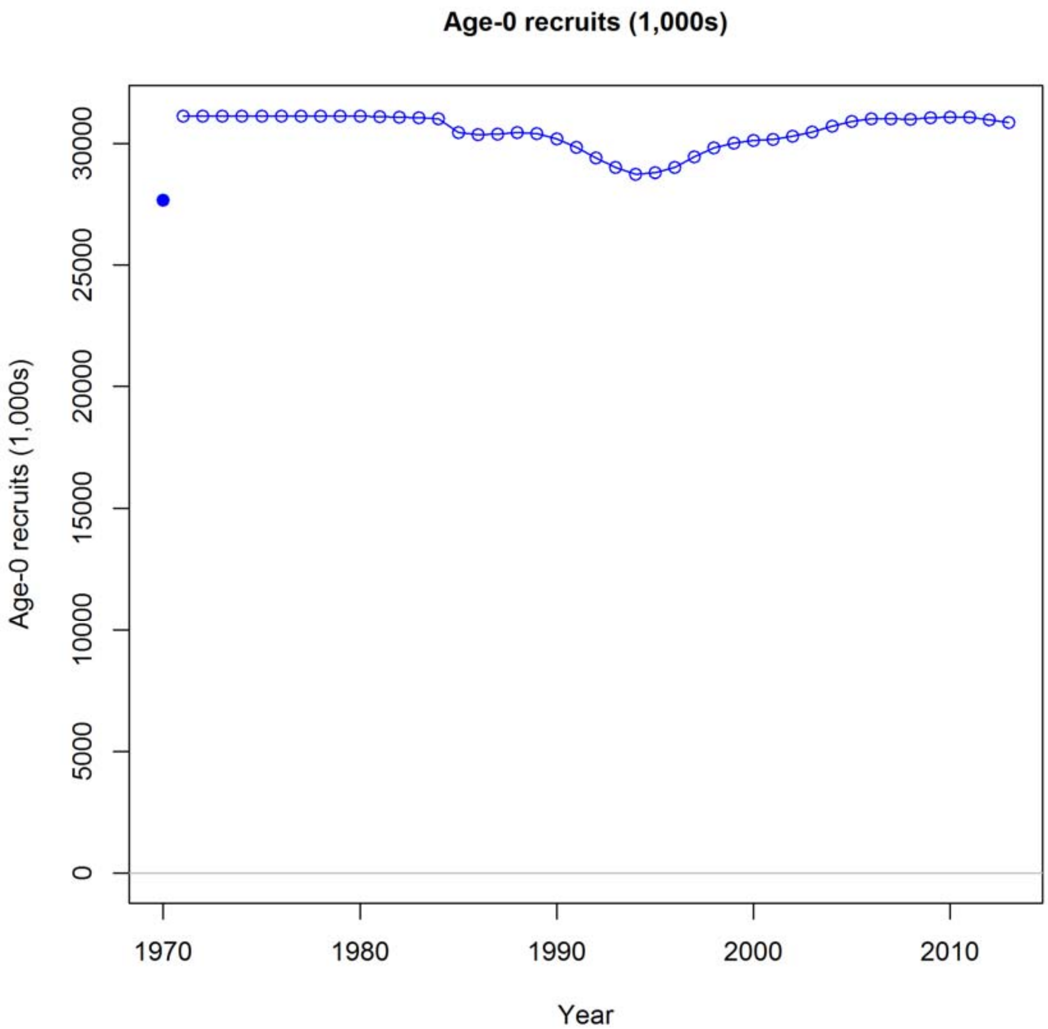


Figure 13: Estimated recruitment including the estimate of virgin recruitment (filled circle at the start of the time series) for the reference case model for the assessment of blue sharks in the north Pacific, note that recruitment is higher than virgin due to the compensation implied by the parameterization of the LFSR.

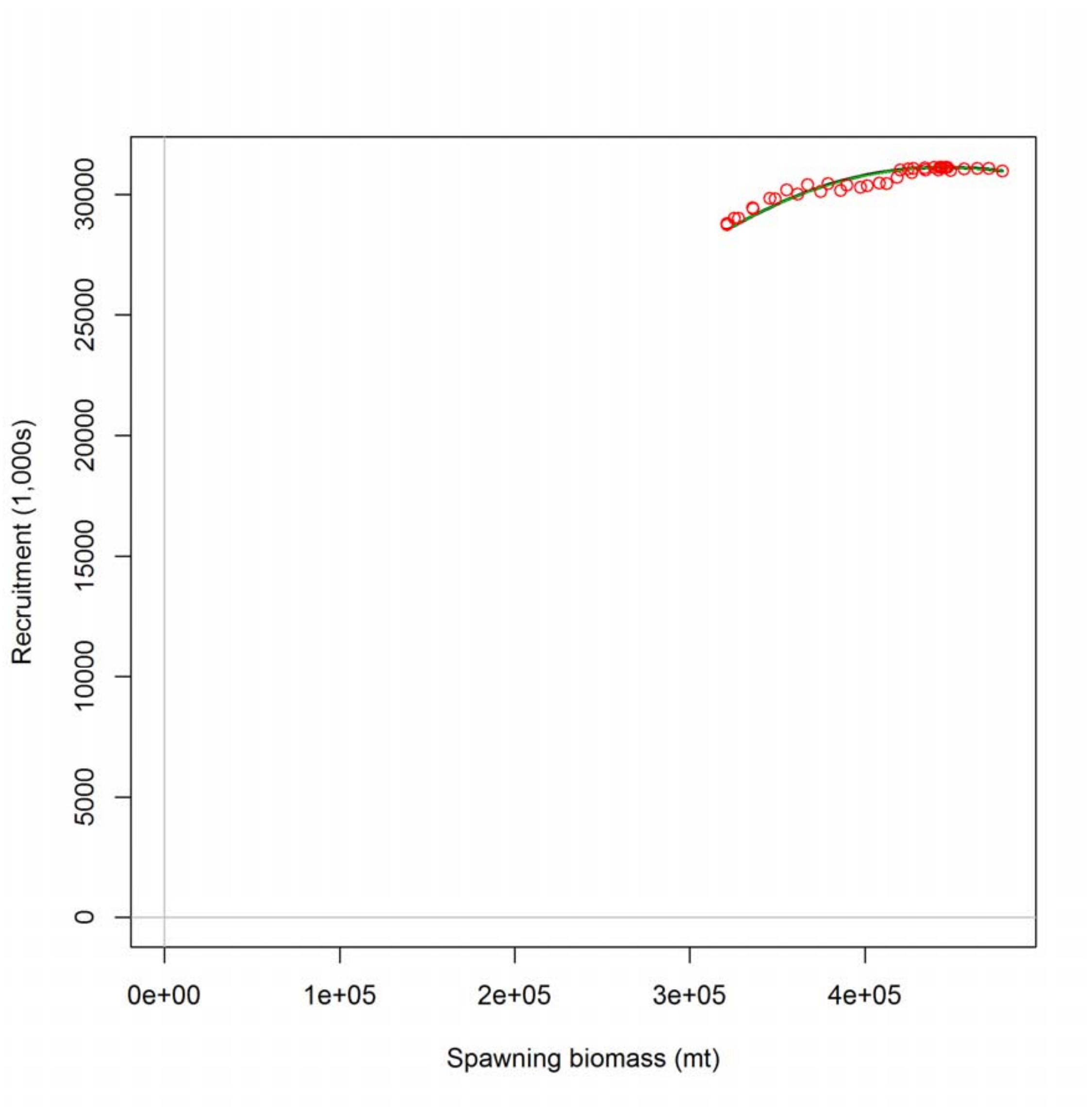


Figure 14: Spawner recruitment time series for the reference case model for the assessment of blue sharks in the north Pacific.

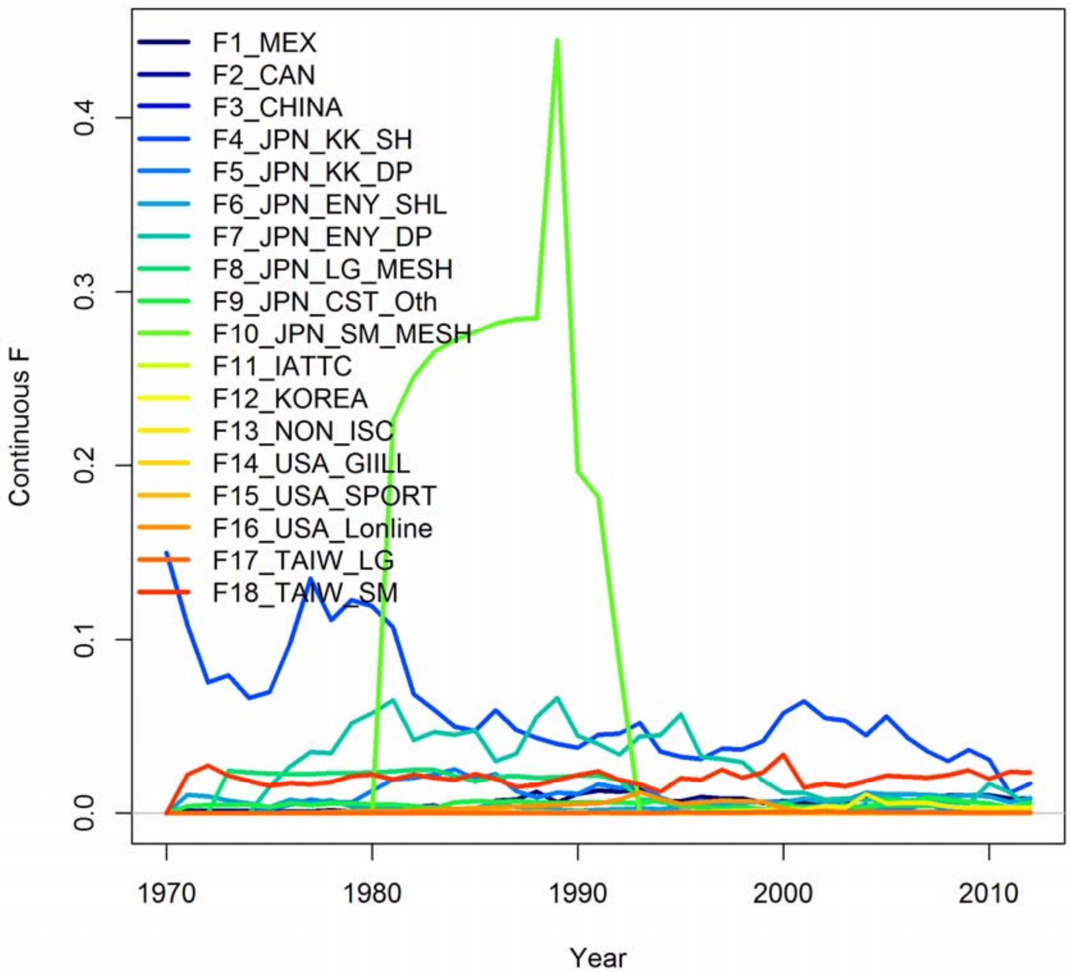


Figure 15: Estimated fishing mortality for each fishing gear for the assessment of blue sharks in the north Pacific.

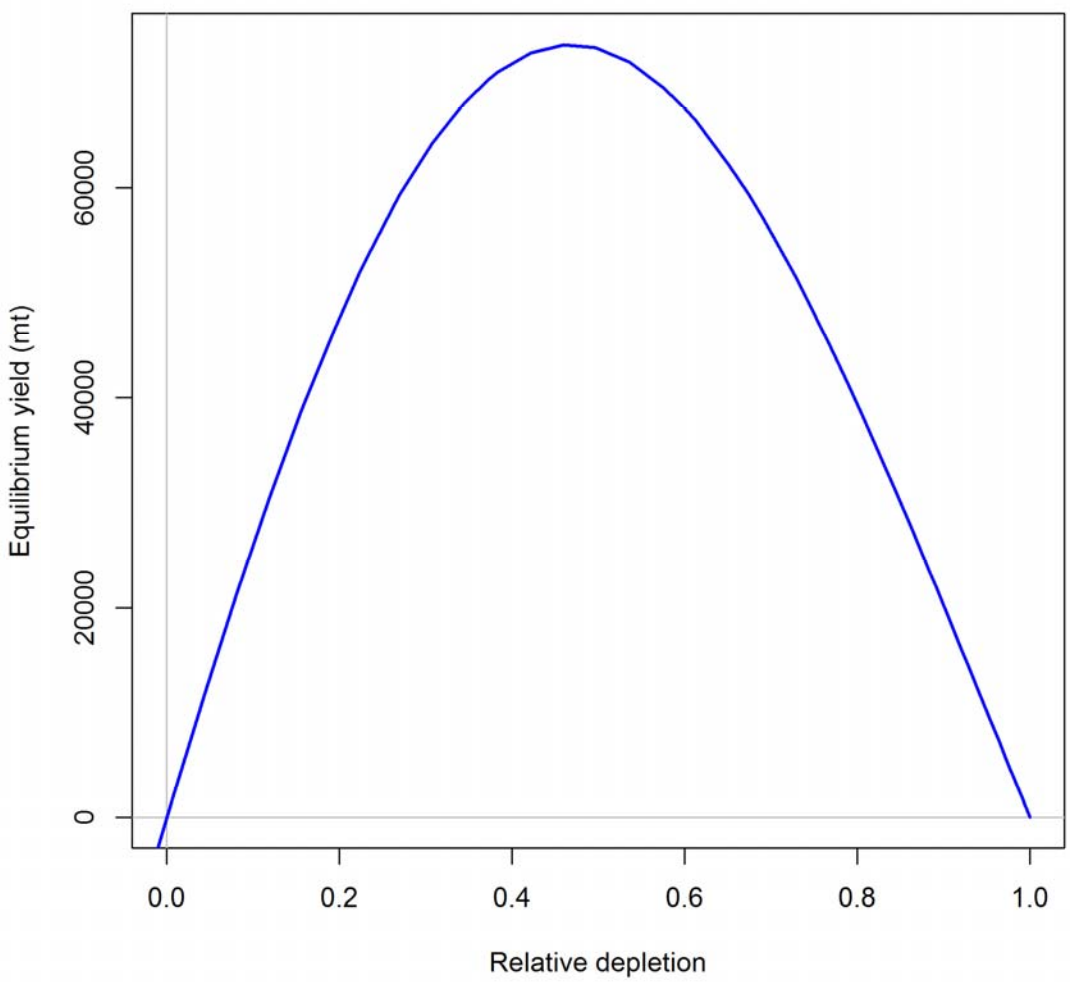


Figure 16: Equilibrium yield curve for the reference case model for the assessment of blue sharks in the north Pacific.

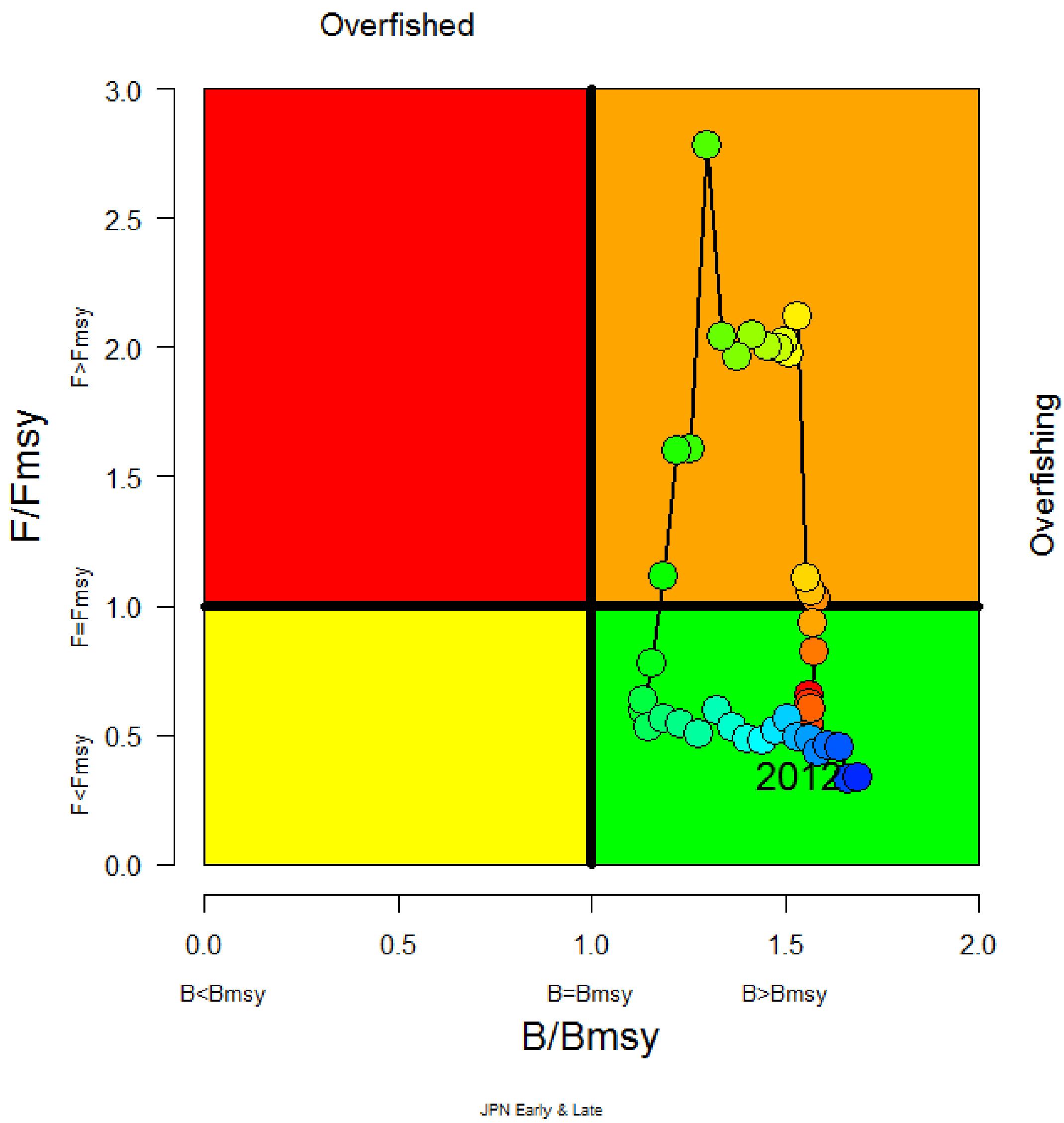


Figure 17: Kobe plot for the reference case model for the assessment of blue sharks in the north Pacific.

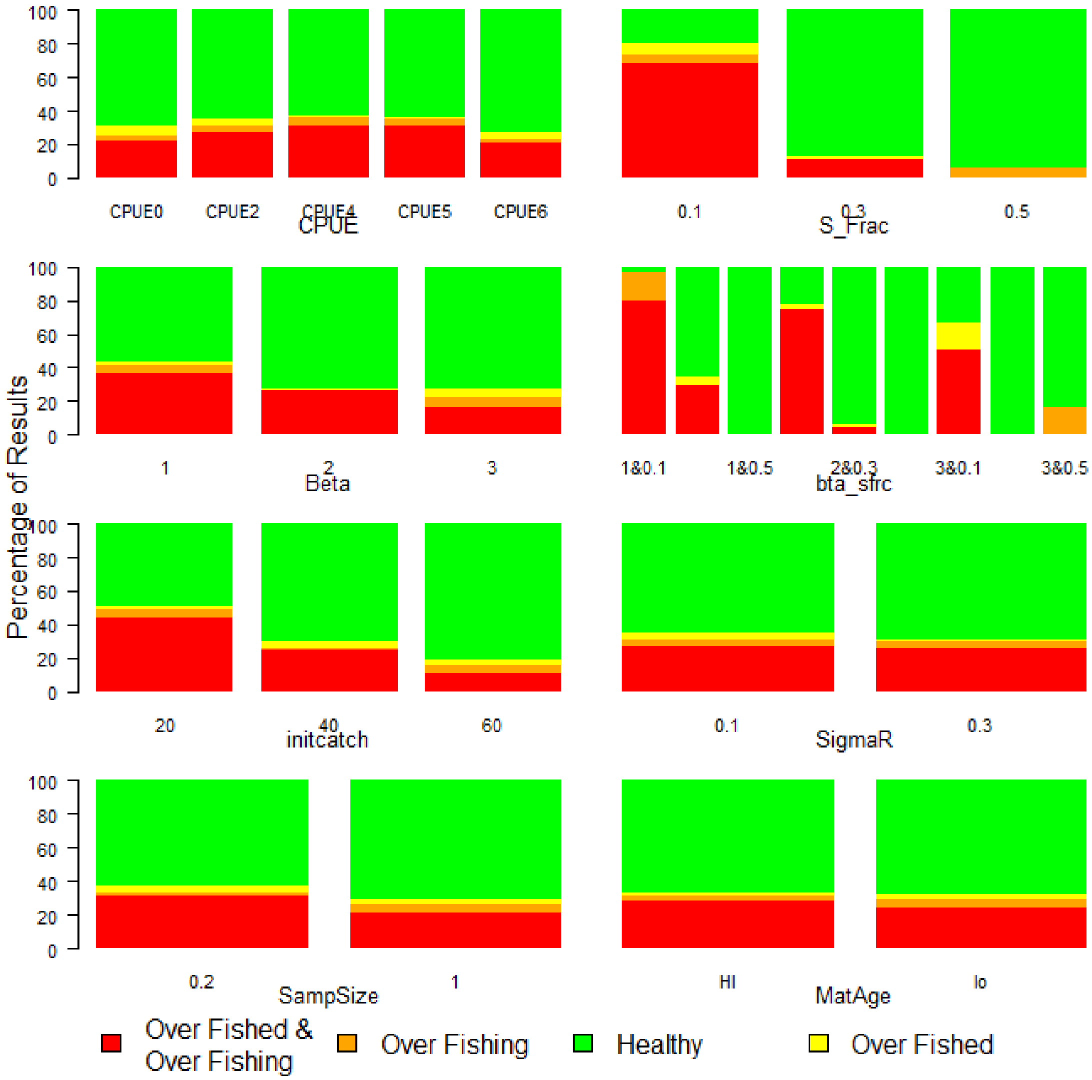
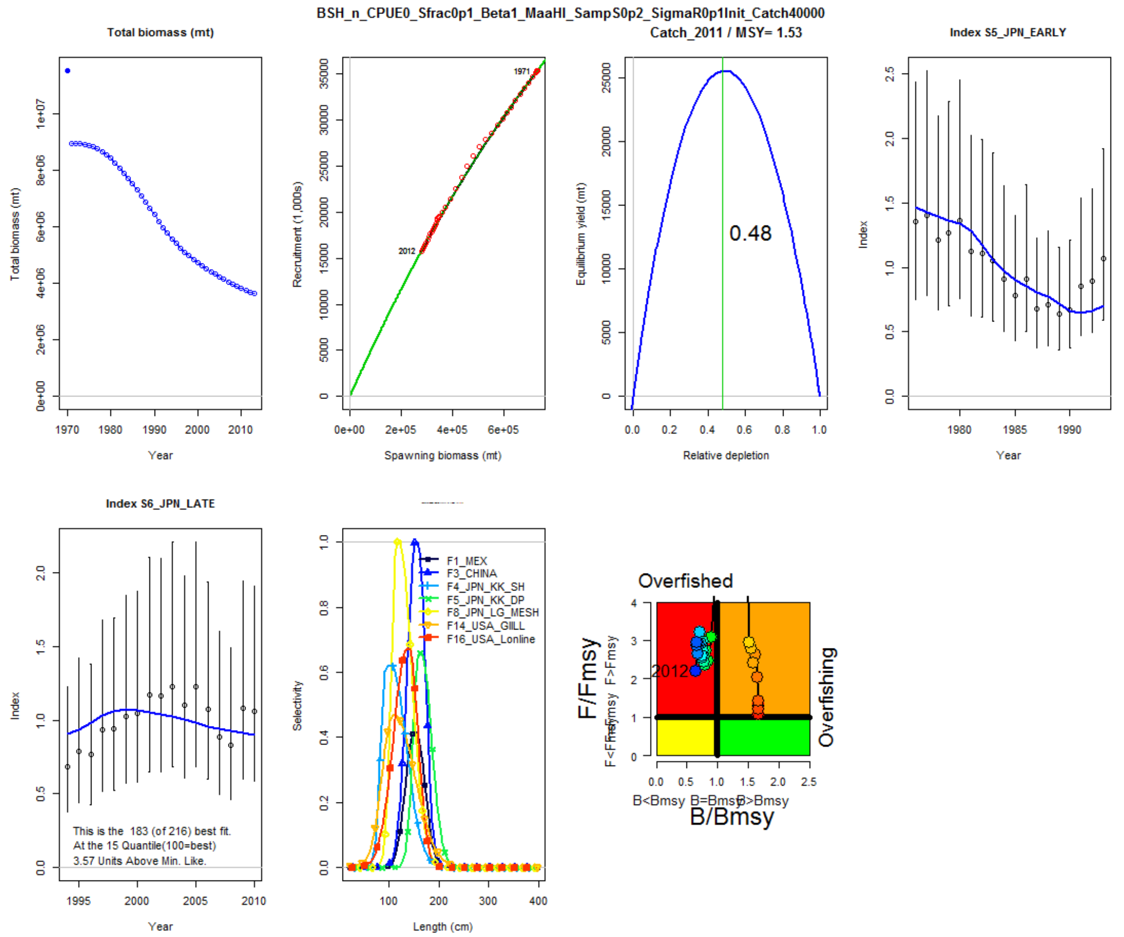


Figure 18: Barplots showing the stock status of blue sharks in the north Pacific corresponding to Kobe plot regions for the entire grid, across the axes of uncertainty.

ANNEX 1: Summary of key outputs for the model runs by JPN Early and JPN Late CPUE series combination

For Anex 1-5 Figures A#.1 – A#.3, the pannels represent: Total biomass trajectory (top left); stock recruitment curve (second from top left); equilibrium catch curve with the equilibrium point printed in the figure; and the catch in 2011 / MSY shown atop the figure; the fit to the index (or indices of abundance); the estimated selectivity; and the temporal kobe plot, with the year 2011 marked with a blue dot. Figures A#.4 shows the SSB/SSB_{MSY} trajectories color coded for each of the axes of uncertaity considered in this assessment. Figures A#.5 shows the CPUE specific results via bar plots in a Kobe matrix results framework. Figures A#.6 shows the management quantites (B_{2011}/B_{ZERO} upper left hand plot, catch in 2011/MSY, upper right hand plot, and current fishing mortality / FmsyFMSY) for the 9 parameterizations of the LFSR curve. These plots are color coded by Beta values.



. Figure A1.1

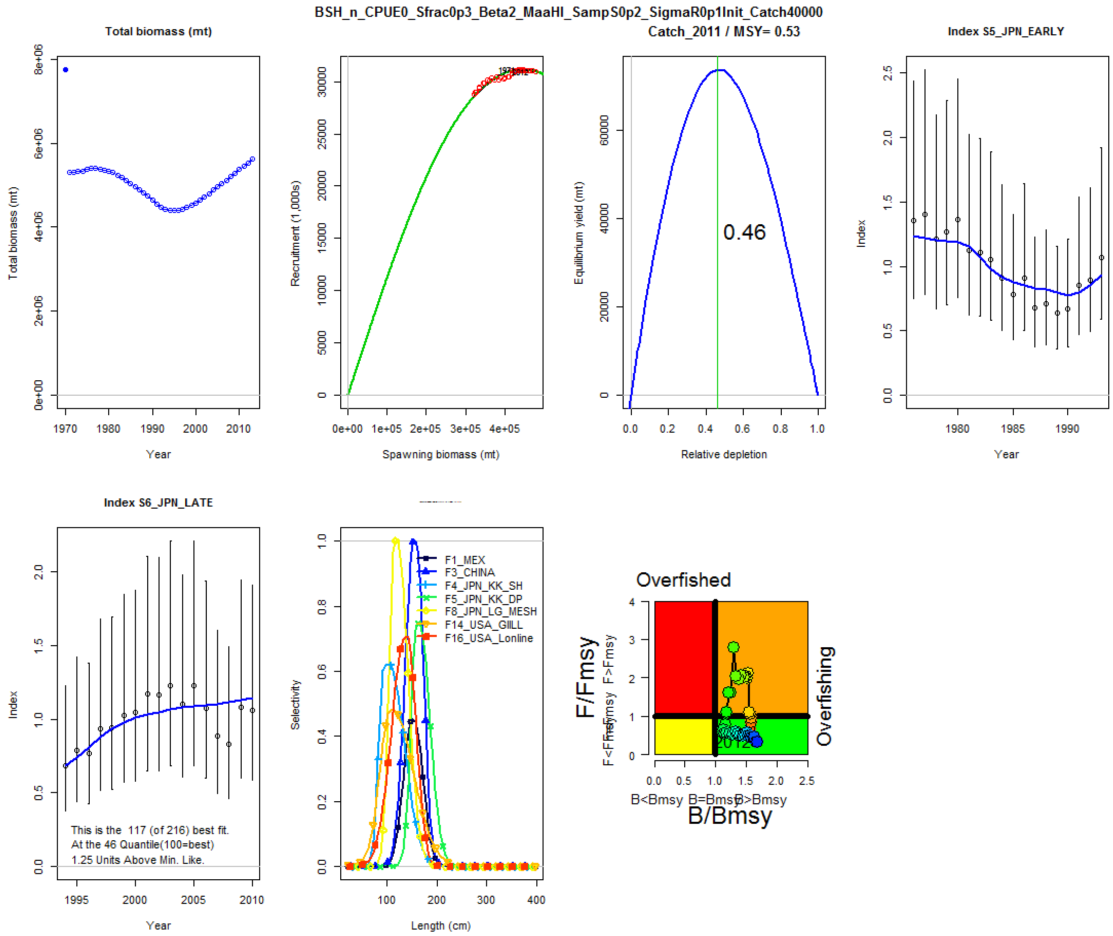

BSH_n_CPUE0_Sfrac0p3_Beta2_MaaHI_SampS0p2_SigmaR0p1Init_Catch40000
Total biomass (mt)
Catch_2011 / MSY= 0.53
Index S5_JPN_EARLY
Index S6_JPN_LATE
0.46
F1_MEX
F3_CHINA
F4_JPN_KK_SH
F5_JPN_KK_DP
F8_JPN_LG_MESH
F14_USA_GILL
F16_USA_Lonline
Overfished
Overfishing
F/Fmsy
B/Bmsy
This is the 117 (of 216) best fit.
At the 46 Quantile(100=best)
1.25 Units Above Min. Like.
Spawning biomass (mt)
Relative depletion
Length (cm)
Year

Figure A1.2

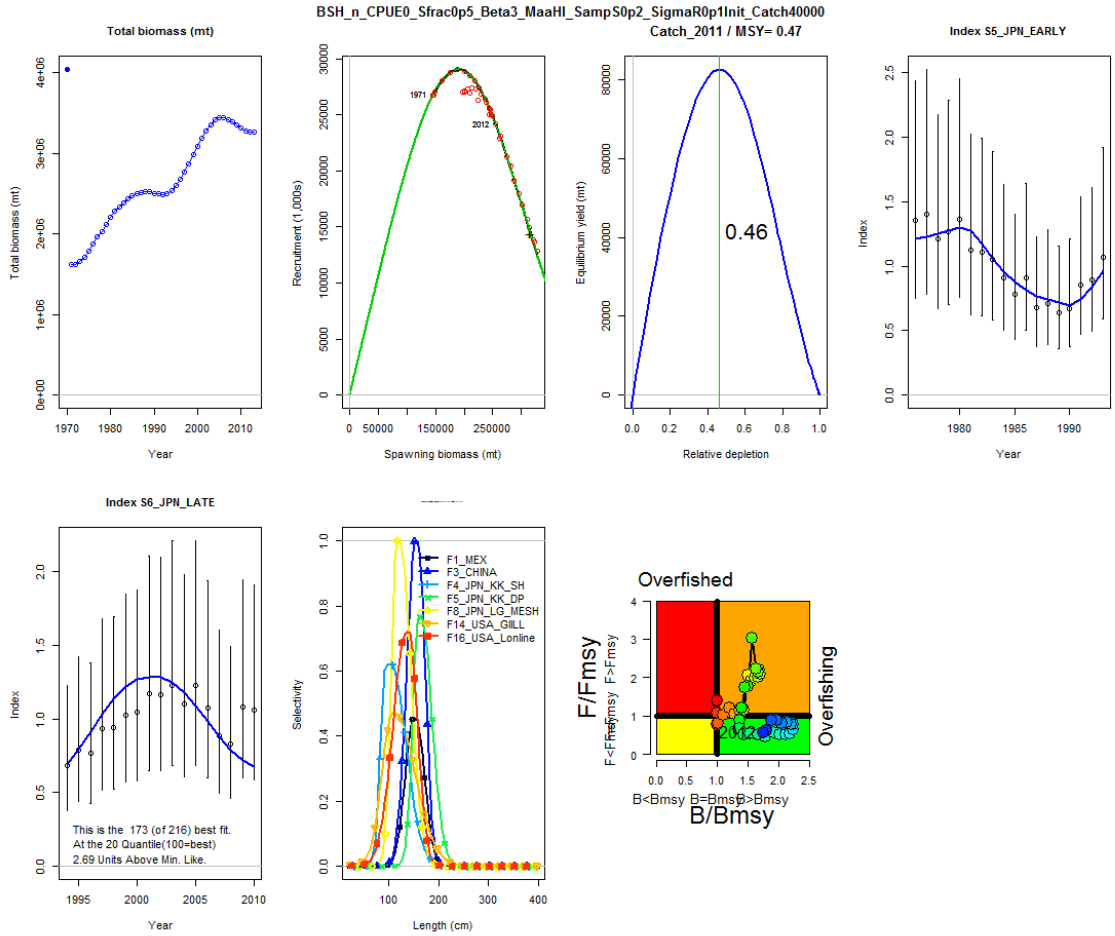

BSH_n_CPUE0_Sfrac0p5_Beta3_MaaHI_SampS0p2_SigmaR0p1Init_Catch40000
Total biomass (mt)
Catch_2011 / MSY= 0.47
Index S5_JPN_EARLY
Index S6_JPN_LATE
0.46
Overfished
Overfishing
F/Fmsy
B/Bmsy
This is the 173 (of 216) best fit.
At the 20 Quantile(100=best)
2.69 Units Above Min. Like.
F1_MEX
F3_CHINA
F4_JPN_KK_SH
F5_JPN_KK_DP
F8_JPN_LG_MESH
F14_USA_GILL
F16_USA_Lonline
Year
Spawning biomass (mt)
Relative depletion
Length (cm)
Total biomass (mt)
Recruitment (1,000s)
Equilibrium yield (mt)
Index
Selectivity

Figure A1.3

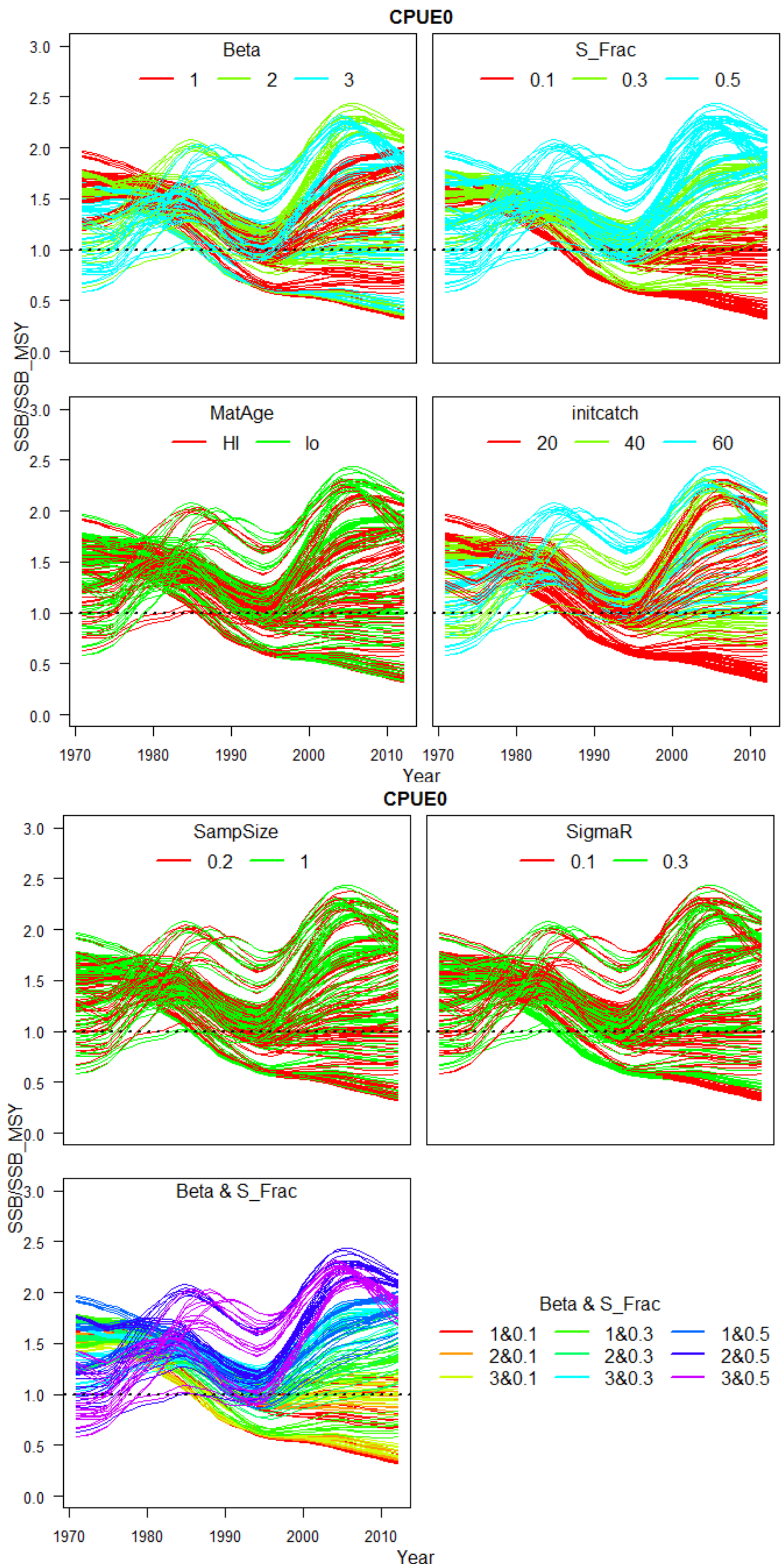

CPUE0
Beta
1 2 3
S_Frac
0.1 0.3 0.5
MatAge
HI lo
initcatch
20 40 60
SSB/SSB_MSY
Year
CPUE0
SampSize
0.2 1
SigmaR
0.1 0.3
Beta & S_Frac
Beta & S_Frac
1&0.1 1&0.3 1&0.5
2&0.1 2&0.3 2&0.5
3&0.1 3&0.3 3&0.5
SSB/SSB_MSY
Year

Figure A1.4

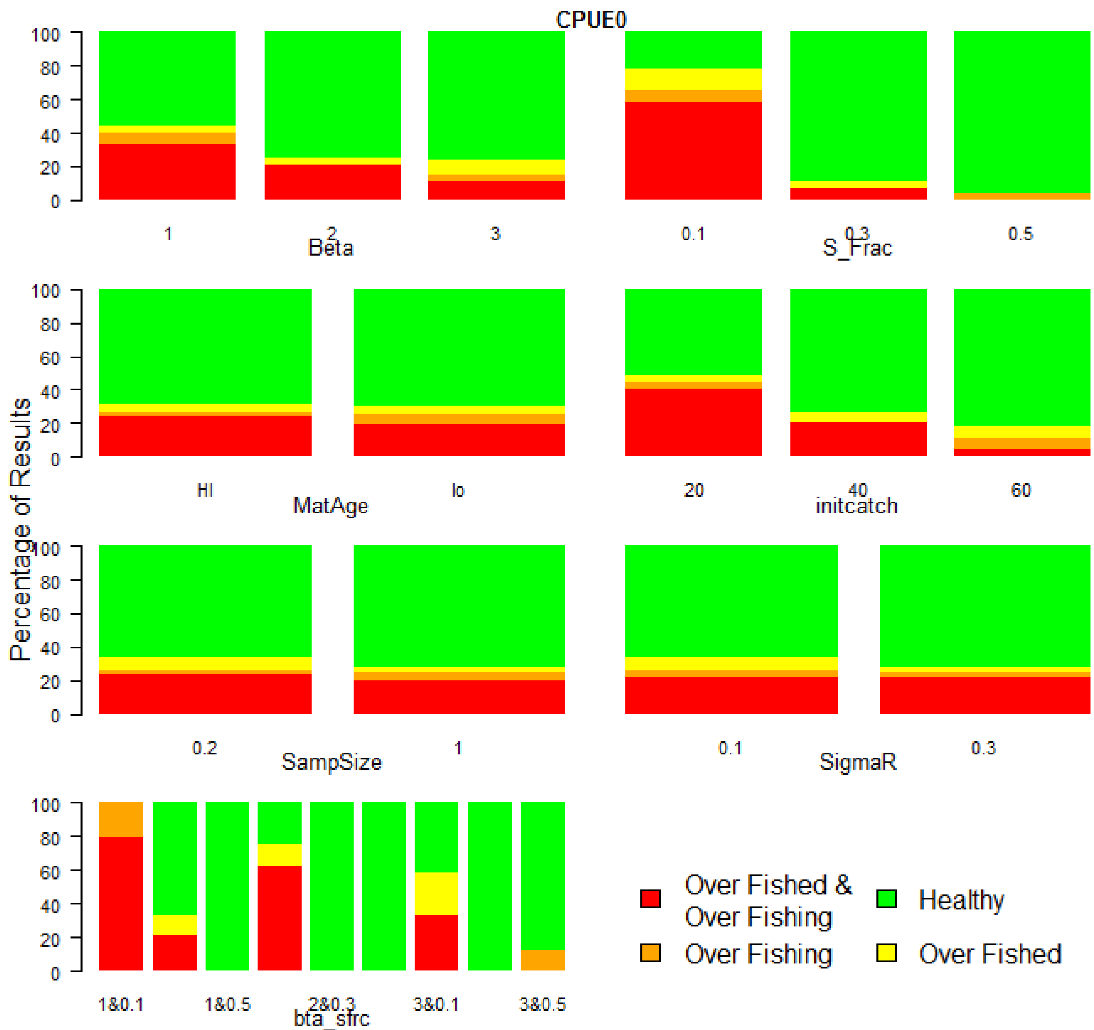

CPUE0
Percentage of Results
100
80
60
40
20
0
1
2
3
Beta
0.1
0.3
0.5
S_Frac
HI
lo
MatAge
20
40
60
initcatch
0.2
1
SampSize
0.1
0.3
SigmaR
1&0.1
1&0.5
2&0.3
3&0.1
3&0.5
bta_sfrc
Over Fished & Over Fishing
Healthy
Over Fishing
Over Fished

Figure A1.5

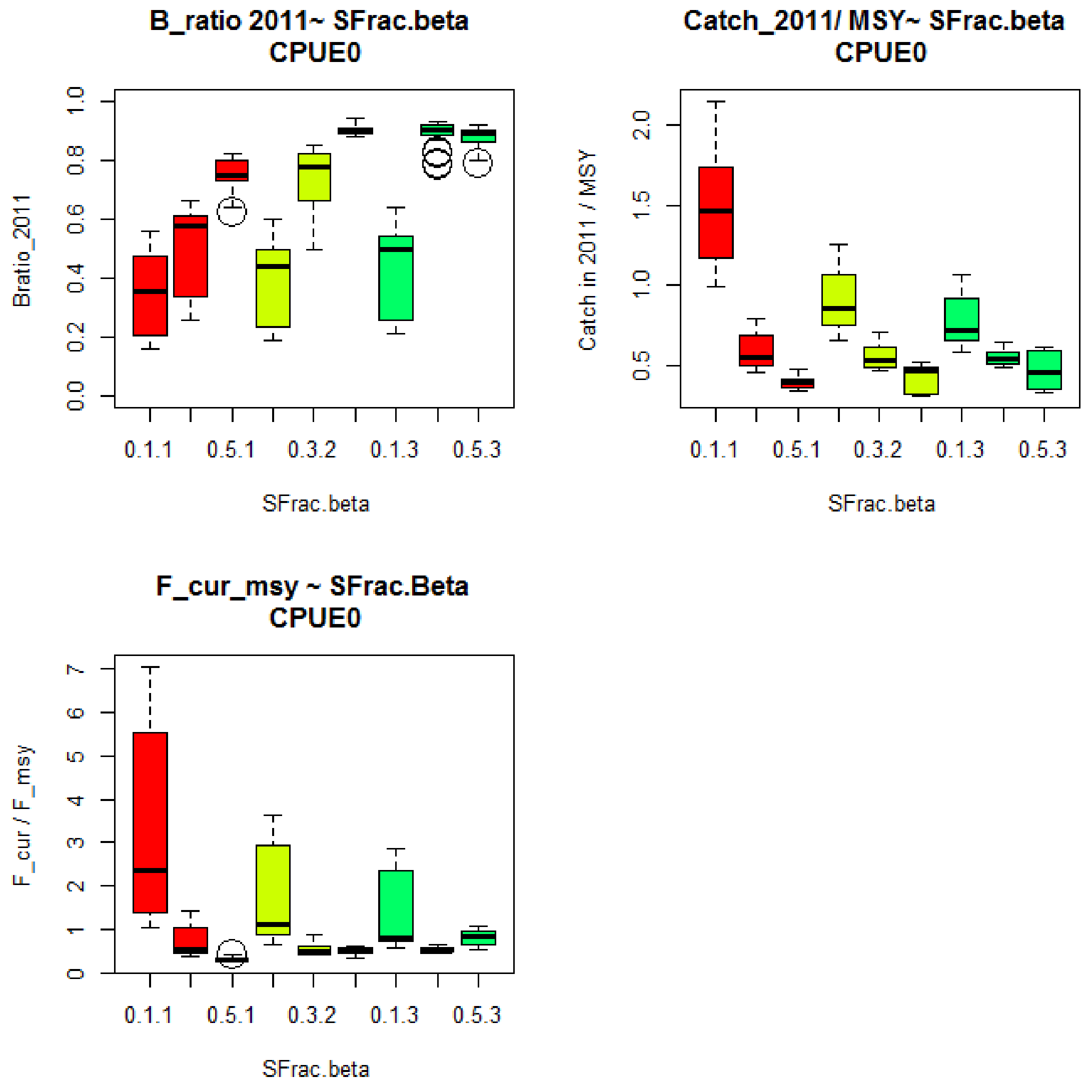

B_ratio 2011~ SFrac.beta
CPUE0
Bratio_2011
0.0
0.2
0.4
0.6
0.8
1.0
0.1.1
0.5.1
0.3.2
0.1.3
0.5.3
SFrac.beta
Catch_2011/ MSY~ SFrac.beta
CPUE0
Catch in 2011 / MSY
0.5
1.0
1.5
2.0
0.1.1
0.5.1
0.3.2
0.1.3
0.5.3
SFrac.beta
F_cur_msy ~ SFrac.Beta
CPUE0
F_cur / F_msy
0
1
2
3
4
5
6
7
0.1.1
0.5.1
0.3.2
0.1.3
0.5.3
SFrac.beta

Figure A1.6

ANNEX 2: Summary of key outputs for the model runs by JPN Early and HW Deep Late CPUE series combination.

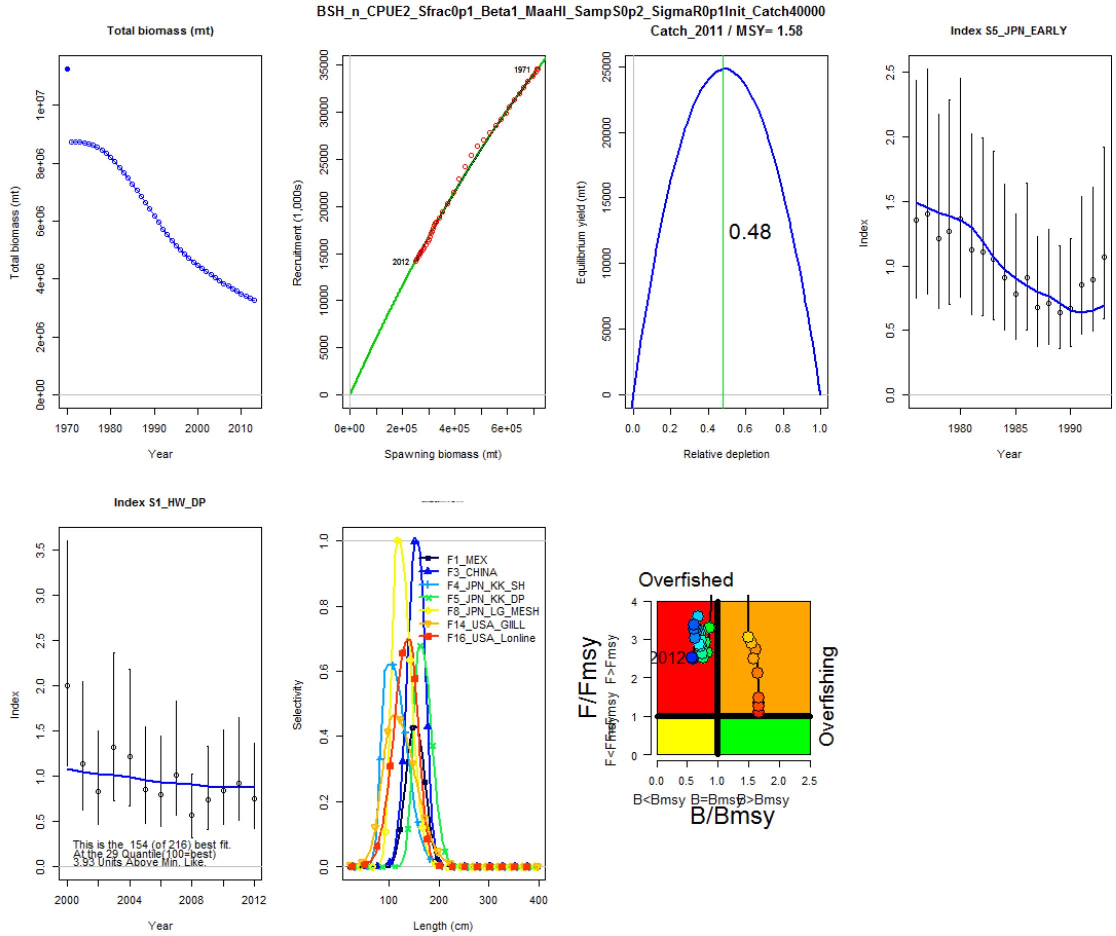


Figure A 2. 1

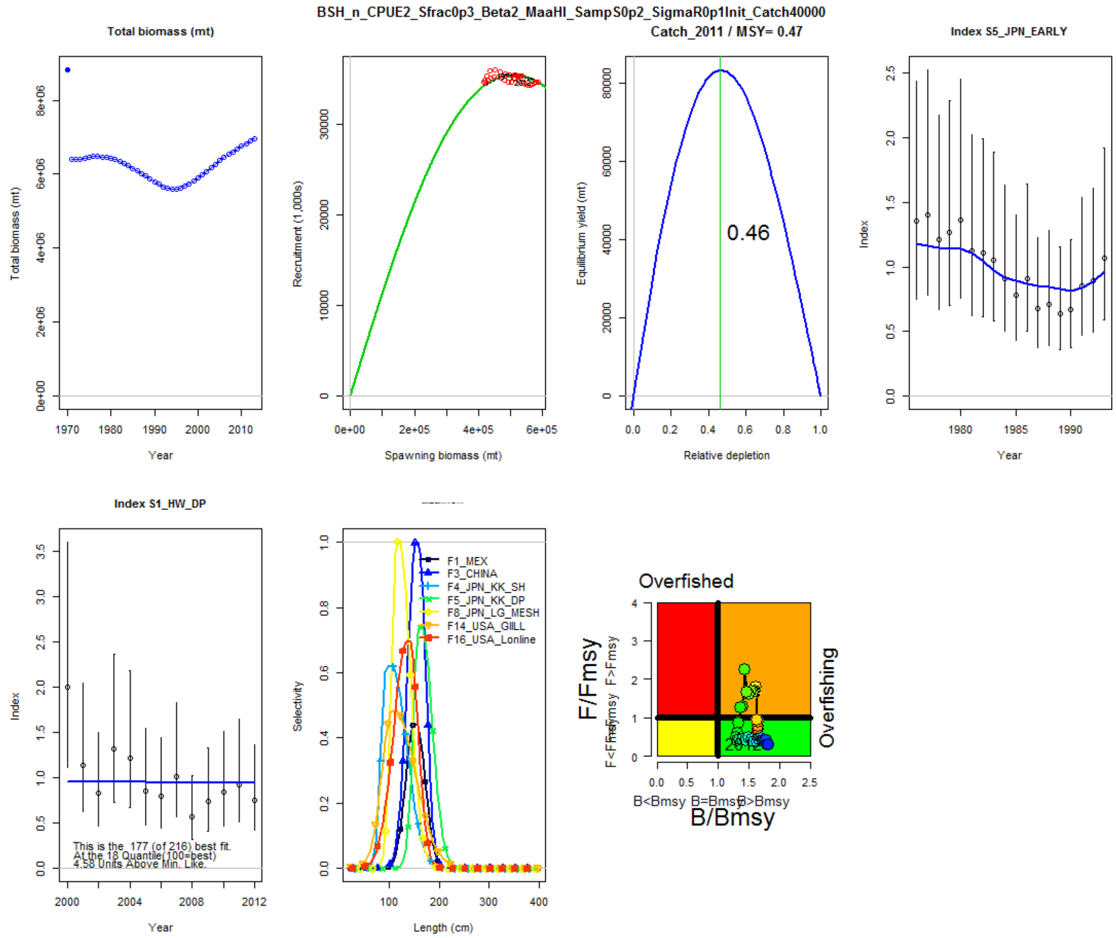

BSH_n_CPUE2_Sfrac0p3_Beta2_MaaHI_SampS0p2_SigmaR0p1Init_Catch40000
Total biomass (mt)
Catch_2011 / MSY= 0.47
Index S5_JPN_EARLY
Index S1_HW_DP
Year
Spawning biomass (mt)
Relative depletion
Recruitment (1,000s)
Equilibrium yield (mt)
0.46
Selectivity
Length (cm)
F1_MEX
F3_CHINA
F4_JPN_KK_SH
F5_JPN_KK_DP
F8_JPN_LG_MESH
F14_USA_GILL
F16_USA_Lonline
This is the 177 (of 216) best fit.
At the 18 Quantile(100=best)
4.58 Units Above Min. Like.
Overfished
Overfishing
F/Fmsy
B/Bmsy

Figure A 2. 2

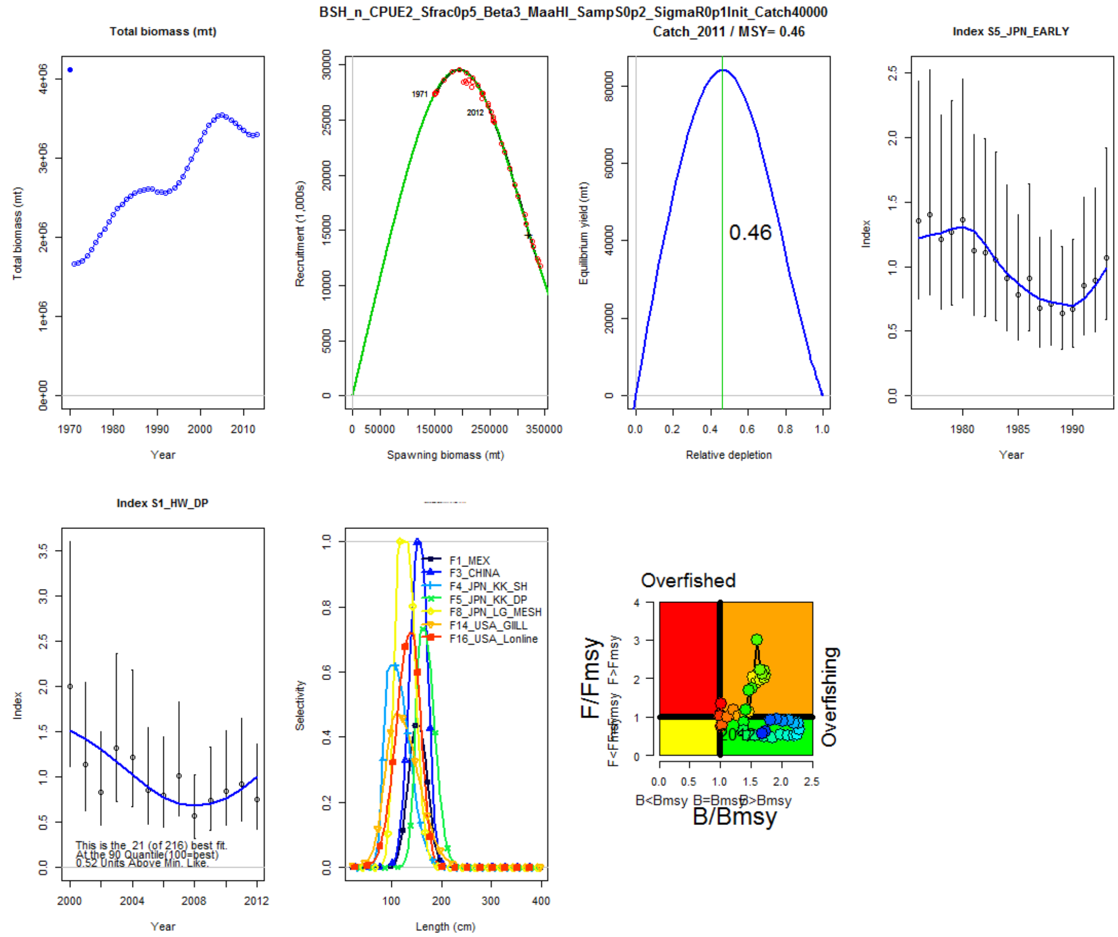

BSH_n_CPUE2_Sfrac0p5_Beta3_MaaHI_SampS0p2_SigmaR0p1Init_Catch40000
Total biomass (mt)
Catch_2011 / MSY= 0.46
Index S5_JPN_EARLY
Index S1_HW_DP
Overfished
Overfishing
F/Fmsy
B/Bmsy
0.46
F1_MEX
F3_CHINA
F4_JPN_KK_SH
F5_JPN_KK_DP
F8_JPN_LG_MESH
F14_USA_GILL
F16_USA_Lonline
This is the 21 (of 216) best fit.
At the 90 Quantile(100=best)
0.52 Units Above Min. Like.

Figure A 2. 3

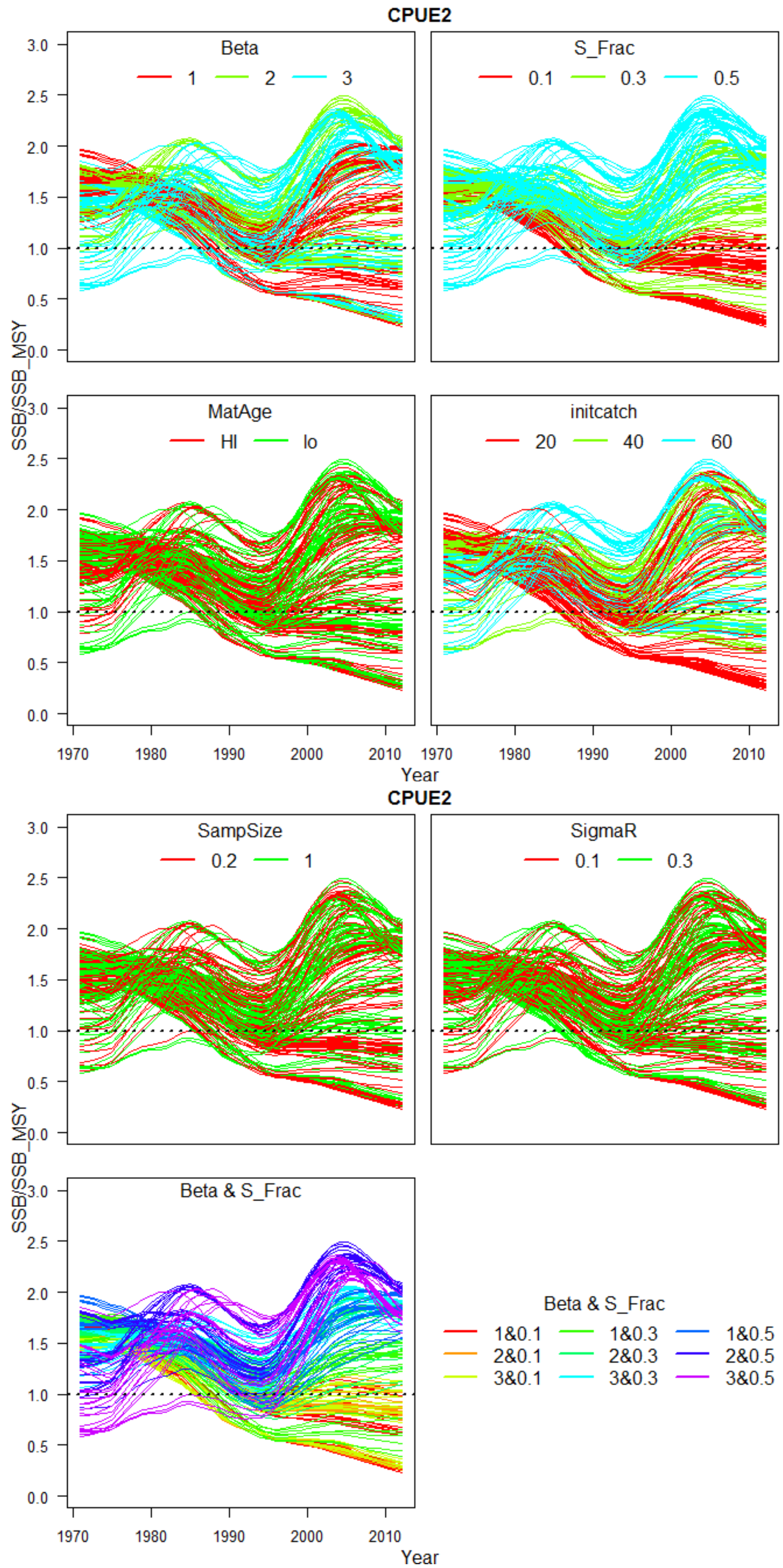

CPUE2
Beta
1 2 3
S_Frac
0.1 0.3 0.5
MatAge
HI lo
initcatch
20 40 60
SSB/SSB_MSY
0.0 0.5 1.0 1.5 2.0 2.5 3.0
1970 1980 1990 2000 2010
Year
CPUE2
SampSize
0.2 1
SigmaR
0.1 0.3
SSB/SSB_MSY
Beta & S_Frac
Beta & S_Frac
1&0.1 1&0.3 1&0.5
2&0.1 2&0.3 2&0.5
3&0.1 3&0.3 3&0.5
Year

Figure A 2. 4

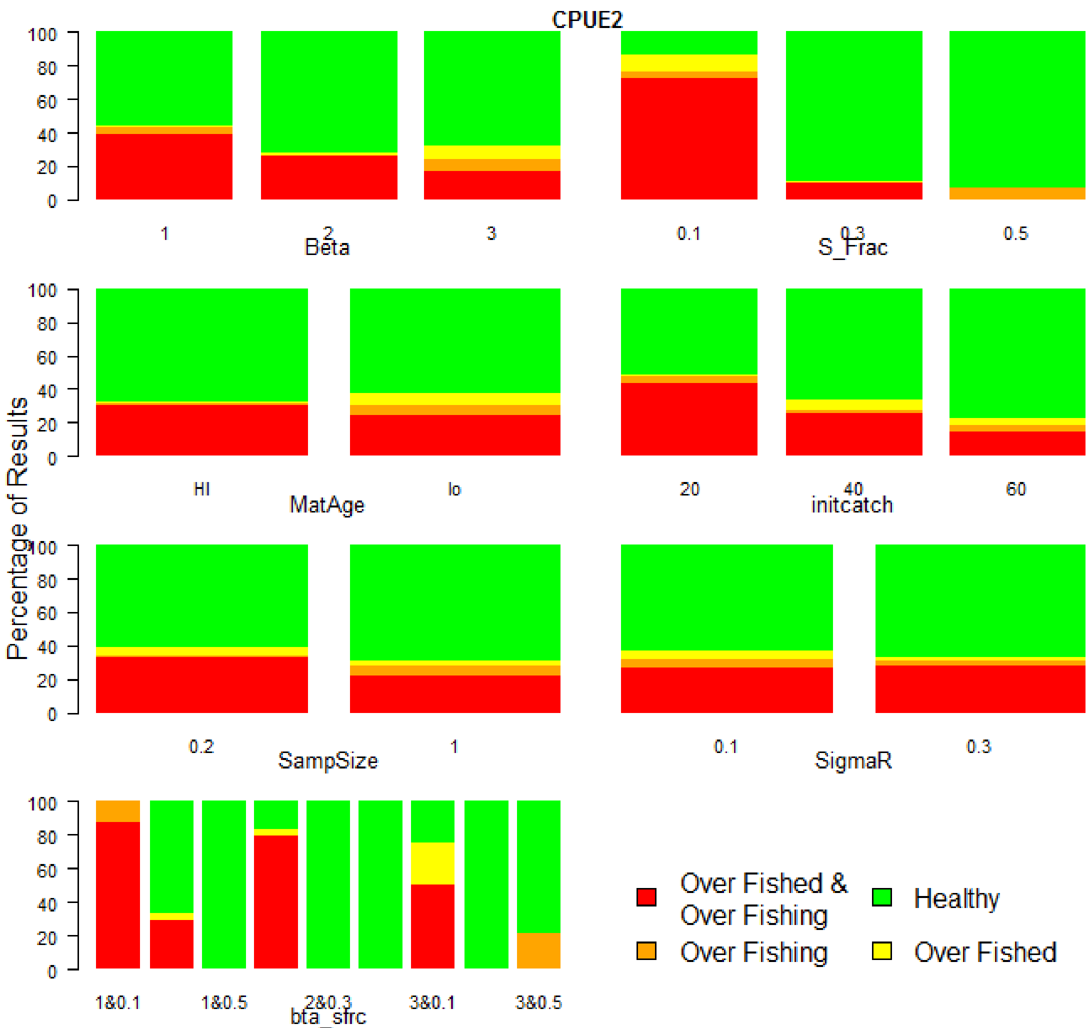

CPUE2
Percentage of Results
100
80
60
40
20
0
1
2
3
Beta
0.1
0.3
0.5
S_Frac
HI
lo
MatAge
20
40
60
initcatch
0.2
1
SampSize
0.1
0.3
SigmaR
1&0.1
1&0.5
2&0.3
3&0.1
3&0.5
bta_sfrc
Over Fished & Over Fishing
Healthy
Over Fishing
Over Fished

Figure A 2. 5

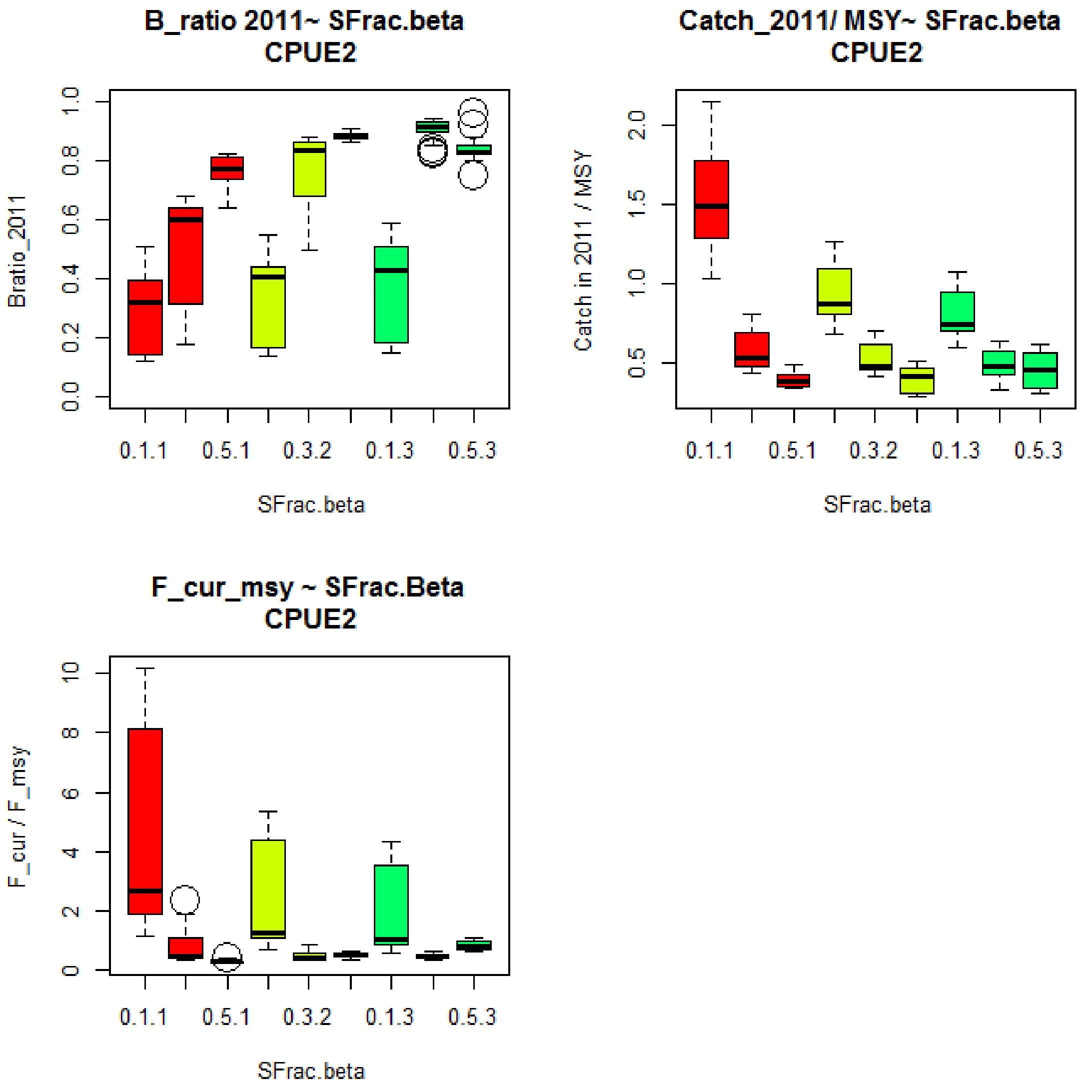

B_ratio 2011~ SFrac.beta
CPUE2
Bratio_2011
0.0
0.2
0.4
0.6
0.8
1.0
0.1.1
0.5.1
0.3.2
0.1.3
0.5.3
SFrac.beta
Catch_2011/ MSY~ SFrac.beta
CPUE2
Catch in 2011 / MSY
0.5
1.0
1.5
2.0
0.1.1
0.5.1
0.3.2
0.1.3
0.5.3
SFrac.beta
F_cur_msy ~ SFrac.Beta
CPUE2
F_cur / F_msy
0
2
4
6
8
10
0.1.1
0.5.1
0.3.2
0.1.3
0.5.3
SFrac.beta

Figure A2.6

ANNEX 3: Summary of key outputs for the model runs by SPC CPUE series (CPUE 4).

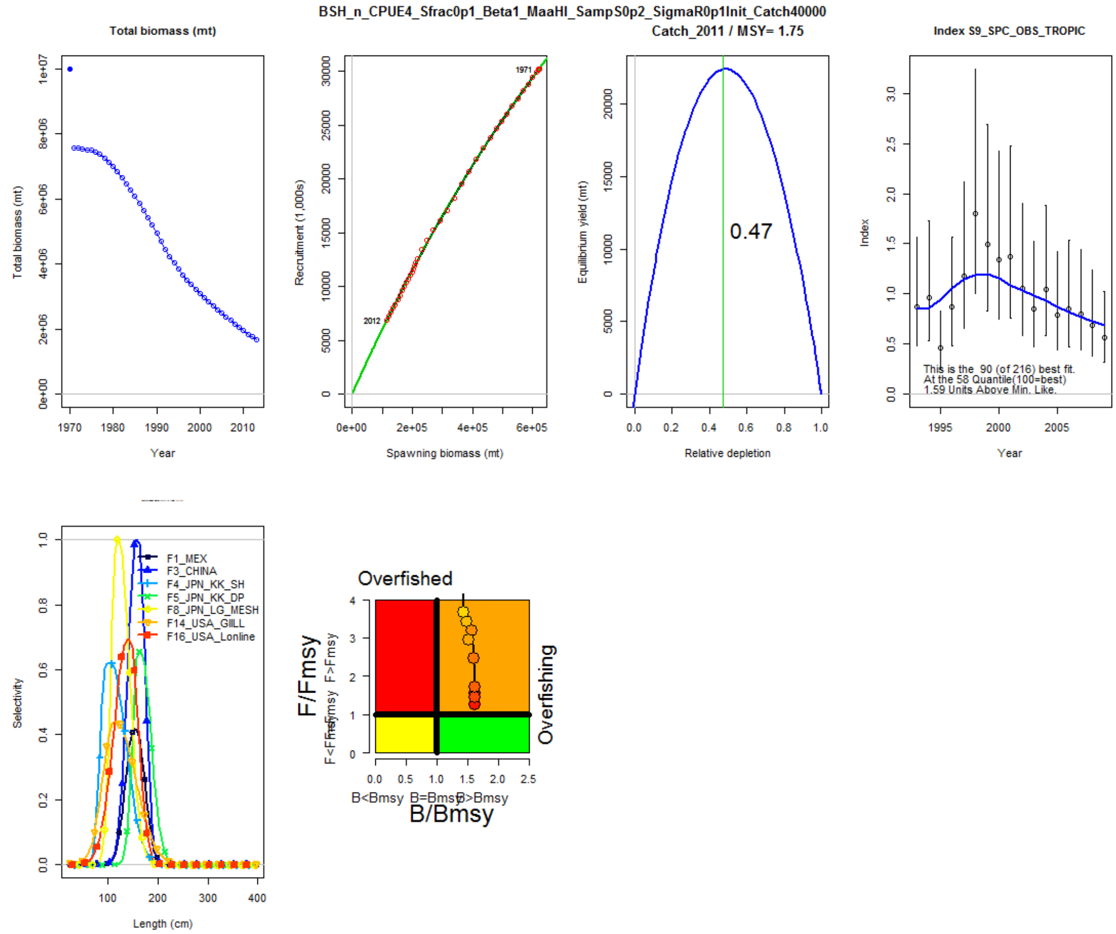
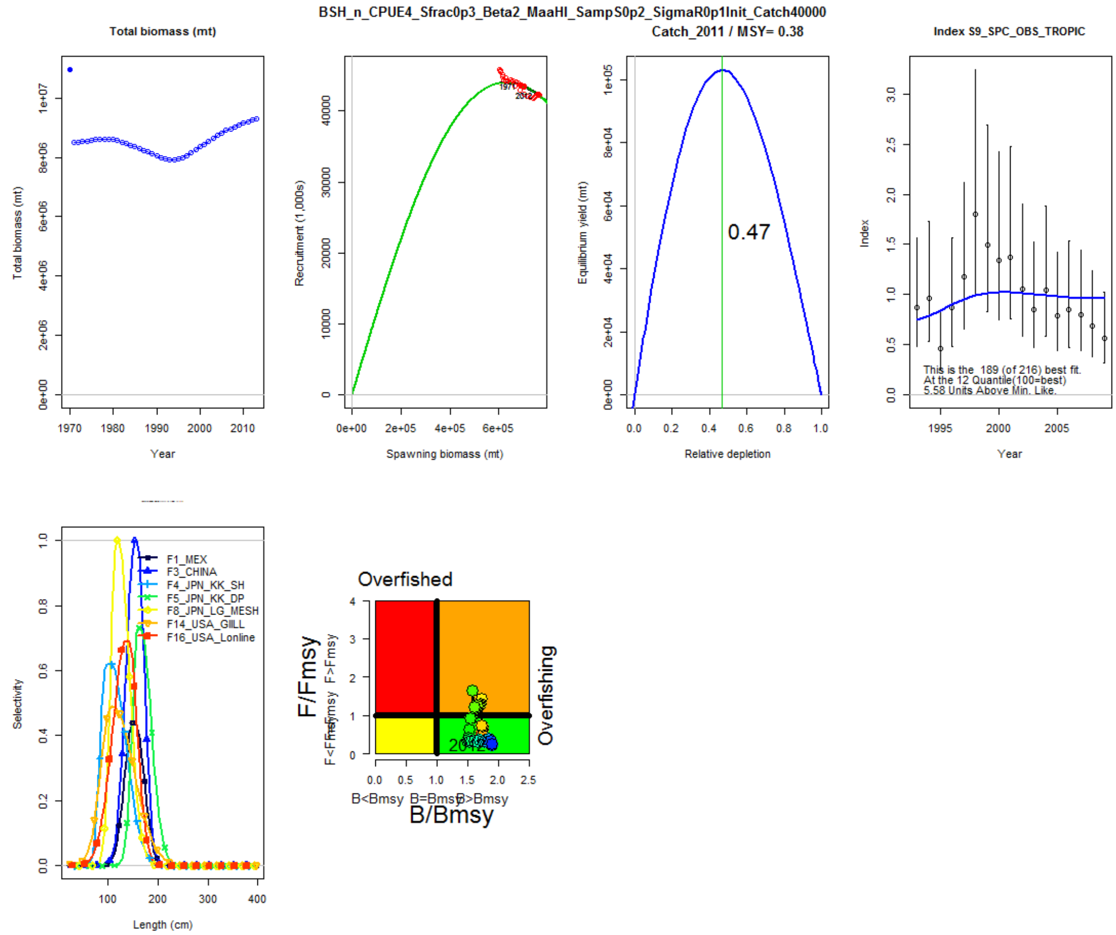


Figure A 3. 1



BSH_n_CPUE4_Sfrac0p3_Beta2_MaaHI_SampS0p2_SigmaR0p1Init_Catch40000
Total biomass (mt)
Catch_2011 / MSY= 0.38
Index S9_SPC_OBS_TROPIC
Total biomass (mt)
Year
Recruitment (1,000s)
Spawning biomass (mt)
Equilibrium yield (mt)
Relative depletion
0.47
Index
This is the 189 (of 216) best fit.
At the 12 Quantile(100=best)
5.58 Units Above Min. Like.
Selectivity
Length (cm)
F1_MEX
F3_CHINA
F4_JPN_KK_SH
F5_JPN_KK_DP
F8_JPN_LG_MESH
F14_USA_GILL
F16_USA_Lonline
Overfished
Overfishing
F/Fmsy
F>Fmsy
F<Fmsy
B/Bmsy
B<Bmsy
B=Bmsy
B>Bmsy
2012

Figure A 3. 2

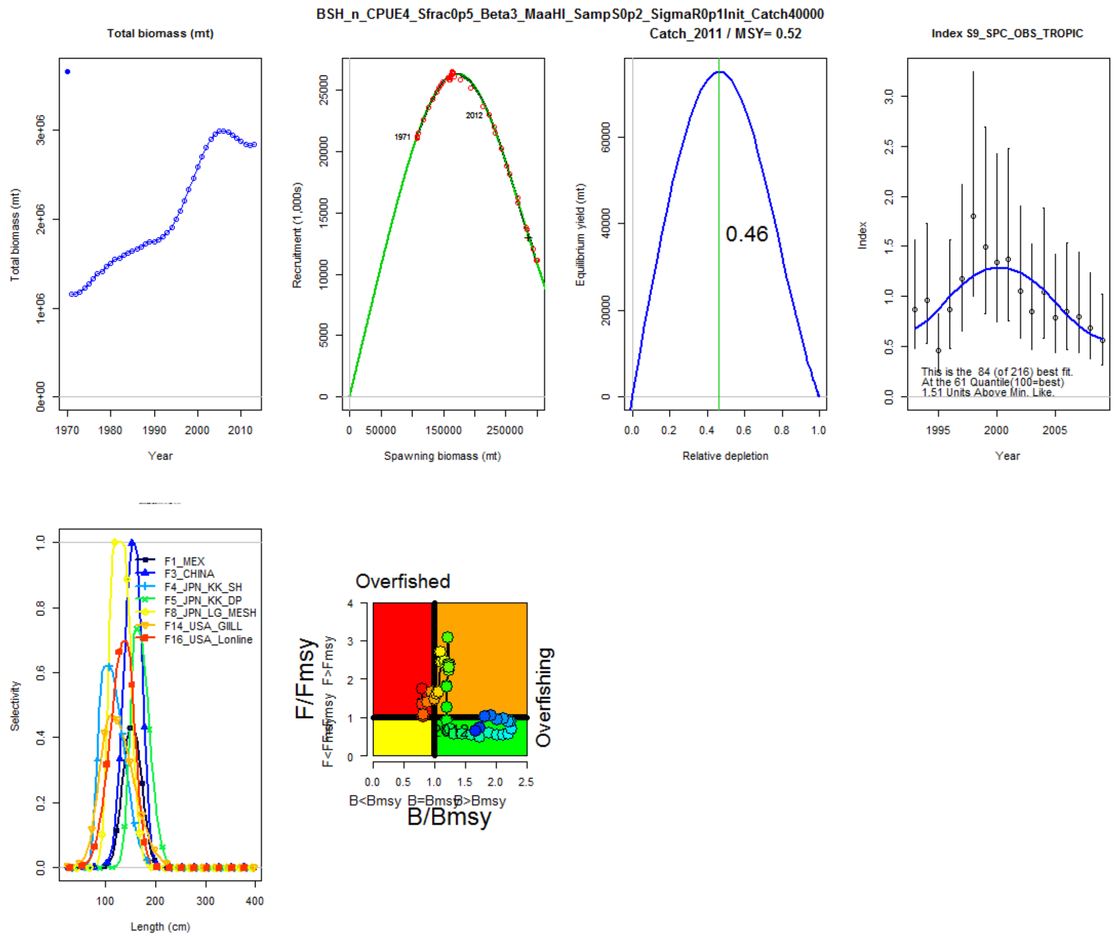

BSH_n_CPUE4_Sfrac0p5_Beta3_MaaHI_SampS0p2_SigmaR0p1Init_Catch40000
Total biomass (mt)
Catch_2011 / MSY= 0.52
Index S9_SPC_OBS_TROPIC
0.46
This is the 84 (of 216) best fit.
At the 61 Quantile(100=best)
1.51 Units Above Min. Like.
F1_MEX
F3_CHINA
F4_JPN_KK_SH
F5_JPN_KK_DP
F8_JPN_LG_MESH
F14_USA_GILL
F16_USA_Lonline
Overfished
Overfishing
F/Fmsy
B/Bmsy

Figure A 3. 3

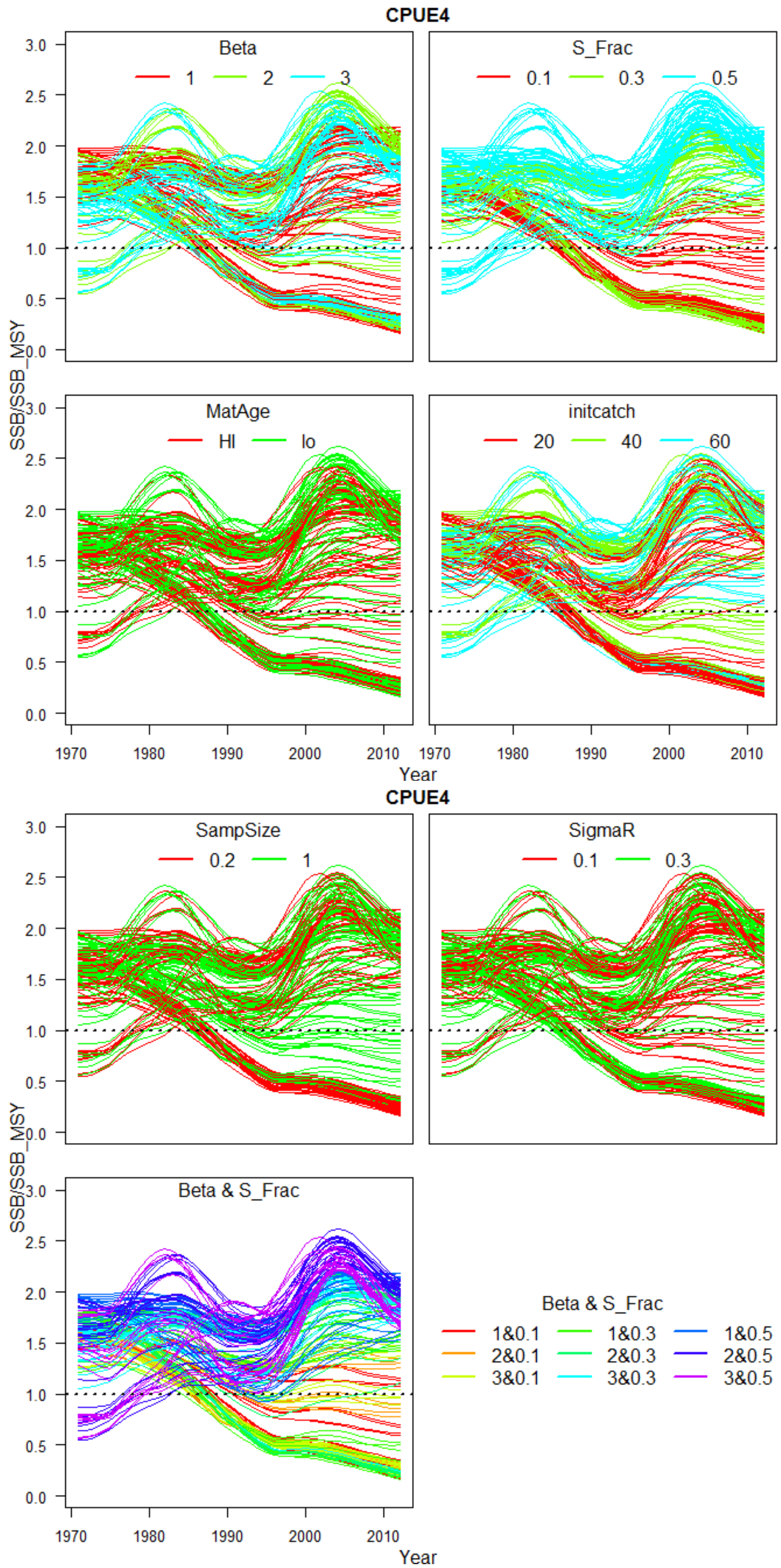

CPUE4
Beta
1 2 3
S_Frac
0.1 0.3 0.5
MatAge
HI lo
initcatch
20 40 60
SSB/SSB_MSY
Year
CPUE4
SampSize
0.2 1
SigmaR
0.1 0.3
Beta & S_Frac
Beta & S_Frac
1&0.1 1&0.3 1&0.5
2&0.1 2&0.3 2&0.5
3&0.1 3&0.3 3&0.5
SSB/SSB_MSY
Year

Figure A 3. 4

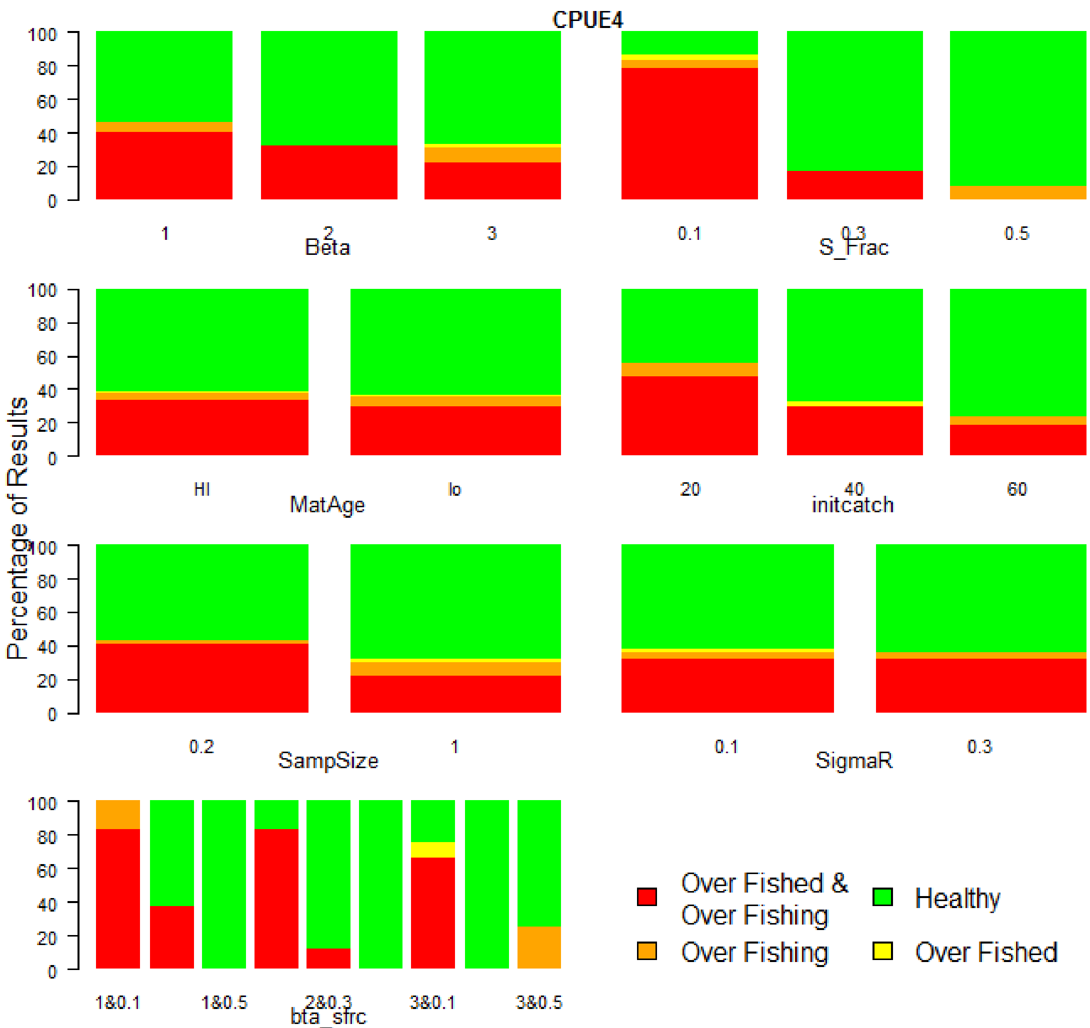

CPUE4
Percentage of Results
Beta
1
2
3
S_Frac
0.1
0.3
0.5
MatAge
HI
lo
initcatch
20
40
60
SampSize
0.2
1
SigmaR
0.1
0.3
bta_sfrc
1&0.1
1&0.5
2&0.3
3&0.1
3&0.5
Over Fished & Over Fishing
Healthy
Over Fishing
Over Fished

Figure A 3. 5

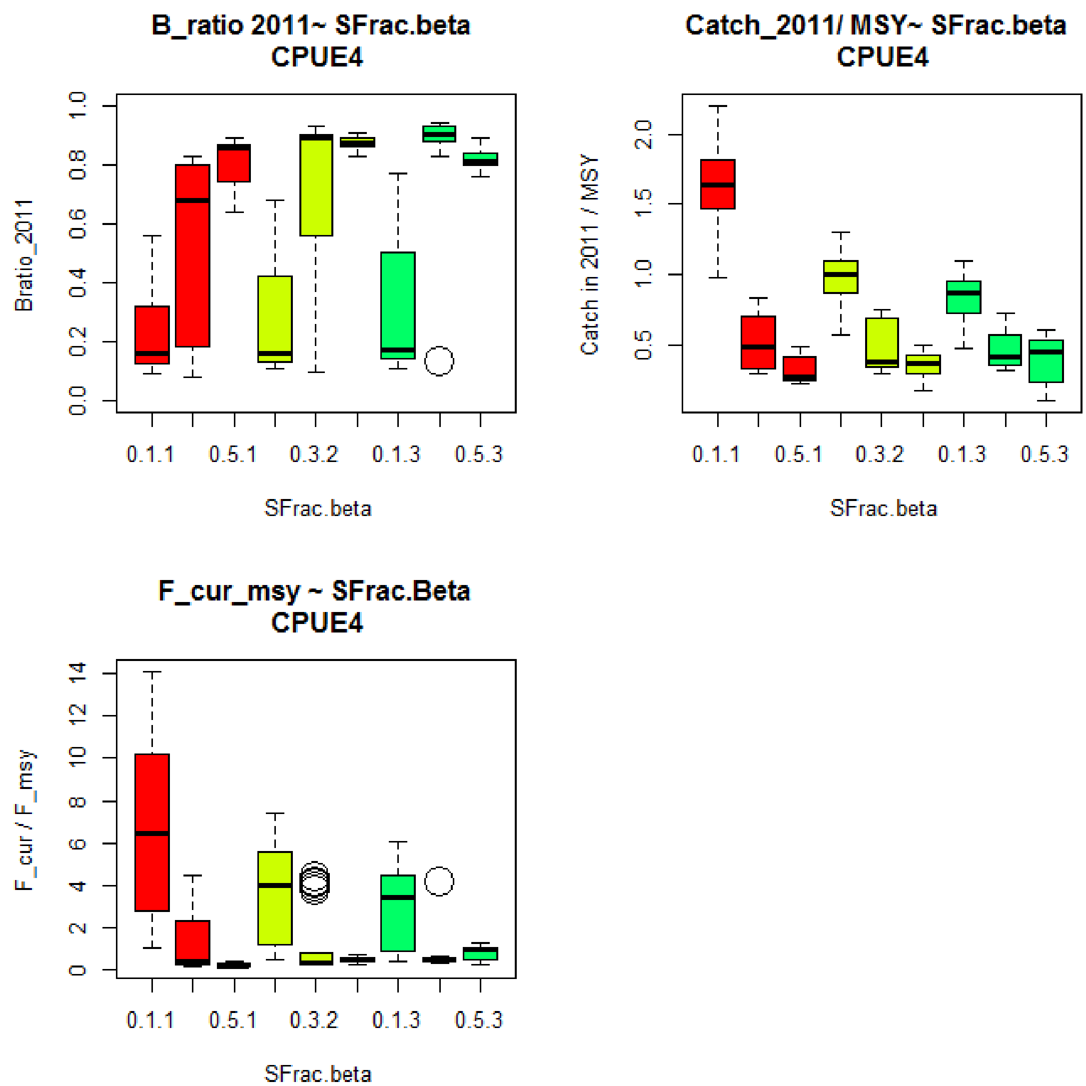

B_ratio 2011~ SFrac.beta
CPUE4
Bratio_2011
0.0 0.2 0.4 0.6 0.8 1.0
0.1.1 0.5.1 0.3.2 0.1.3 0.5.3
SFrac.beta
Catch_2011/ MSY~ SFrac.beta
CPUE4
Catch in 2011 / MSY
0.5 1.0 1.5 2.0
0.1.1 0.5.1 0.3.2 0.1.3 0.5.3
SFrac.beta
F_cur_msy ~ SFrac.Beta
CPUE4
F_cur / F_msy
0 2 4 6 8 10 12 14
0.1.1 0.5.1 0.3.2 0.1.3 0.5.3
SFrac.beta

Figure A 3. 6

ANNEX 4: Summary of key outputs for the model runs by HW CPUE series (CPUE 5). Figure A 4. 1

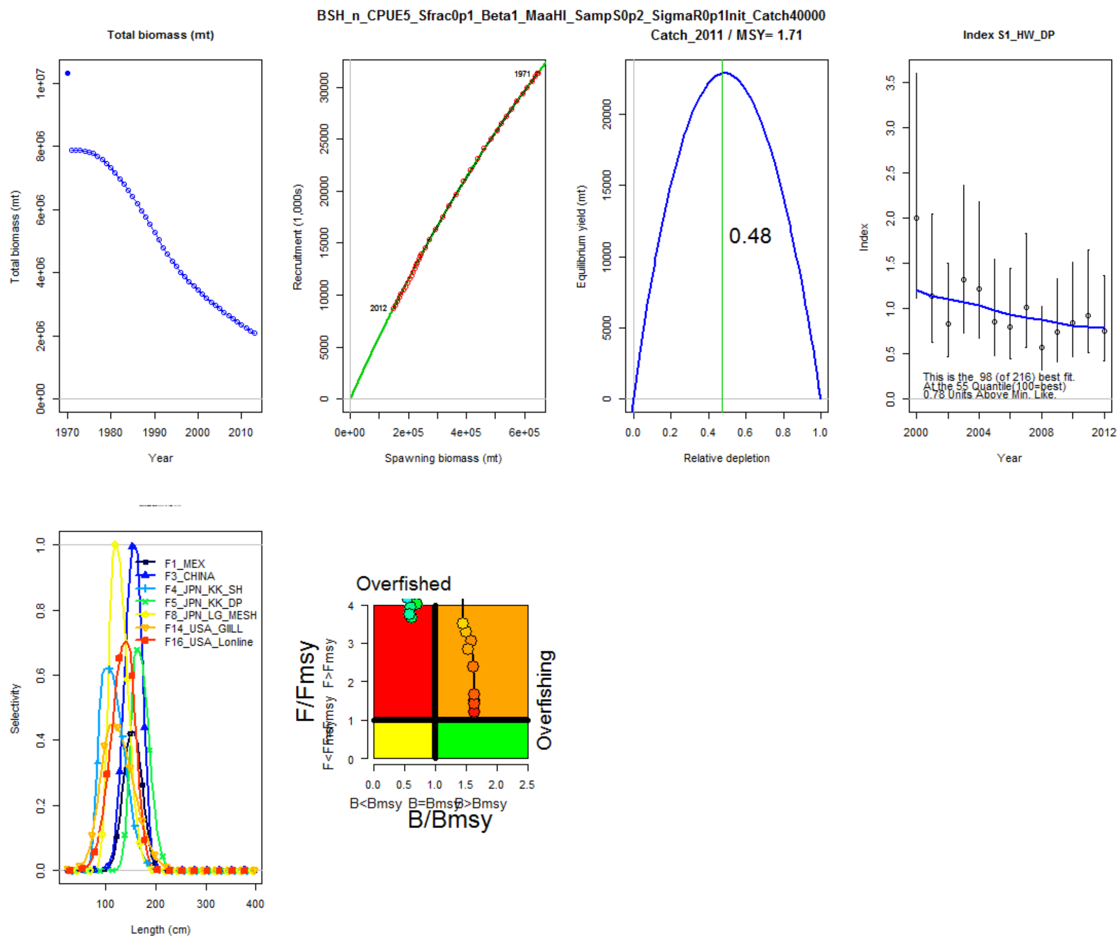


Figure A 4. 1

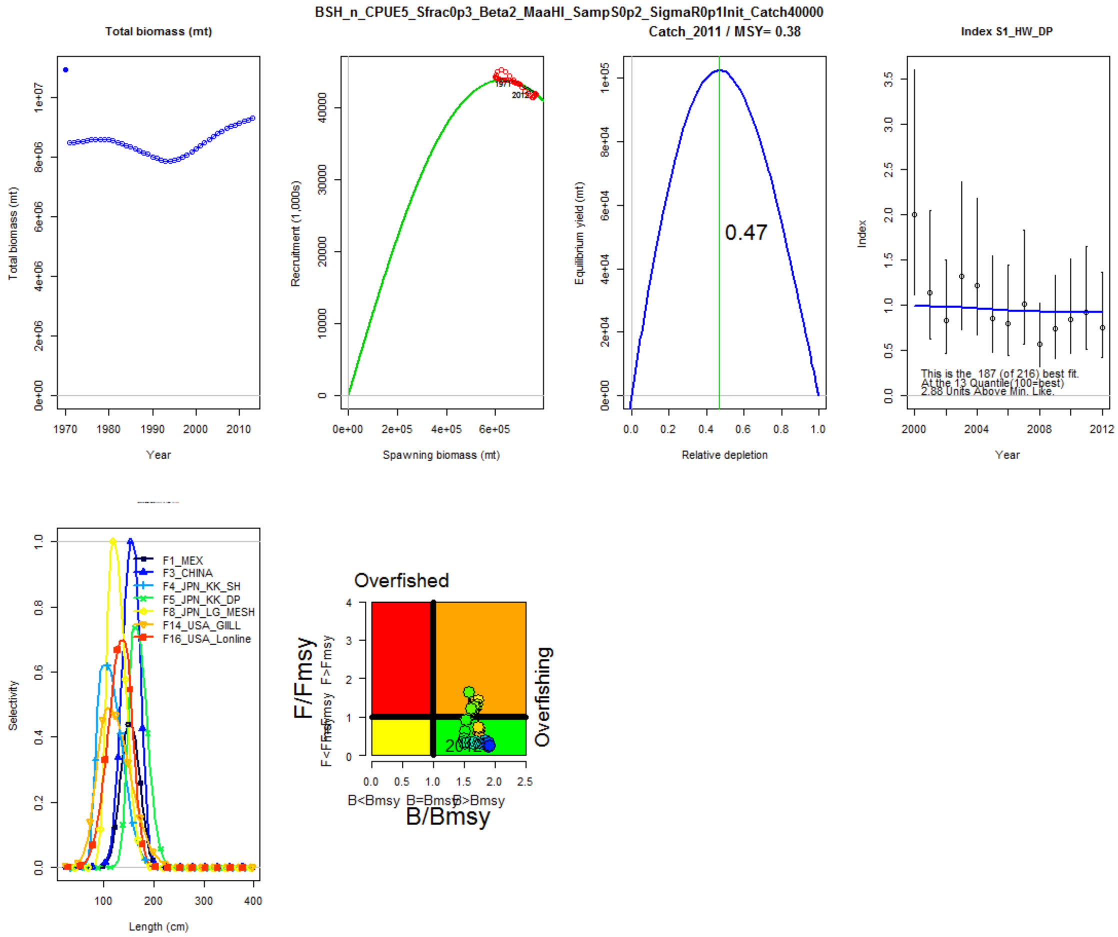
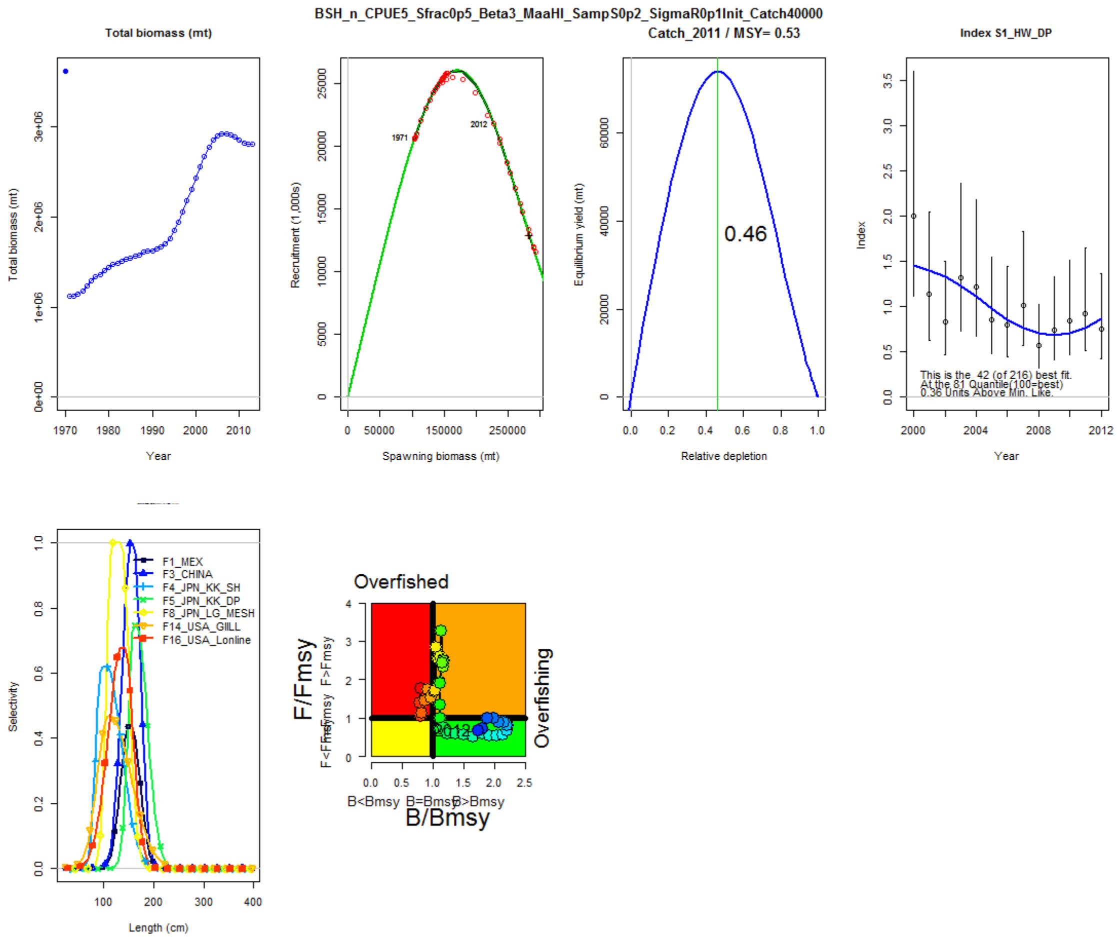

BSH_n_CPUE5_Sfrac0p3_Beta2_MaaHI_SampS0p2_SigmaR0p1Init_Catch40000
Total biomass (mt)
Catch_2011 / MSY= 0.38
Index S1_HW_DP
Total biomass (mt)
Year
Recruitment (1,000s)
Spawning biomass (mt)
Equilibrium yield (mt)
Relative depletion
0.47
Index
Year
This is the 187 (of 216) best fit.
At the 13 Quantile(100=best)
2.88 Units Above Min. Like.
Selectivity
Length (cm)
F1_MEX
F3_CHINA
F4_JPN_KK_SH
F5_JPN_KK_DP
F8_JPN_LG_MESH
F14_USA_GILL
F16_USA_Lonline
Overfished
Overfishing
F/Fmsy
B/Bmsy
B<Bmsy
B=Bmsy
B>Bmsy
F<Fmsy
F>Fmsy

Figure A 4. 2



BSH_n_CPUE5_Sfrac0p5_Beta3_MaaHI_SampS0p2_SigmaR0p1Init_Catch40000
Total biomass (mt)
Total biomass (mt)
Year
Recruitment (1,000s)
Spawning biomass (mt)
1971
2012
Catch_2011 / MSY= 0.53
Equilibrium yield (mt)
Relative depletion
0.46
Index S1_HW_DP
Index
Year
This is the 42 (of 216) best fit.
At the 81 Quantile(100=best)
0.36 Units Above Min. Like.
F1_MEX
F3_CHINA
F4_JPN_KK_SH
F5_JPN_KK_DP
F8_JPN_LG_MESH
F14_USA_GILL
F16_USA_Lonline
Selectivity
Length (cm)
Overfished
Overfishing
F/Fmsy
F>Fmsy
B/Bmsy
B<Bmsy
B=Bmsy
B>Bmsy
2012

Figure A 4. 3

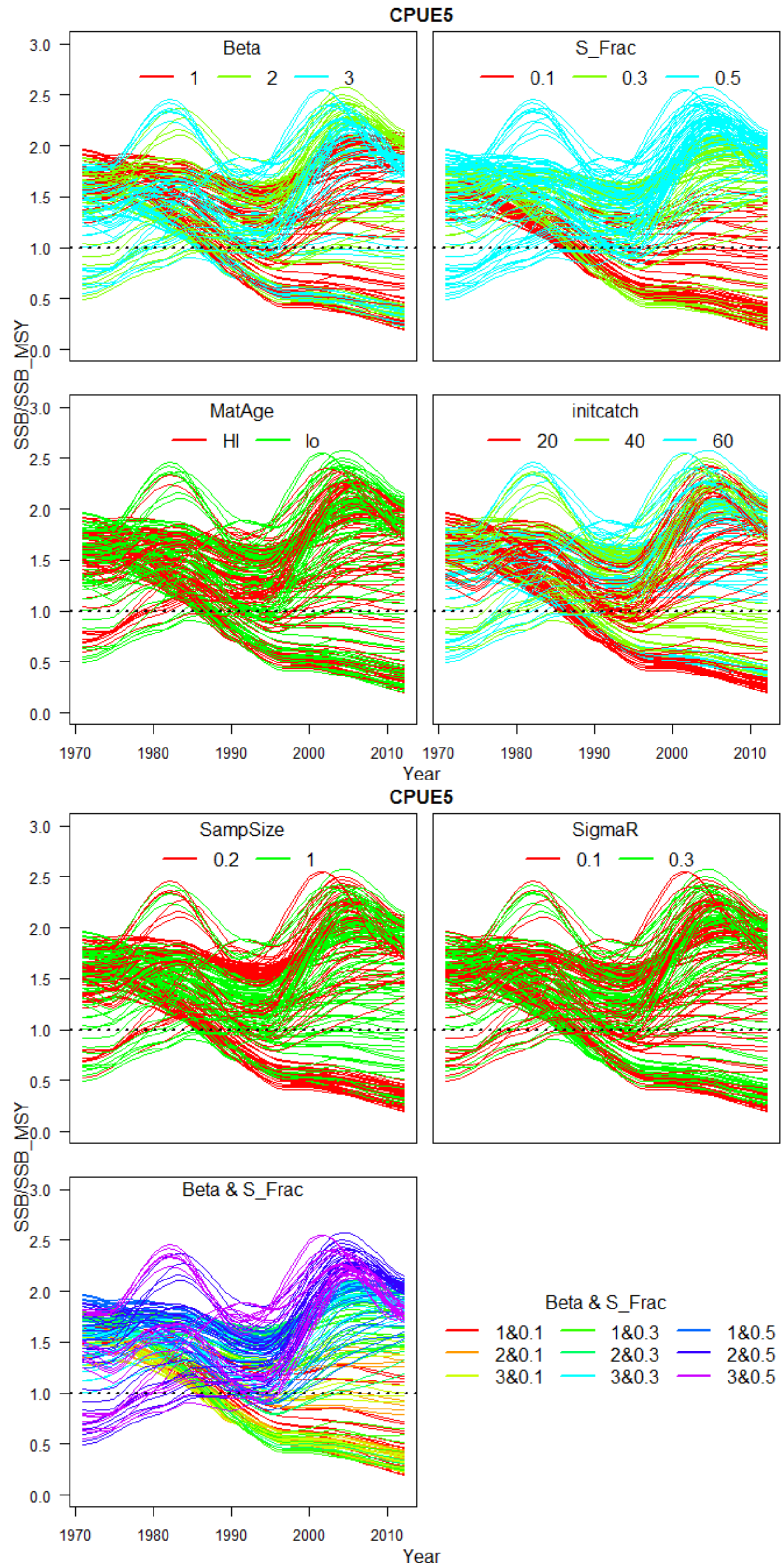

CPUE5
Beta
1 2 3
S_Frac
0.1 0.3 0.5
MatAge
HI lo
initcatch
20 40 60
SSB/SSB_MSY
Year
CPUE5
SampSize
0.2 1
SigmaR
0.1 0.3
Beta & S_Frac
Beta & S_Frac
1&0.1 1&0.3 1&0.5
2&0.1 2&0.3 2&0.5
3&0.1 3&0.3 3&0.5
SSB/SSB_MSY
Year

Figure A 4. 4

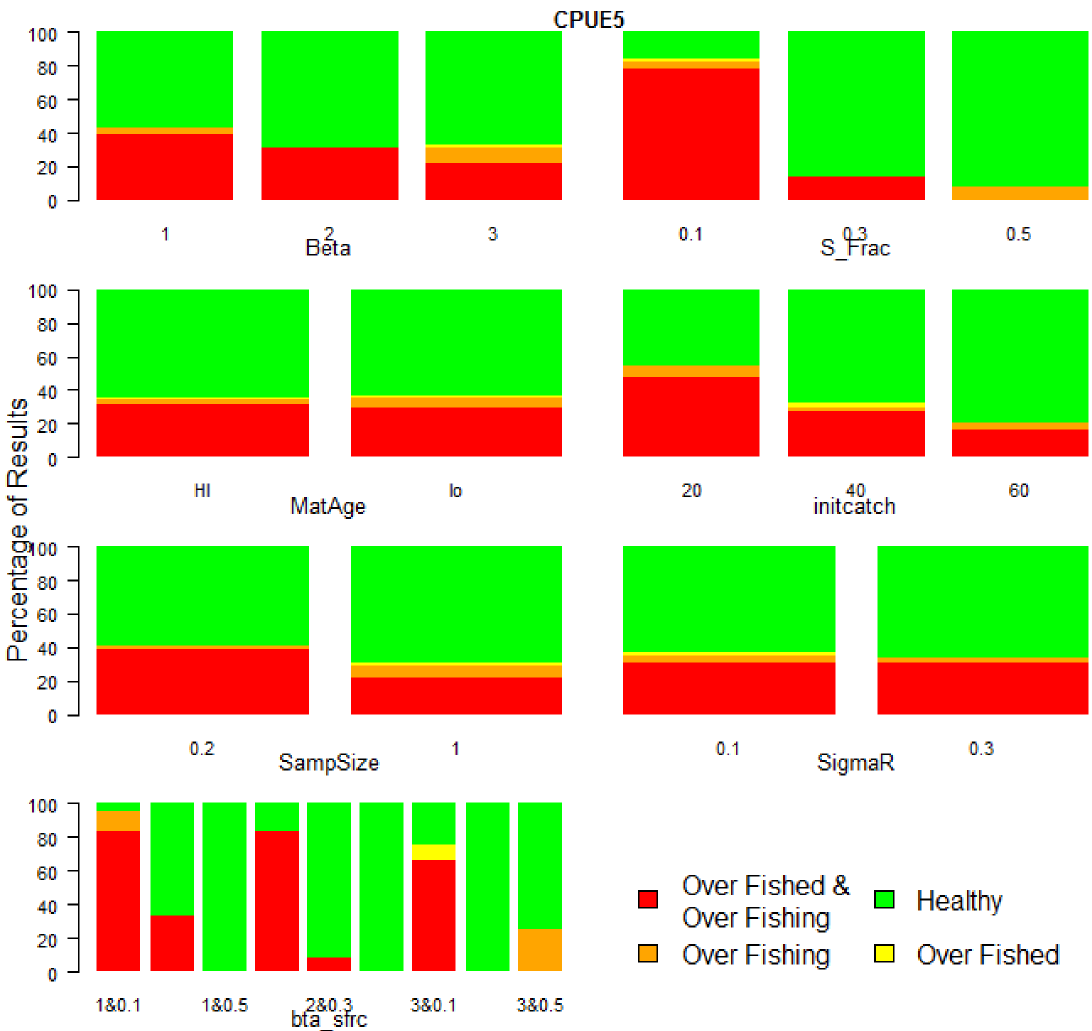

CPUE5
Percentage of Results
Beta
1
2
3
S_Frac
0.1
0.3
0.5
MatAge
HI
lo
initcatch
20
40
60
SampSize
0.2
1
SigmaR
0.1
0.3
bta_sfrc
1&0.1
1&0.5
2&0.3
3&0.1
3&0.5
Over Fished & Over Fishing
Healthy
Over Fishing
Over Fished

Figure A 4. 5

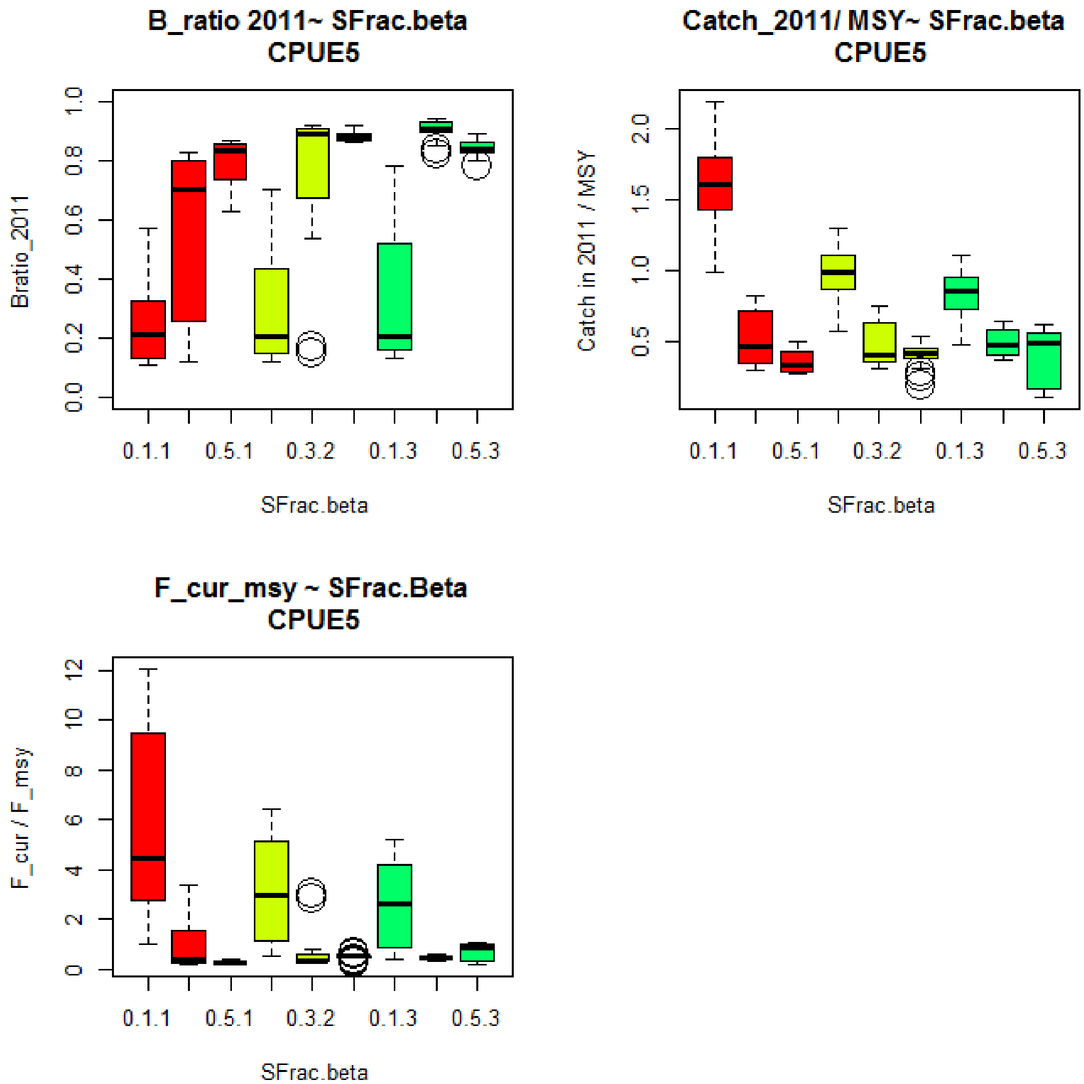

B_ratio 2011~ SFrac.beta
CPUE5
Bratio_2011
0.0
0.2
0.4
0.6
0.8
1.0
0.1.1
0.5.1
0.3.2
0.1.3
0.5.3
SFrac.beta
Catch_2011/ MSY~ SFrac.beta
CPUE5
Catch in 2011 / MSY
0.5
1.0
1.5
2.0
0.1.1
0.5.1
0.3.2
0.1.3
0.5.3
SFrac.beta
F_cur_msy ~ SFrac.Beta
CPUE5
F_cur / F_msy
0
2
4
6
8
10
12
0.1.1
0.5.1
0.3.2
0.1.3
0.5.3
SFrac.beta

Figure A 4. 6

ANNEX 5: Summary of key outputs for the model runs by TW CPUE series (CPUE 6).

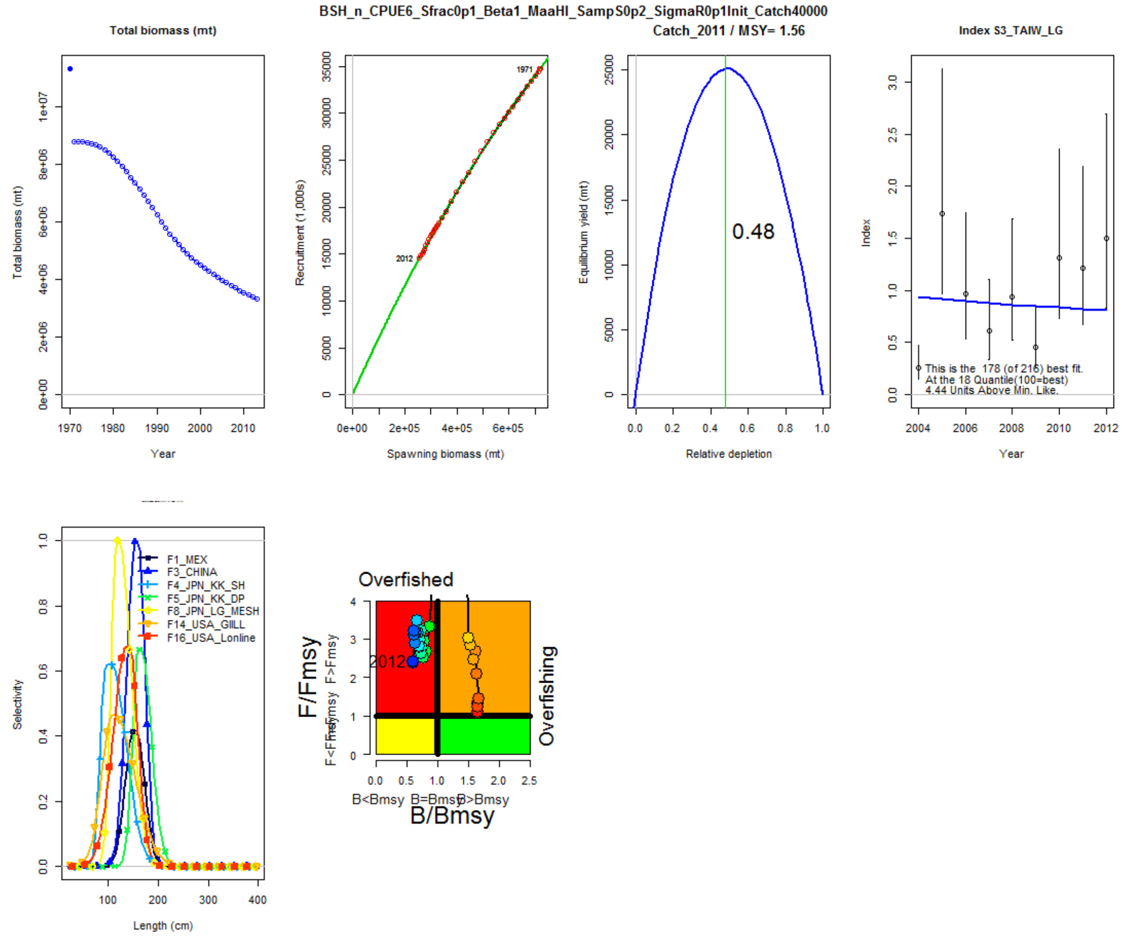


Figure A 5. 1

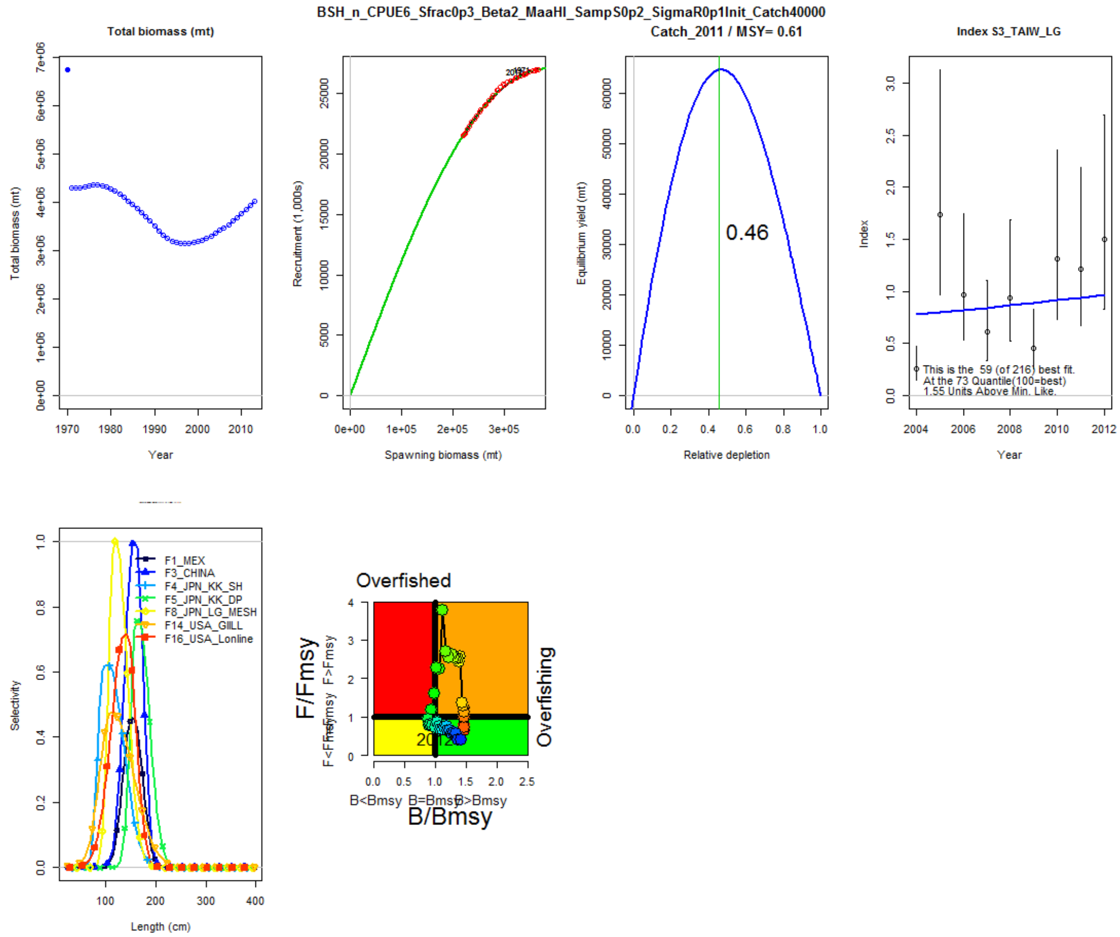

BSH_n_CPUE6_Sfrac0p3_Beta2_MaaHI_SampS0p2_SigmaR0p1Init_Catch40000
Total biomass (mt)
Total biomass (mt)
Year
Recruitment (1,000s)
Spawning biomass (mt)
Catch_2011 / MSY= 0.61
Equilibrium yield (mt)
0.46
Relative depletion
Index S3_TAIW_LG
Index
This is the 59 (of 216) best fit.
At the 73 Quantile(100=best)
1.55 Units Above Min. Like.
Year
Selectivity
F1_MEX
F3_CHINA
F4_JPN_KK_SH
F5_JPN_KK_DP
F8_JPN_LG_MESH
F14_USA_GILL
F16_USA_Lonline
Length (cm)
Overfished
F/Fmsy
F<Fmsy
F>Fmsy
Overfishing
B<Bmsy
B=Bmsy
B>Bmsy
B/Bmsy

Figure A 5.2

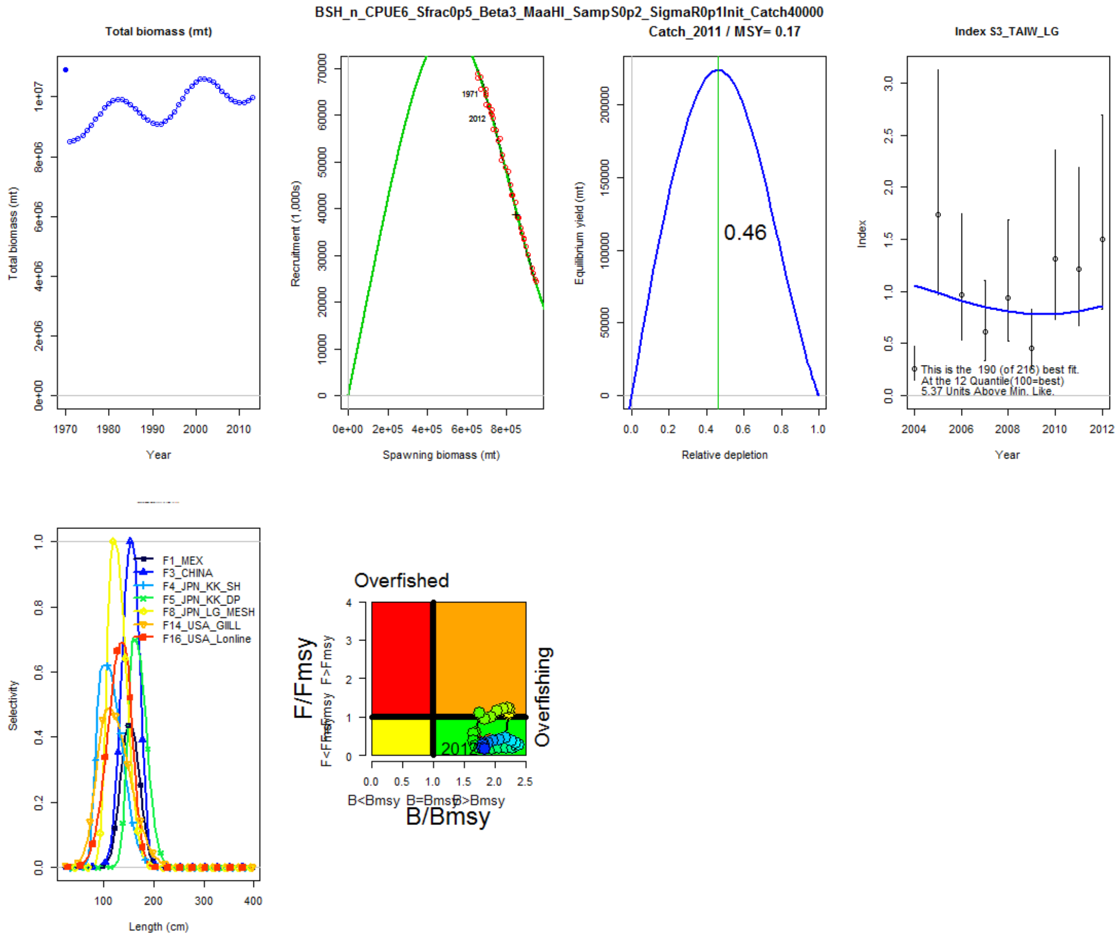

BSH_n_CPUE6_Sfrac0p5_Beta3_MaaHl_SampS0p2_SigmaR0p1Init_Catch40000
Total biomass (mt)
Catch_2011 / MSY= 0.17
Index S3_TAIW_LG
Total biomass (mt)
Year
Recruitment (1,000s)
Spawning biomass (mt)
Equilibrium yield (mt)
Relative depletion
0.46
Index
This is the 190 (of 216) best fit.
At the 12 Quantile(100=best)
5.37 Units Above Min. Like.
Selectivity
Length (cm)
F1_MEX
F3_CHINA
F4_JPN_KK_SH
F5_JPN_KK_DP
F8_JPN_LG_MESH
F14_USA_GILL
F16_USA_Lonline
Overfished
Overfishing
F/Fmsy
B/Bmsy
B<Bmsy
B>Bmsy
F>Fmsy
2012

Figure A 5. 3

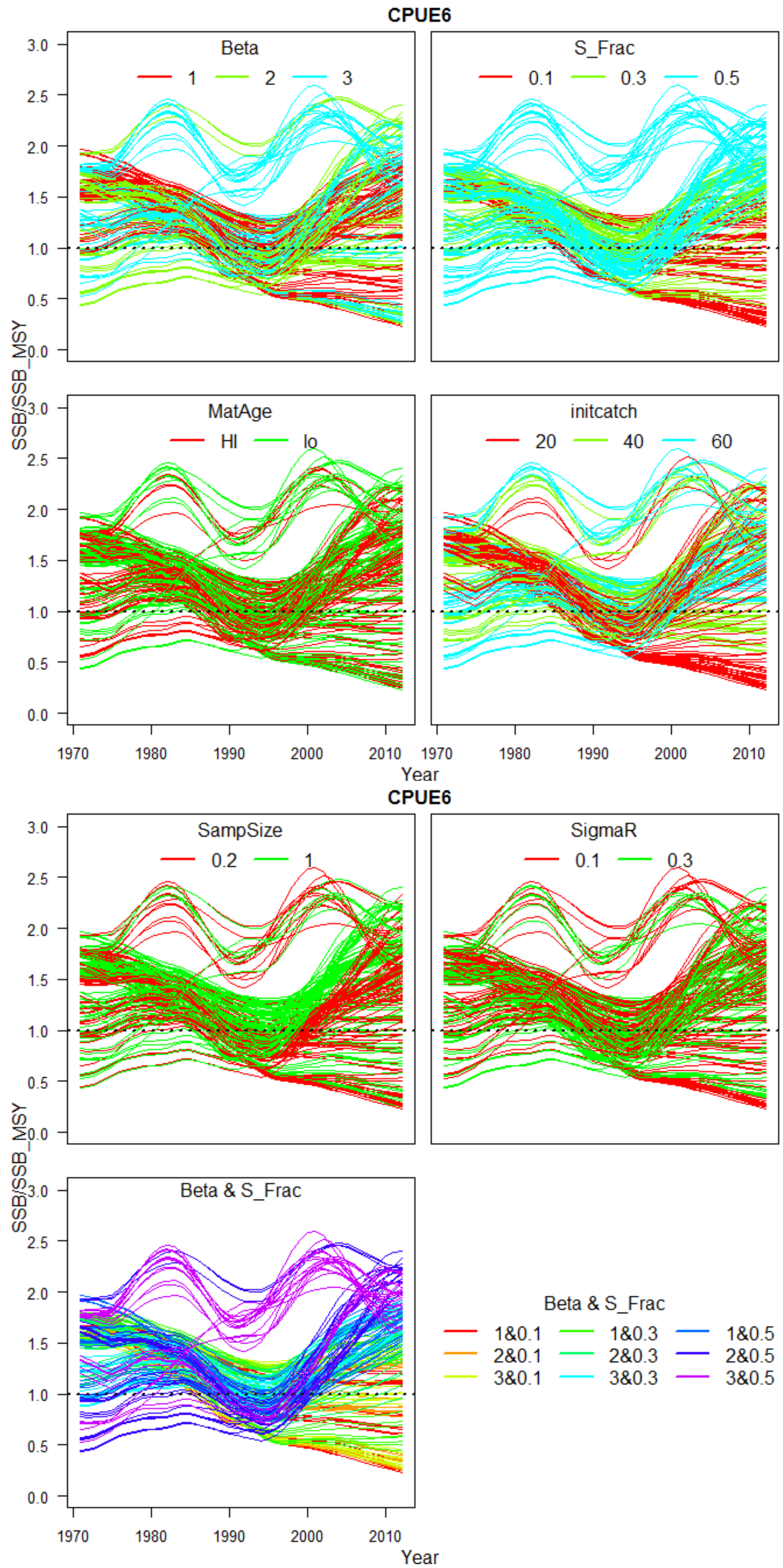

CPUE6
Beta
1 2 3
S_Frac
0.1 0.3 0.5
MatAge
HI lo
initcatch
20 40 60
SSB/SSB_MSY
Year
CPUE6
SampSize
0.2 1
SigmaR
0.1 0.3
Beta & S_Frac
SSB/SSB_MSY
Beta & S_Frac
1&0.1 1&0.3 1&0.5
2&0.1 2&0.3 2&0.5
3&0.1 3&0.3 3&0.5
Year

Figure A 5. 4

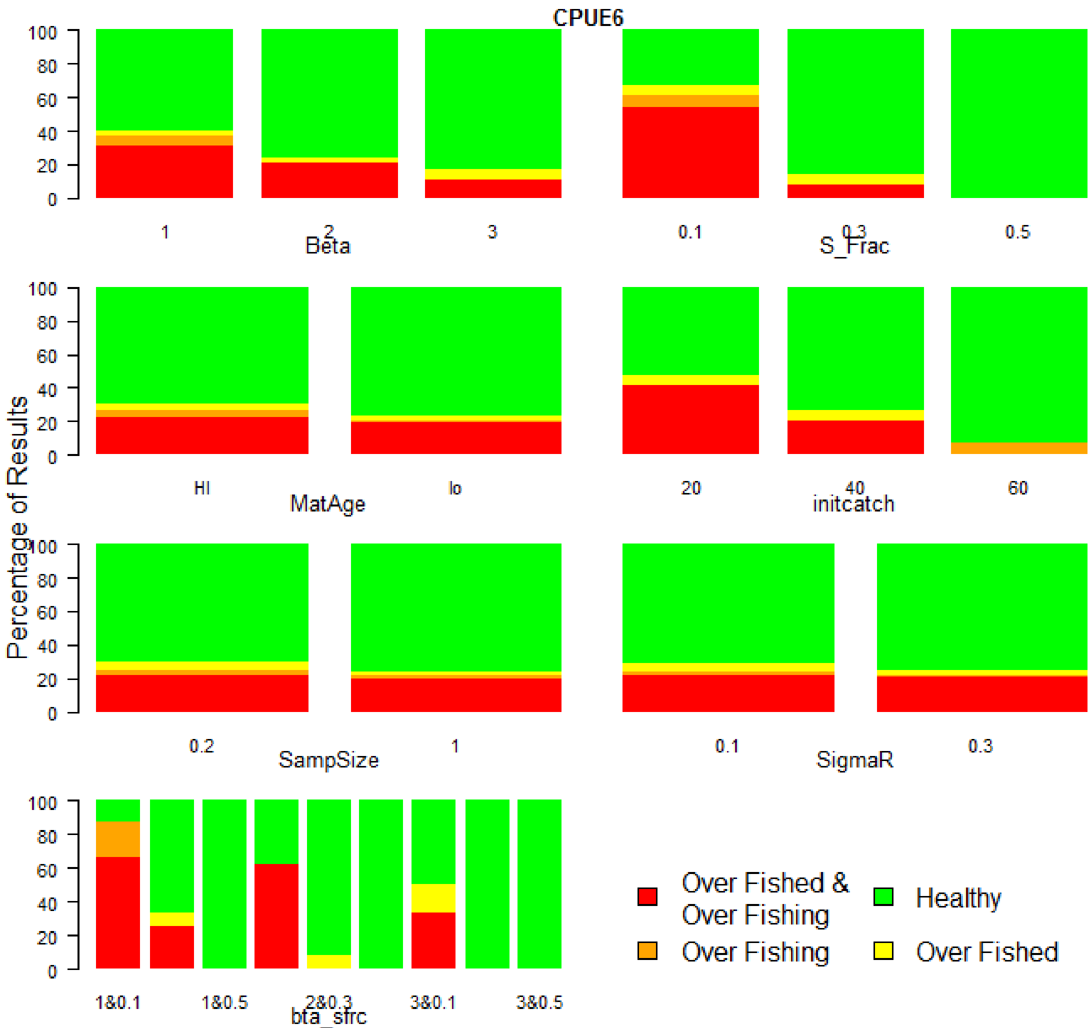

CPUE6
Percentage of Results
Beta
S_Frac
MatAge
initcatch
SampSize
SigmaR
bta_sfrc
Over Fished & Over Fishing
Healthy
Over Fishing
Over Fished

Figure A 5. 5

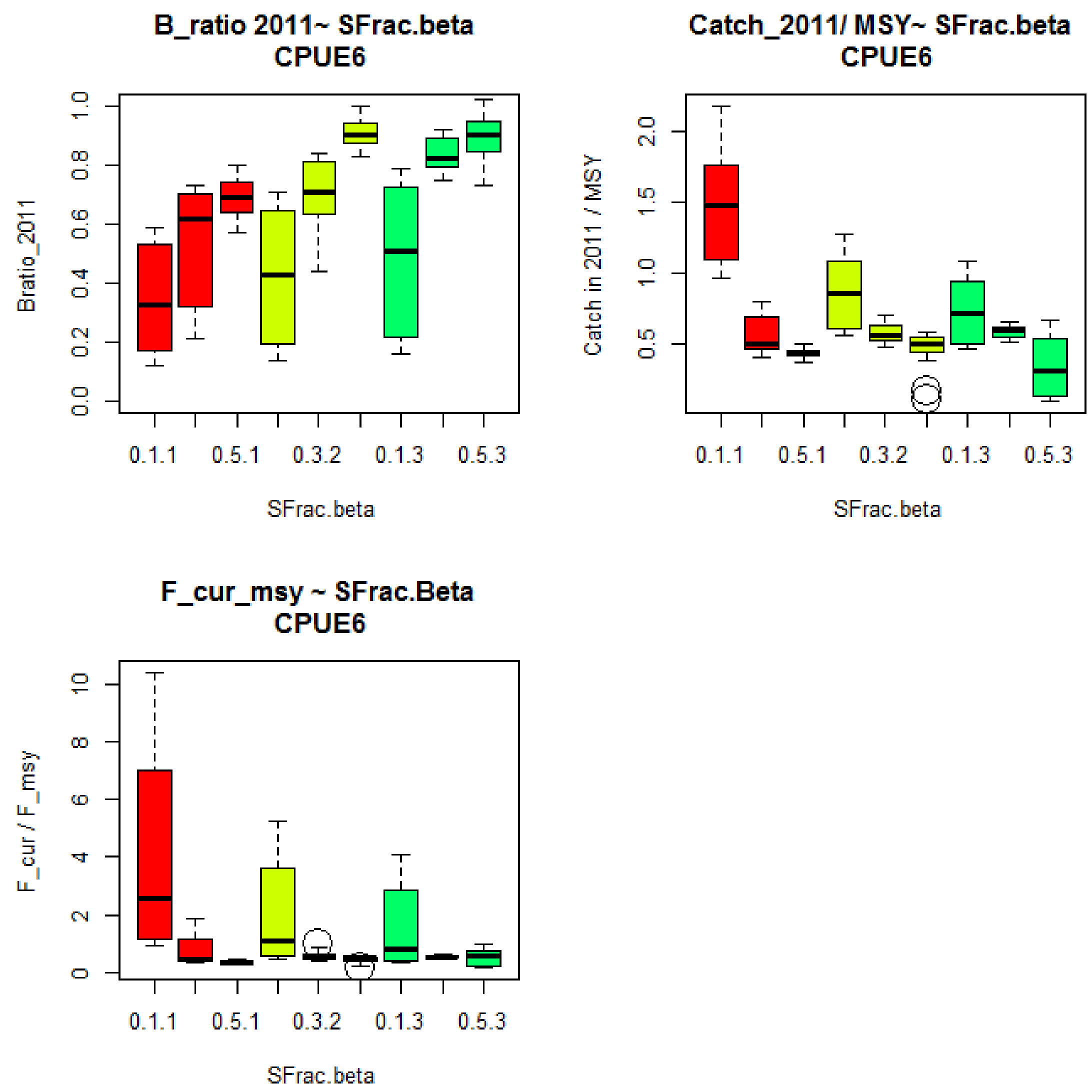

B_ratio 2011~ SFrac.beta
CPUE6
Bratio_2011
0.0
0.2
0.4
0.6
0.8
1.0
0.1.1
0.5.1
0.3.2
0.1.3
0.5.3
SFrac.beta
Catch_2011/ MSY~ SFrac.beta
CPUE6
Catch in 2011 / MSY
0.5
1.0
1.5
2.0
0.1.1
0.5.1
0.3.2
0.1.3
0.5.3
SFrac.beta
F_cur_msy ~ SFrac.Beta
CPUE6
F_cur / F_msy
0
2
4
6
8
10
0.1.1
0.5.1
0.3.2
0.1.3
0.5.3
SFrac.beta

Figure A 5. 6

ANNEX 6 Projections

Forecasts of two models were conducted under seven scenarios. The seven scenarios were:

1. status quo catch (average 2006-2010)
2. status quo catch +20%
3. status quo catch -20%
4. status quo F (average 2006-2010)
5. status quo F +20%
6. status quo F -20%
7. F_{MSY}

The first model selected was based on the WG decision of a reference case model for the provision of management advice parameterized by, Japanese early and late CPUE S_Frac=0.3; Beta=2; higher mortality-at-age; sample size weighting=0.2; sigma r=0.3; and initial catch=40,000mt. The second model had the same specifications except the LFSR curve had less compensation (S_Frac=0.1 and Beta=1). In an early ISC-WG, 0.3 was recommended as the value of sigma-r to be more biologically realistic, and to allow extra freedom to better fit the CPUE data, but it had little impact on the model results, so 0.1 was retained as a reference case in this document. In this annex we provide the diagnostics for the models selected by the WG and projections from that model as specified above.

We first provide the basic model fit and description plots for each model and then the biomass trajectory under the seven scenarios.

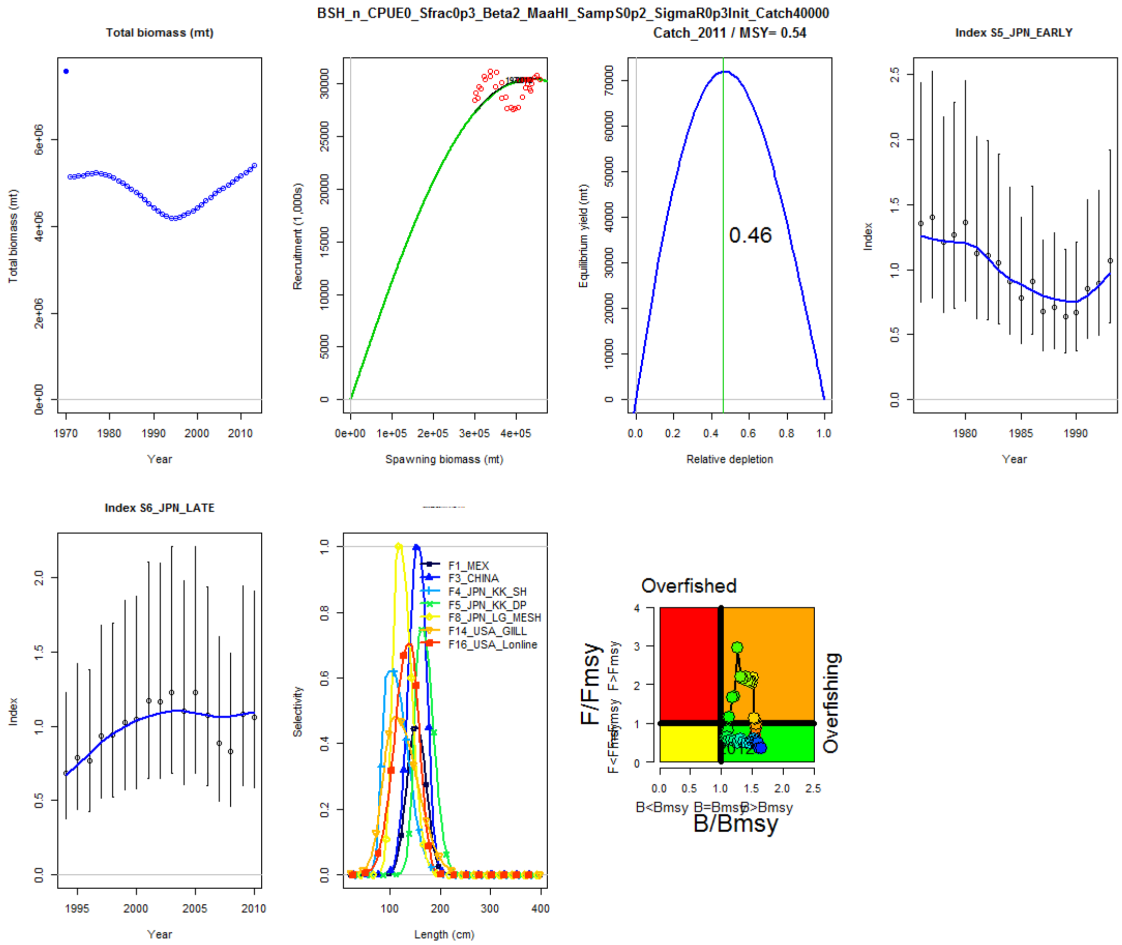


Figure A6.1 Diagnostic and summary plots for the ISC shark working group selected reference case model for blue shark in the North Pacific.

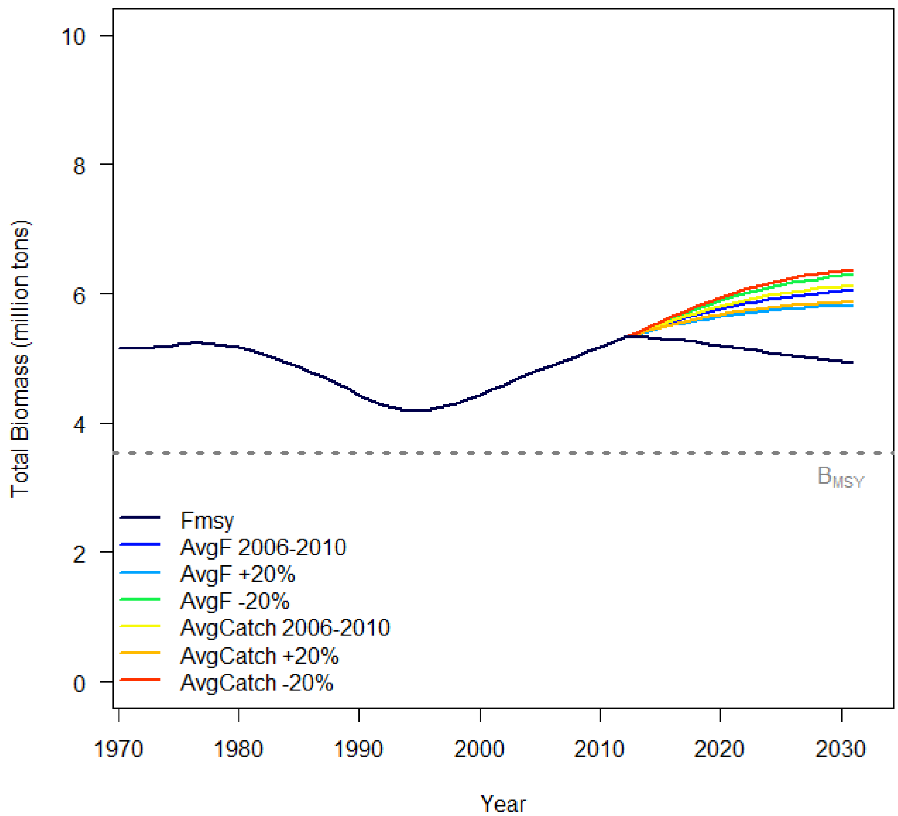


Figure A6.2 Forecast plot for the ISC shark working group selected reference case model for blue shark in the North Pacific.

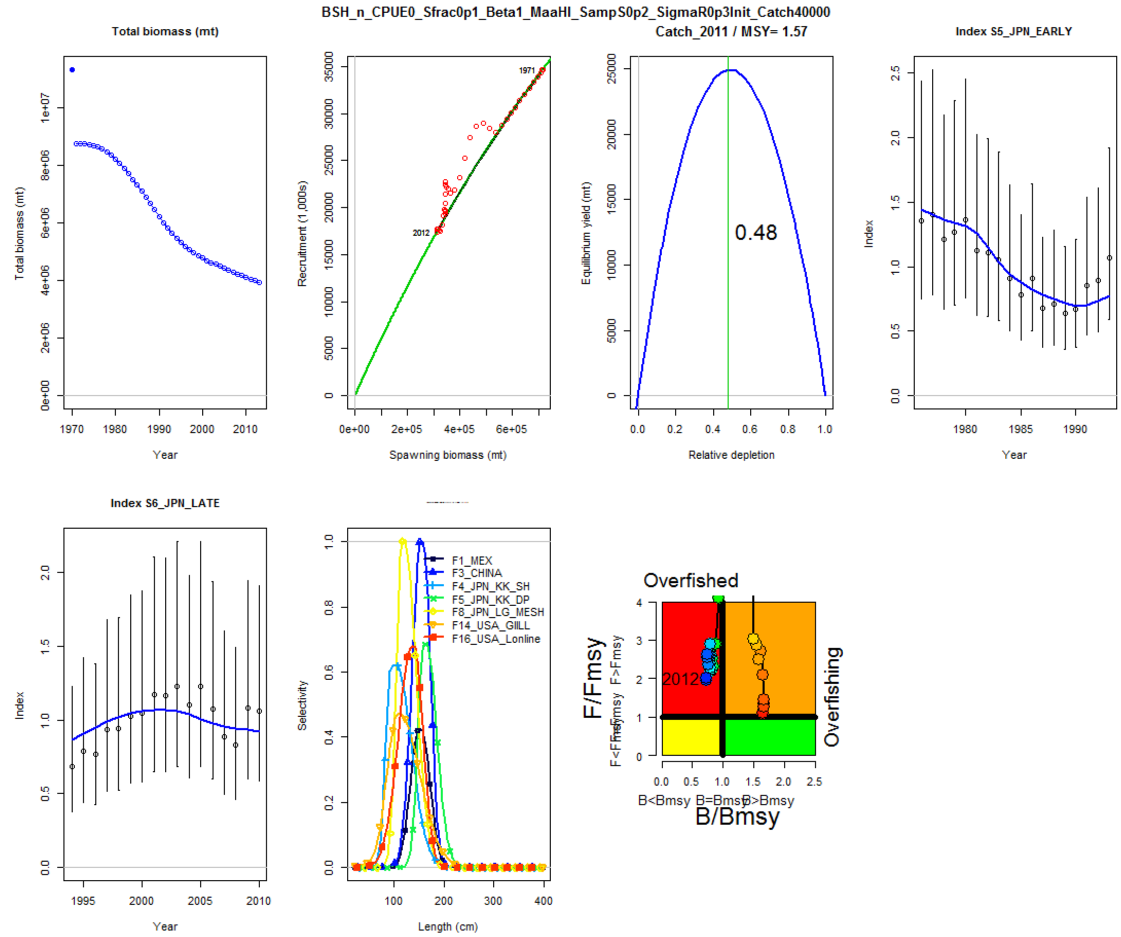


Figure A6.3 Diagnostic and summary plots for the alternative model run for blue sharks in the north Pacific with the LFSR curve that had less compensation.

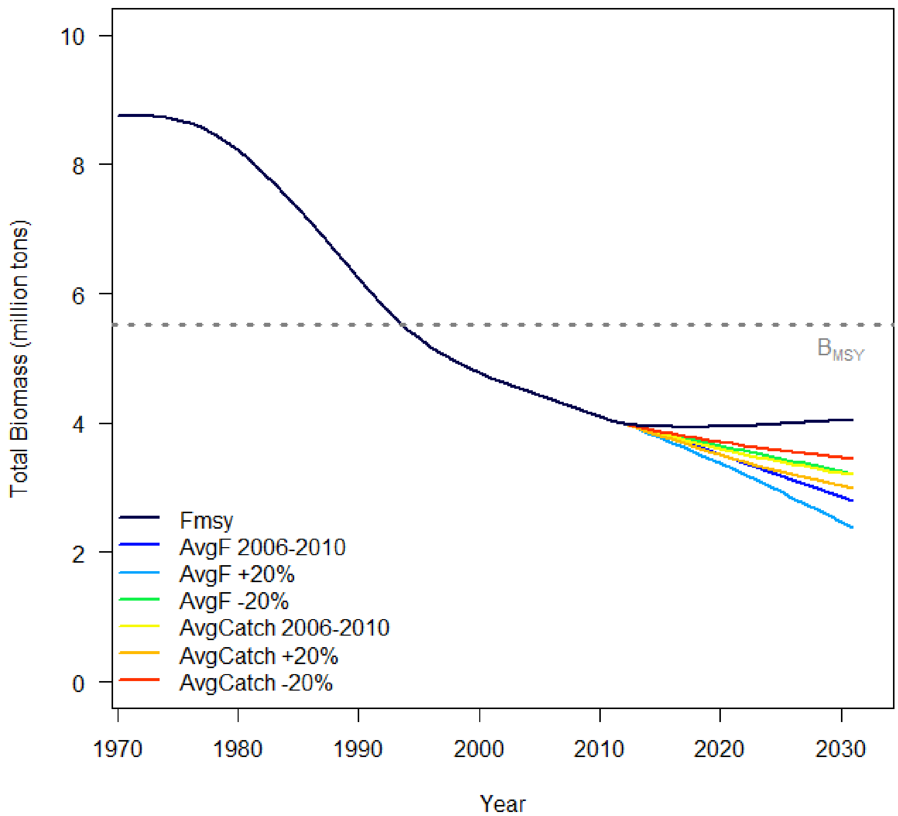


Figure A6.4 Forecast plot for the for the alternative model run for blue shark in the north Pacific with the LFSR curve that had less compensation.

Table A6.1: Reference quantities for the model projections, WG selected SS reference case, model run from 1971-2011.

	C_2011	B_2011 / Bmsy	F_2011 / Fmsy		C_2016	B_2016 / Bmsy	F_2016 / Fmsy		C_2021	B_2021/ Bmsy	F_2021 / Fmsy		C_2031	B_2031/ Bmsy	F_2031/ Fmsy
BSH_ref_projection_FMSY	39083	1.62	0.35		88109	1.60	1.00		85551	1.53	1.00		84890	1.47	1.00
BSH_ref_projection_SQ_Catch	39083	1.62	0.35		46389	1.73	0.47		46389	1.80	0.48		46389	1.83	0.47
BSH_ref_projection_SQ_Catch-20	39083	1.62	0.35		37111	1.76	0.37		37111	1.85	0.38		37111	1.90	0.37
BSH_ref_projection_SQ_Catch+20	39083	1.62	0.35		55667	1.70	0.58		55667	1.74	0.59		55667	1.76	0.59
BSH_ref_projection_SQF	39083	1.62	0.35		49567	1.72	0.49		49307	1.78	0.49		48807	1.81	0.49
BSH_ref_projection_SQF-20	39083	1.62	0.35		40700	1.75	0.39		40618	1.83	0.39		39909	1.88	0.39
BSH_ref_projection_SQF+20	39083	1.62	0.35		57961	1.70	0.59		57441	1.73	0.59		57147	1.75	0.59